Edrolo

VCE BIOLOGY

Units 3 & 4

2ND EDITION

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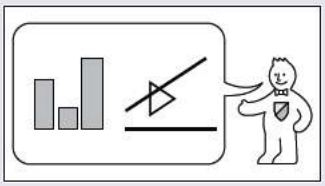
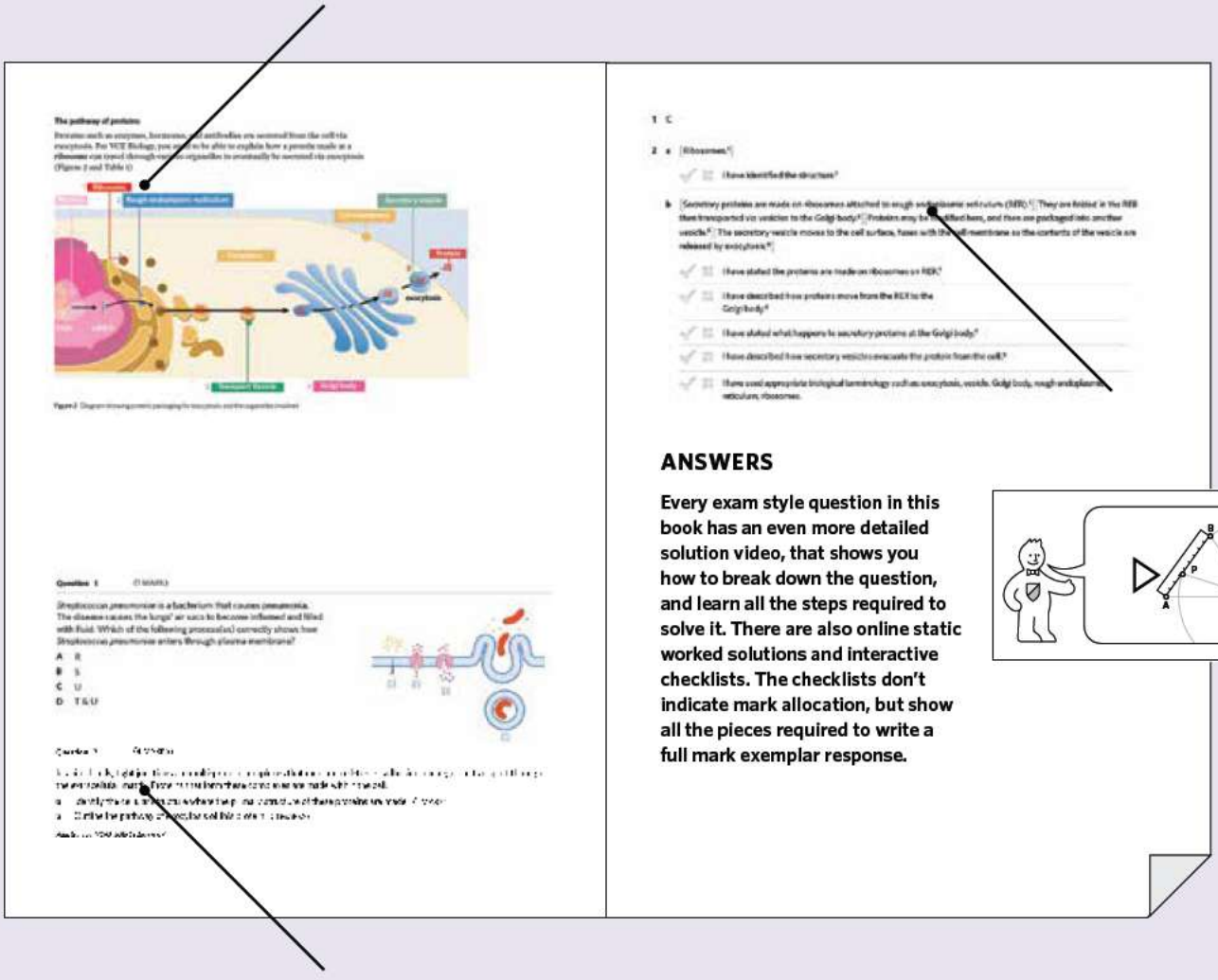
VIDEO LESSONS

Each lesson in this book has a corresponding online video that further unpacks each and every concept.





ANSWERS

Every exam style question in this book has an even more detailed solution video, that shows you how to break down the question, and learn all the steps required to solve it. There are also online static worked solutions and interactive checklists. The checklists don't indicate mark allocation, but show all the pieces required to write a full mark exemplar response.

QUESTIONS

There are hundreds of questions in this book, and these questions can also be found and completed online. Answering your textbook questions online will enable you to better track your progress, and will enable your teacher to engage with your responses – so they support you even further.

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Key science skills

01

1A What is a key science skill?

1B Assessment of key science skills

This chapter will introduce and develop the key science skills, which are applicable to all practical, research, and investigation tasks throughout Units 1–4. In particular, these skills will build the foundation of knowledge that you will use to conduct the practical investigation for Unit 4 AOS 3. To do this, we will examine the key knowledge dot points related to Unit 4 AOS 3 in combination with the key science skills outlined in the study design.

Key knowledge

- independent, dependent, and controlled variables
- the characteristics of scientific research methodologies and techniques of primary qualitative and quantitative data collection relevant to the selected investigation, including laboratory work (biochemistry, cytology, immunology) and/or fieldwork (geomorphology); precision, accuracy, reliability, and validity of data; and minimisation of experimental bias
- ethics and issues of research including identification and application of relevant health, safety, and bioethical guidelines
- methods of organising, analysing, and evaluating primary data to identify patterns and relationships including sources of error and limitations of data and methodologies
- models, theories, and classification keys, and their use in organising and explaining observed phenomena and biological concepts including their limitations
- the nature of evidence that supports or refutes a hypothesis, model, or theory
- the biological concepts specific to the investigation and their significance, including definitions of key terms, and biological representations
- the key findings of the selected investigation and their relationship to cytological, biochemical, and/or evolutionary concepts
- the conventions of scientific report writing and scientific poster presentation including biological terminology and representations, standard abbreviations, units of measurement, and acknowledgment of references

Image: Konstantin Kolosov/Shutterstock.com

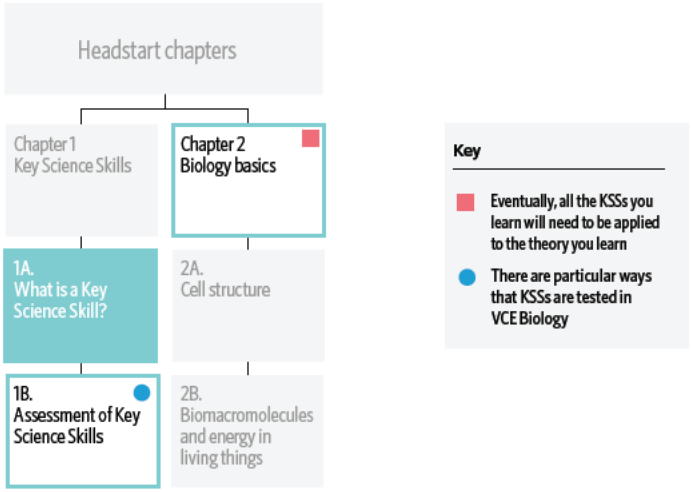
The development of a set of key science skills is a core component of the study of VCE Biology and applies across Units 1 to 4 in all areas of study. In designing teaching and learning programs and in assessing student learning for each unit, teachers should ensure that students are given the opportunity to develop, use and demonstrate these skills in a variety of contexts when undertaking their own investigations and when evaluating the research of others. As the complexity of key knowledge increases from Units 1 to 4 and as opportunities are provided to undertake investigations, students should aim to demonstrate the key science skills at a progressively higher level.

Key science skills

- Develop aims and questions, formulate hypotheses, and make predictions
- Plan and undertake investigations
- Comply with safety and ethical guidelines
- Conduct investigations to collect and record data
- Analyse and evaluate data, methods, and scientific models
- Draw evidence-based conclusions
- Communicate and explain scientific ideas

1A WHAT IS A KEY SCIENCE SKILL?

Experiment. Fail. Learn. Repeat.



In this lesson you will learn what Key Science Skills (KSSs) are and how to design a valid, ethical, and safe experiment.

Study design dot points

- independent, dependent, and controlled variables
- the characteristics of scientific research methodologies and techniques of primary qualitative and quantitative data collection relevant to the selected investigation, including laboratory work (biochemistry, cytology, immunology) and/or fieldwork (geomorphology); precision, accuracy, reliability, and validity of data; and minimisation of experimental bias
- ethics and issues of research including identification and application of relevant health, safety, and bioethical guidelines
- methods of organising, analysing and evaluating primary data to identify patterns and relationships including sources of error and limitations of data and methodologies
- models, theories, and classification keys, and their use in organising and explaining observed phenomena and biological concepts including their limitations
- the nature of evidence that supports or refutes a hypothesis, model, or theory

Key knowledge units

Science and Key Science Skills	4.3.1
What does a 'good' experiment look like?	4.3.2
Ethics and safety in science	4.3.3

Science and Key Science Skills 4.3.1

OVERVIEW

Science uses the scientific method to test hypotheses and explain observations. Use of Key Science Skills ensures that your tests are scientific (reproducible, repeatable, and valid).

THEORY DETAILS

Biology is a science, but what on Earth is science? Science is both a body of knowledge and the process of acquiring new knowledge through the scientific method. Put simply, the scientific method involves gaining knowledge through observation or testing. If knowledge is gained, but not through observation or testing, the new knowledge is not considered scientific. Figure 1 outlines the scientific method in more detail.

What has this got to do with your VCE Biology SACs and exams? Well, every time you use the scientific method - to research theories, to design an experiment, or to analyse and present data - you demonstrate KSSs. The KSSs tested in VCE Biology are outlined on pages 10 and 11 of the VCE Biology Study Design and summarised in Table 1.

Tip Previous exams have not tested the steps in the scientific method, but they may be assessed in your SACs.

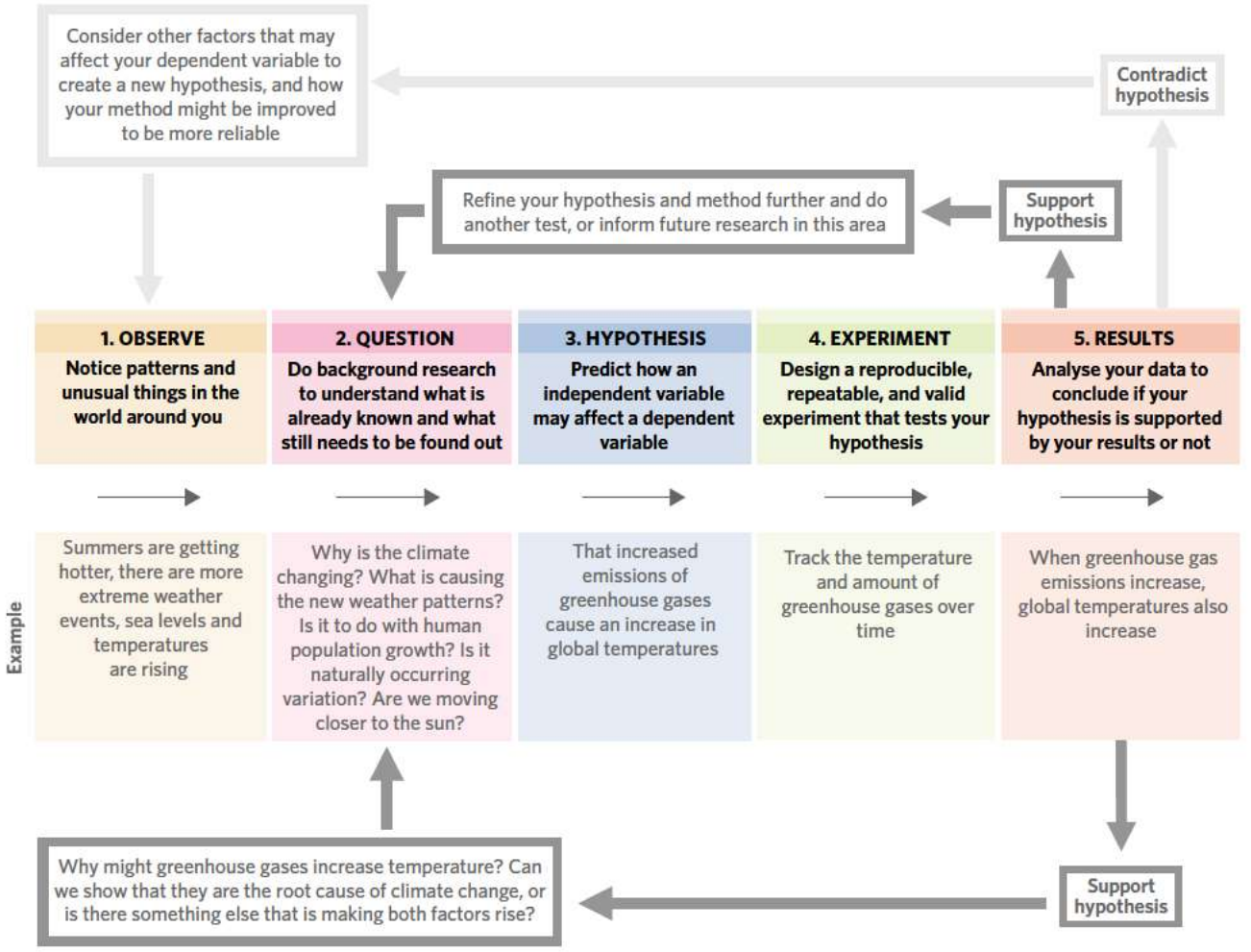


Figure 1 The scientific method

Table 1 The KSSs tested in VCE Biology and examples of how you might demonstrate that skill when testing a new drug

KSS	Example - testing new medicines
Develop aims and questions, formulate hypotheses, and identify variables	*Question:* Does a new drug help fight the flu? *Aim:* To determine if a new drug reduces the symptoms of the flu. *Variables:* the **IV** is the treatment with the drug, the **DV** is the presence of flu symptoms. *Hypothesis:* That individuals given the drug will have less flu symptoms than individuals not given the drug.
Plan and undertake investigations, including using controls and **replicates**	Get a large sample (e.g. 40) of mice. Infect all the mice with the flu virus. Ensure the mice are kept in the same conditions. Give half the mice the new drug. Give the other half of the mice a **placebo**, ensuring that both groups are handled in the same manner. Measure the occurrence of flu symptoms in each group over the following days and weeks.
Comply with safety and ethical guidelines	Ethicists recommend testing new drugs on cell cultures and animals before humans. If tested on animals, the experiment should stop if side effects of the new drug cause great discomfort. In addition, if the drug is effective, the impact of not giving it to the control group should be considered. In terms of safety, the scientists developing the drug should ensure they wear appropriate protective gear and use well-maintained equipment.
Conduct investigations to collect and record **qualitative** and **quantitative** data	Every day, the scientists should: • count any mortalities • record the number of sneezes over five minutes in each mouse • measure the body temperature of each mouse • take blood samples from each mouse, and determine the number of immune cells and inflammatory markers in a sample. Because there are 20 individuals in each group, they can take an average of each group to get a more **precise** result.

independent variable (IV) the factor(s) that is manipulated in an experiment

dependent variable (DV) the factor(s) changed by the manipulation of the IV

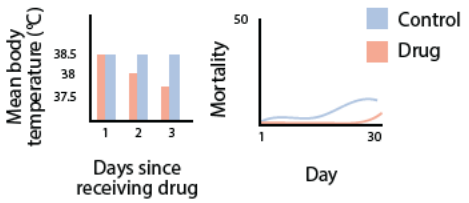
placebo a substance that has no therapeutic benefit or side effects and can be used as a control when testing new drugs

replicates multiple experimental runs exposed to the same level of the IV

qualitative data non-numerical data, typically collected through observations and interviews. Also known as **categorical data**

quantitative data numerical data that expresses an amount or range of values

precise two or more measurements that closely agree with each other

Analyse and evaluate data, methods, and scientific models. This includes: • Interpreting ratios, percentages, and means • Explaining the effect of replication and sample size on reliability • Analysing accuracy, precision, reliability, validity, **uncertainty**, **bias**, and **errors** of results • Suggesting improvements and limitations of experiments	 Data like those above may be presented in the results. Limitations that could be discussed include: • testing nasal or throat swabs for the presence of the flu virus may increase the **accuracy** of results • using common tests like the rapid flu diagnostic test could improve the application of results to new contexts • mice sneezing may be caused by other factors, such as allergens. This could be an invalid method to measure the impact of the IV • there could have been problems sampling the mice, keeping conditions constant, or other issues with the method • there may be different results if the drug is tested on humans • a larger sample size would increase the replication, precision, and reliability of the results. Strengths that could be discussed include: • the experiment proceeds ***in vivo*** rather than ***in vitro***, so it may provide more contextually relevant results • multiple methods of measuring flu symptoms are used, so if the results agree across methods, they are likely very reliable • the scientists do not use measurements that may be subject to bias, like 'how sick the mouse looks'.
Draw evidence-based conclusions	*Drawing conclusions:* report what your data shows, not what you had expected to see. This is one of the reasons why a hypothesis is important! You can show what you used to think, and how evidence (may have) changed your position. *Implications:* if the drug is effective, what are the biological, social, economic, and ethical implications? Does the use of this drug challenge any other research, media opinions, or certain community beliefs? If there are minor side effects or risks involved, how can scientists communicate these clearly and honestly to pharmacists and patients?
Communicate and explain scientific ideas by using biological terminology and clear, concise language	The scientists could achieve this by: • Using topic sentences for paragraphs and subheadings for sections in their report • Writing short, direct sentences • Using terms such as 'firstly', 'secondly' to signpost ideas • Using terms such as 'in contrast to' or 'as opposed to' to compare ideas • Including a reference list and acknowledgements section.

Luckily for you, the standard structure of experiments and laboratory reports (aim, **hypothesis**, etc.) makes you practice the scientific method and demonstrate many of the KSSs. If you don't understand some of the terms in Table 1, don't worry - we are going to dive in and look at why things like controls, accuracy, and replication make experiments reliable in the next section.

Tip VCAA suggest using the following template to write hypotheses – simply insert your DV, IV, and appropriate changes in the right spots!

Template:

If the [DV] is affected by the [IV], then [effect on the DV] when [change in IV].

We can use this template to write a new hypothesis for the influenza drug experiment from Table 1:

If the presence of flu symptoms is affected by the treatment with the drug, then mice will show fewer flu symptoms when they are given the drug.

VCAA emphasise that different writing styles for hypotheses can be equally valid, but it is important to include the direction of change in the DV and IV (by saying 'more', 'increase', 'smaller' etc.). Some hypotheses also include reasons for the prediction.

accurate a measurement that is close to the 'true' value of the quantity being measured

uncertainty a quantification of the error associated with a measurement, often represented by the symbol '±' after a reading

experimenter bias the inclination for scientists conducting research to alter their results based on their prior beliefs, for example by selecting an unrepresentative sample or by recording the results they expect to see

error the difference between the measured value and the true value of what is being measured

personal error mistakes or miscalculations due to human fault. Can be eliminated by performing the experiment again correctly

random error variation in results caused by uncontrollable conditions between replicates in the measuring process, resulting in a less precise spread of readings. Can be reduced using more replicates or refining the measurement process

systematic error faults that cause measurements to differ from the true value by a consistent amount each time a measurement is made, resulting in a less accurate result. Can be reduced by calibrating and maintaining instruments

in vitro processes or experiments performed outside a living organism (e.g. in a culture dish, test tube)

in vivo processes or experiments performed in the body

hypothesis a testable statement that describes how experimenters expect the dependent variable to change as the independent variable changes

What does a 'good' experiment look like? 4.3.2

OVERVIEW

Good experimental design should include a dependent variable (DV) and an independent variable (IV); a control group; a hypothesis; replication of groups; attempts to minimise bias, error, and confounding factors; a large and representative sample; accurate and precise data collection; and clear communication. Your experiment must also be ethical, safe, and the data needs to be presented clearly.

THEORY DETAILS

One of the beautiful things about science is that things that are 'true' one day can be disproven the next. Scientists draw the most reasonable conclusions based on the evidence available at the time. If evidence to the contrary arises, what is 'true' can also change. However, we cannot shift paradigms unless we can trust the results of an experiment. To trust results, the experiment must be designed to be **reproducible**, **repeatable**, and **valid**. These characteristics ensure that any conclusions drawn are 'evidence-based', **reliable**, and meaningful.

representative sample the subset of a population (e.g. of bacteria, tomato plants, yeast) that takes part in the experiment and accurately reflects the characteristics of the larger group

reproducible an experiment/measurement in which a group of scientists, using the original methods designed by others, can obtain the same results as another group's experiment

repeatable an experiment/measurement in which scientists, using the methods they designed, can obtain the same result multiple times

valid a measurement or experiment that actually tests what it claims to be evaluating

reliable describes a measurement, tool, or experiment that produces similar results when repeated and reproduced, and therefore can be trusted

How do I design a good experiment?

There are a number of things you can do to ensure you are designing a strong experiment that will produce meaningful results that are reproducible, repeatable, and valid.

In science, I must make sure my experiment is:

Reproducible	Repeatable	Valid
Different scientists can get the same results when they follow the same method as the original scientists	The same scientists can get the same results when they replicate the experiment	The experiment measures what it claims to be measuring

I can ensure this by designing an experiment that:

1 tests the effect of an **independent variable(s)** on one **dependent variable**	2 has a **'control'** treatment	3 has **replicates** of each treatment group and control group	4 minimises potential for **uncontrolled** variables and sources of error	5 collects data that is **reliable**	6 Is communicated clearly, so other scientists can peer-review my work
The IV is the thing you control or change. The DV is the thing you measure. You want to test if/how your IV affects your DV. Both of these should be mentioned in your **hypothesis**, which should predict how the IV influences the DV.	Positive control: apply a treatment that is known to produce a positive response in the DV. Negative control: apply a treatment that is known to produce no effect on the DV (e.g. remove the IV).	**Replication** means you have multiple groups under the same conditions. This means that your results are not outliers or due to random error, and you can take the average of your replicates for each treatment group. If your experiment is well-designed, the values for different replicates of the same treatment should be similar. If they are similar, this tells you that your measurements are **precise**.	**Personal errors** are mistakes or miscalculations. They can be eliminated by doing the experiment again. **Systematic errors** cause readings to differ by a consistent amount from the true value each time. For example, when an instrument is not calibrated correctly. They affect the **accuracy** of the experiment. Replication does not reduce the impact of systematic errors. **Random errors** are unpredictable variations in the measurement process that result in a spread of readings. For example, when a quantity is estimated by reading between lines on a measuring instrument. They affect the **precision** of the experiment. You can reduce random errors with increased replication or by refining the measurement process.	To collect reliable data: • Get a large, unbiased sample • Be **accurate** • Be **precise** • Minimise **uncertainty** in measurements To minimise uncertainty, you need to ensure the tool you are using to measure is appropriate. For example, don't use a 100 mL beaker to measure 5 mL of liquid. An accurate measurement is one that is close to what is considered to be the 'true' value. An experiment can be made 'more accurate' by reducing measurement/systematic error (e.g. by using more sophisticated instruments). Precision refers to how closely two or more measurements are to each other. Precision can be increased by having a larger sample size and using appropriately graduated instruments.	This means you need to present data in a meaningful way, give a clear method section so your work can be reproduced, and consider safety and ethical factors.
The groups that have the IV applied to them are known as the 'treatment' or 'experimental' groups	This is a treatment where the IV is not applied to the DV.				
The results from control groups are compared to experimental groups, and any difference between the groups is attributed to the IV.					
Uncontrolled factors are potential variables besides the IV that may affect your results. You should remove them or control them by keeping them constant. At the very least, you should measure them so you know how they change. If one is likely to influence your results, it is a **confounding** factor.					

Figure 2 Accurate results are close to the true value whereas precise results have very little spread around the mean value.

outlier readings that vary drastically from other results

You can think of the characteristics of a good experiment as a checklist (RICCHER).

- Replication
- Independent variable/dependent variable
- Control
- Clear communication
- Hypothesis
- Errors minimised
- Reliable data.

If you read about an experiment that is overlooking one or more of these factors (RICCHER), you need to decide if you can still trust the results presented. Read through the annotated excerpt from a student's logbook. Have they included all these parts of the experiment? Can you trust their results?

This student hasn't communicated very clearly here: in the methods they state much more specific locations.

The IV (the thing you are changing) is the location sampled. The DV (the thing you are measuring) is the amount of bacteria.

They state their hypothesis, which includes the IV, DV, and direction of change!

The treatment groups have been replicated three times - this means the experimenters will know if their results are precise, and reduce the likelihood of outliers affecting their results.

The student has included a control treatment, where the independent variable is not applied! If no/little growth occurs on the control plates, they can be sure any effect they observe is due to the IV (location sampled).

How was diameter measured? Colonies are very small so a very precise ruler would be required. Also, the results for diameter are not presented, which causes us to question the reliability and integrity of the experimenter.

Bacteria in the house

Introduction

The aim of this experiment was to determine the relative amounts of bacteria in different household areas. In particular, the amount of bacterial growth on plates from swabs in the toilet, kitchen bench, shower, couch, and bedroom were compared. The hypothesis was that the toilet seat would have the most bacteria, and that the couch would have the least.

Method

1. Eighteen Petri dishes with nutrient agar jelly were prepared using standard techniques. The lids on the Petri dishes were kept on as much as possible to prevent possible contamination.
2. A cotton bud was moistened with distilled water, then wiped across the toilet seat. The swab was pressed into the nutrient agar on one plate for five seconds, then removed. The Petri dish was covered quickly with its lid to minimise time exposed to air. This was repeated twice more.
3. Step 2 was repeated with the kitchen bench, shower curtain, couch seat, and mattress. For the final three Petri dishes, the moistened cotton ball was pressed to the surface of the nutrient agar for five seconds without swabbing any surface.
4. All dishes were labelled clearly, then incubated at 25°C for three days.
5. After incubation, the number of bacterial colonies on each Petri dish were counted, and the diameter of colonies was measured. The results were averaged across replicates.

Results

	Number of colonies					
Replicate #	Toilet	Mattress	Couch	Kitchen bench	Shower curtain	Control
1	15	15	14	3	22	3
2	12	14	8	5	28	2
3	10	15	2	6	28	2
Mean	12.3	14.7	8.0	4.7	26.0	2.3

Given the experiment wanted to measure the 'amount' of bacteria in certain household locations, the students need to consider if counting the number of colonies is a valid way to measure 'amount'. It is possible that measuring the number of different types of bacteria would provide more valid results. This would need to be considered in the discussion.

Some factors that may affect the results have been minimised - they state how they try to prevent contamination by keeping lids on the Petri dishes.

Are there any other potential sources of error or confounding variables? E.g. the pressure they apply to the cotton swab? Is the same person taking the samples each time (different people may do it differently)? They should have considered these things before beginning the experiment, and will hopefully bring it up in the discussion.

Image: Satirus/Shutterstock.com

Figure 3 The students may have seen something like this growing on their Petri dishes in the annotated experiment 'Bacteria in the house'.

You can see from the annotations of the logbook excerpt that there are many strengths to the experimental design (green): they include a negative control, an IV and DV, some consideration of potential error, and replication. However, there are also lots of potential improvements to be made (red). This doesn't mean the experiment is useless, but it is important that any limitations are clearly communicated in the discussion.

Case study

Shifting paradigms in Biology

Biological models and theories change when more evidence is gathered. Some key changes include:

- *Evolutionary theory.* Scientists used to accept the biblical doctrine that all living things had been the same since creation. Then, Charles Darwin presented evidence that species like the Galápagos finches could change over time, and that new species could arise from older ones. Evolution by natural selection is now the dominant theory of how living things change over time.
- *Gene transfer.* Scientists used to assert that genes could only be passed down from parents. But in the 20th Century biologists discovered that bacteria could transfer genes horizontally between individuals, like swapping clothes. The fields of evolution and phylogenetics are still trying to include, understand, and adapt to this new understanding of genetic transmission.
- *Taxonomies.* The classification of species changes as new technologies improve our understanding of how organisms are related. For example, all 12 000 species of grass (from bamboo to spinifex) used to be classified into one genus, *Poa*. Now, there are 771 genera.

lesson link In ***lesson 14C***, you will learn about how scientists are constantly changing their explanation of how *Homo sapiens* (humans) evolved as new fossil and DNA evidence is discovered.

Control groups and experimental groups

Some terms can get confusing when discussing experimental design. Note that a '**control group**' is also often referred to as the 'experimental control' or simply as the 'control'. This is the group to which no IV is applied. The opposite of a control group is an **experimental group** (often referred to as a treatment group). For example, if you measured the impact of fertilizer levels (IV) on tomato plant growth (DV), a control group would be a group of plants that are not fertilized at all (but are otherwise exposed to the same conditions as the experimental groups). Different experimental groups might be the 'low fertilizer' group and the 'high fertilizer' group.

control group a group of individuals/samples that are not exposed to the independent variable. Also known as an **experimental control**, **control treatment**, or **'the control'**

experimental group a group of individuals/samples in which the independent variable is manipulated. Also known as the **treatment group**

confounding variable an uncontrolled variable that affects the validity of the results

Case study

The placebo as a control treatment

Placebos are often used in control groups, especially when testing medicines. They are typically pills that look identical to the treatment drug, but have no active ingredients and do not result in therapeutic benefit. This means that the participants do not know if they are part of the experiment group or the control group. In such studies, we often note an improvement in patients treated with the placebo. This improvement is known as the 'placebo effect' and is due to the psychological beliefs of the person (i.e. if you believe you are going to get better, you will probably get better).

Types of control groups

There are two types of control groups: positive controls and negative controls. Negative controls are the most common. They are groups to which the IV is not applied. Negative controls are not expected to produce results. If they do, we know that something other than the IV (**a confounding factor**) may be causing the change in the DV and our experiment is flawed. Positive controls are groups where you expect to see results. Scientists apply a treatment which induces a well-understood effect on the DV, so they can see if the effect of the IV is comparable.

Imagine an experiment testing the effect of a new pesticide on crop yield. A negative control group would be a field not exposed to the pesticide. A positive control group would be a field exposed to an already-existing pesticide that is known to be effective at protecting crops from pests. The experimental group would be the field exposed to the new pesticide.

Controlled and uncontrolled variables

A '**controlled variable**' (also known as a 'constant variable') is a factor that remains the same throughout the experiment in an effort to reduce the chance of other factors (besides the IV) influencing the DV. For example, when testing the impact of fertilizer levels (IV) on tomato plant growth (DV), you would want to make sure that each group of plants with different fertilizer levels were exposed to the same level of sunlight, water, and wind. If they weren't constant, these factors would be **uncontrolled variables** that could potentially confound the results, making the experiment inaccurate and invalid (Figure 4).

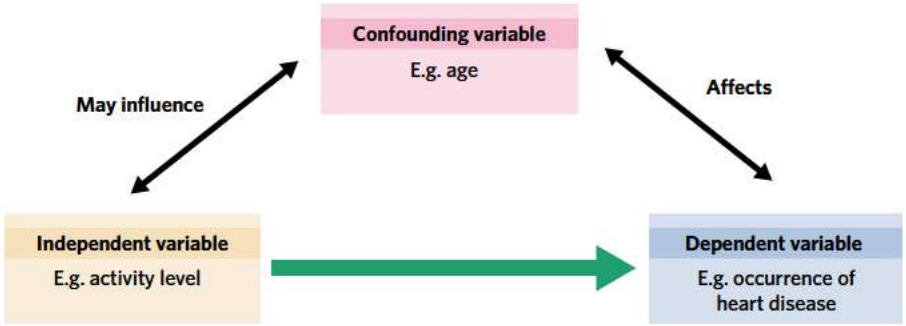


Figure 4 In this experiment scientists are interested in determining if activity levels directly impact a person's likelihood of developing heart disease. Age is another variable in this experiment, however, since it can influence a person's activity level (old people exercise less) and a person's likelihood of developing heart disease (older people are more likely to develop heart disease). If it is not controlled for (by only including people of a similar age in the experiment) it will serve as a confounding variable, making it difficult to determine if exercise alone has an impact on heart disease.

Memory device

Remember the IV-DV-TV! Old TVs had antennae on top of them. When you moved the antennae, it affected what you saw on the screen. In this way, the antenna is the thing you manipulate (the IV) and the image is the thing you watch/measure (the DV).

controlled variable a factor that is kept constant throughout the experiment. Also known as a **constant variable**

uncontrolled variable a factor that is not kept constant or accounted for throughout the experiment. Also known as an **extraneous variable**

Ethics and safety in science 4.3.3

OVERVIEW

The ethical principles of integrity, justice, beneficence, and respect can help you decide if an experiment is ethically designed. Risk assessments are important parts of preparing a safe experiment, especially in a laboratory environment where lots of people could be impacted by unsafe practices.

THEORY DETAILS

Ethical principles

Experiments must be ethical. This sounds obvious, but you'd be surprised by the number of horrible tests undertaken throughout history in the name of science. Ethical conduct is valued so highly in modern day science that at universities, experimental procedures must be presented to an ethics board before being permitted to proceed. Ethics boards also require scientists to consider the potential consequences of any discoveries for individuals or communities. For VCE Biology, you should be able to analyse an experiment and consider if the experimenters have developed an ethically-sound method. To do this, you can consider the experiment through the lens of four ethical principles (Table 2).

Table 2 How to use the principles of integrity, justice, beneficence, and respect to analyse if an experiment is ethical

Ethical principle	Questions to ask
Integrity	Has this research been reported honestly? Are all sources of information referenced?
Justice	Have all points of view been considered? Is there equal access to and fair distribution of any benefits that have arisen from this research?
Beneficence	Has harm to living things been minimised? For example, if living things are kept in captivity, is their welfare secured? Are there long-term impacts on the health of participants?
Respect	Has this research considered the welfare, beliefs, perceptions, customs, and cultural heritage of those involved in the experiment (e.g. participants, those affected by the results)? Have all participants given their fully-informed consent to be involved?

Case study

The cost of science

Medical progress saves lives, but at what cost? Here are two experiments that have breached ethical boundaries:

1 Researchers in the 1960s set out to determine if personality is determined by nature (our genes) or nurture (how we are brought up). To do this, scientists separated identical twins and triplets from each other, and adopted them out as singlets. One set of triplets ended up finding each other, and were devastated that they were 'robbed' of a life together. The findings of the study are currently withheld, and will not be released until 2066, making the scientific community question the integrity of the research. Furthermore, it did not gain consent from participants and the consequences on participant wellbeing were not considered.

2 The 'father of modern gynecology', J. Marion Sims, is renowned for his discoveries regarding vesico-vaginal fistulas (tears in the tissue between the vagina and bladder), but he gained all his knowledge from performing surgery on slaves without anaesthesia. It is unlikely his patients gave consent and the surgery would have been very painful, so this experiment breaches the ethical principles of respect and beneficence. Further, it is unjust that Sims took advantage of a vulnerable and powerless sub-section of the population.

We can try to analyse the student's experiment 'Bacteria in the house' according to these principles. For example, there may be some questions surrounding the integrity of the experiment, as the student said they were measuring the diameter of bacterial colonies but didn't present this data in their results. In addition, the principle of beneficence dictates that the welfare of living things is considered. Ethicists don't usually worry about harming non-animal life such as bacteria, but the scientists themselves could become infected. Stringent protection and disinfection procedures should be outlined in the methods and followed to prevent the spread of bacteria. Notably, this is something missing from the student's experiment.

If an experiment involved the participation of people from different cultural backgrounds, the ethical principles of justice and respect would be very important to apply. Researchers and ethicists would have to ask questions like: does the research undermine any cultural values? How could the results impact different communities? Do we have the right to investigate this? Can we consult with stakeholders? If any money is made from the products of this research, who should get paid?

There are not always 'right' or 'wrong' answers to these questions, but scientists must ask them to decide if it is ethical to proceed with an experiment. If some ethical dilemmas arise, it is sometimes possible to redesign the experiment to avoid the issue.

Safety

An experiment needs to be safe in order to be reproduced by other scientists. More simply, getting hurt sucks and can have big consequences for you, your class, and your teacher - whether it is a small cut from a microscope slide or something more serious.

It is likely that, during Year 11 and 12, your teacher will ask you to take ownership of your own safety during an experiment by doing a risk assessment. This means more than simply 'not breaking anything' or 'not sticking your face in the beaker'. A risk assessment is a process where you consider all potential risks in the experiment according to your context, and identify ways to minimise risks (Table 3).

Table 3 Examples of factors that could be identified as possible risks, contextual factors, and strategies to minimise risk in a biological risk assessment

Aspect of risk assessment	Examples
Possible risks	• Sharp objects • Flammable materials • Hazardous chemicals • Open flames • Culturing of microorganisms.

cont'd

Contextual factors	• The experience of staff and students with procedures • The behaviour of the class • Allergies of the class • Facilities available.
Strategies to minimise risk	• Wearing gloves, safety glasses, lab coats, enclosed footwear, and other appropriate personal protective equipment (PPE) • Following procedures • Following instructions from the teacher or laboratory during spills, breaks, or other accidents • Tying long hair back • Understanding and following standard handling procedures and Safety Data Sheets (SDSs) for specific chemicals (available online or through your risk assessment software) • Conducting experiments in an aseptic environment • Conducting experiments in isolation • Sanitising benches, equipment, and hands after lab work.

aseptic surgically clean and free from contamination by microorganisms. Also known as **sterile**

You can undertake a risk assessment online (e.g. riskassess.com.au) or using a printed template provided by your school. The online risk assessments are great because they usually outline standard handling procedures for all equipment and SDSs for chemicals.

Theory summary

You'll use and be tested on KSSs a lot during Units 3 & 4 VCE Biology. Sound experimental design involves creating repeatable, reproducible, and valid methods. Experiments should include a control, hypothesis, replication, clear communication, an IV, a DV, and attempts to minimise error and generate reliable data. Experiments should not proceed if they are unethical or unsafe.

1A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a group to which the IV is applied

b _____ a type of error that affects the accuracy of a measurement, where readings differ from the true value by a consistent amount each time

c _____ a quality of an experiment that measures what it claims to be measuring

d _____ describes measurements that are close to the true value

e _____ a factor other than the IV that might affect the DV

f _____ a measurement that differs greatly from other results

g _____ a group to which the IV is not applied

h _____ unpredictable variations in the measurement process cause this type of error

i _____ a measurement that is close to previous measurements

j _____ describes an experiment that generates the same results when it is undertaken by different scientists

k _____ describes a test in which the same operator can produce the same results multiple times

l _____ the variable that is measured during the experiment

m _____ the variable that is manipulated during the experiment

Question 2

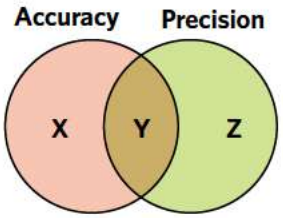
Which of the following options outlines all true statements about variables in experiments?

	Independent variable	Dependent variable	Controlled variable	Uncontrolled variable
A	Manipulated	Measured	A group in which the IV is not manipulated	A factor that might influence the results
B	Measured	Manipulated	Kept constant	Neither measured nor kept constant

C	Manipulated	Measured	Kept constant	Neither measured nor kept constant
D	Measured	Manipulated	Measured	Not measured but kept constant

Question 3

Which of the following options correctly describes X, Y, and Z?



	X	Y	Z
A	Measurements close to the 'true' value	Increases the number of replicates	Measurements that are close together
B	Measurements that are close together	Increases validity of results	Measurements close to the 'true' value
C	Measurements close to the 'true' value	Measurements that are close together	Removes uncertainty from experiments
D	Measurements close to the 'true' value	Increases reliability of results	Measurements that are close together

Question 4

Which of the following contain all true statements about control groups?

Control groups

A	are groups to which the IV is not applied.	don't need to be replicated because they are just a comparison.
B	are groups to which the IV is not applied.	should be replicated, as this will reduce the effect of outliers.
C	are groups to which the IV is applied.	should be replicated, as this will test the precision of measurement.
D	are groups to which a variable with a known, well-researched response is applied.	should be replicated, as this will make the experiment reproducible.

Question 5

Fill in the blanks in the following sentences.

_____**I**_____ errors decrease the precision of results. _____**II**_____ errors decrease the accuracy of results. One way to increase _____**III**_____ is to ensure all instruments are calibrated correctly. One way to increase _____**IV**_____ is to use appropriately sized measuring equipment.

	I	II	III	IV
A	Systematic	Random	precision	accuracy
B	Random	Systematic	precision	accuracy
C	Systematic	Random	accuracy	precision
D	Random	Systematic	accuracy	precision

Question 6

Which of the following statements is false?

A Confounding factors affect the validity of the test.

B Confounding factors may influence the dependent variable.

C Uncontrolled factors should not be mentioned in the discussion of a report.

D If an uncontrolled factor is measured or kept constant, it becomes a controlled factor.

Question 7

Identify the ethical principle(s) to which the following statements most clearly relate.

NOTE: statements can be classified into multiple groups.

I A new drug is designed that can save lives, but it is too expensive for people without private health insurance to buy.

II One person in your group writes the discussion but everyone takes equal credit.

III The results of one trial are excluded from a report, as they contradict the other trials.

IV When keeping barramundi in an experimental tank, the water temperature is much warmer than the conditions they would experience in the wild.

V Patients with a debilitating disease are not part of the 'treatment group' that is given an experimental, but potentially life-saving, drug. Instead, they are given a placebo.

VI No consultation with the community occurs before a group of scientists study its members.

VII An experimental treatment to cure a disease involves blood transfusions, but the procedure is not considered ethical by some religious groups.

	Integrity	Justice	Beneficence	Respect
A	I, V	II, III	IV, V	VI, VII
B	II, III	I, V, VI	VI, VII	IV, V
C	II, III	VI, VII	IV, V	I, V
D	II, III	I, V, VI	IV, V	VI, VII

Exam-style questions

Key science skills

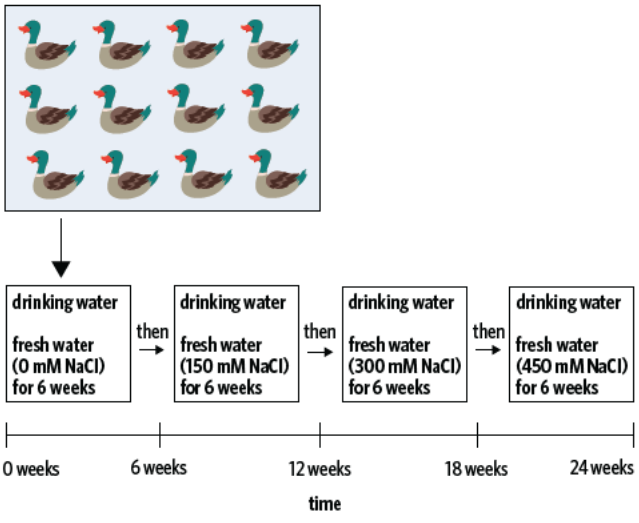
Use the following information to answer Questions 8–13.

Biologists investigating the regulation of body water in Peking ducks, *Anas platyrhynchos,* put forward the hypothesis that Peking ducks drink more as the saltiness of their drinking water increases.

The drinking water was to be supplied in 70 litre wading pools and replenished twice each day. Twelve adult Peking ducks, males and females, were available and two experimental designs were suggested.

Design 1

The same twelve ducks are provided with drinking water of increasing saltiness over a 24-week period.



Design 2

The twelve ducks are randomly divided into four groups of three ducks and each group is exposed to drinking water of a different salt concentration.

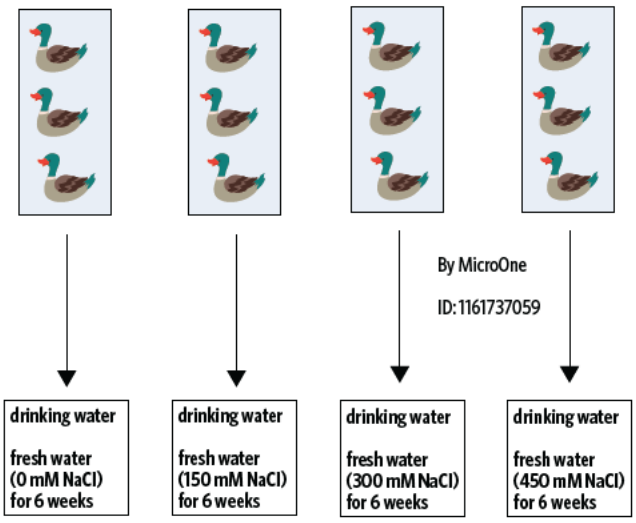


Image: Microone/Shutterstock.com

Question 8 (1 MARK)

The dependent variable is

A time.
B the gender of the ducks.
C the amount the ducks drink.
D the saltiness of the drinking water.

Adapted from VCAA 2004 Exam 1 Section A Q17

Question 9 (1 MARK)

The independent variable is

A time.
B the gender of the ducks.
C the amount the ducks drink.
D the saltiness of the drinking water.

Question 10 (1 MARK)

A controlled variable is

A the age of the ducks.
B the amount of water in the ponds.
C the saltiness of the drinking water.
D the ducks not exposed to the independent variable.

Question 11 (1 MARK)

An uncontrolled variable in Design 1 is

A the species of duck.
B the age of the duck.
C the number of replicates.
D the length of time in the ponds.

Question 12 (1 MARK)

One strength of Design 1 is that it better accounts for

A random error.
B systematic error.
C potential confounding factors.
D ethical and safety considerations.

Question 13 (1 MARK)

One strength of Design 2 is that it better accounts for

A validity.
B variation between individual ducks.
C time taken for the ducks to acclimatise to the conditions.
D the potential impact of previous conditions on duck drinking behaviour.

Question 14 (11 MARKS)

Some plants are resistant to attack by insects. The plants produce a protein that poisons the larval stage of some insects that feed on them. The production of the protein is under the control of a gene found in the plant. A particular species of crop plant that does not usually produce the protein was genetically engineered to contain this gene. Such plants are referred to as genetically modified (GM) plants. These GM plants do produce the insecticide protein.

Two farmers have properties next door to each other. They grow the same cereal crop.

- Farmer X wishes to grow GM crops that are resistant to attack by insects
- Farmer Y wishes to continue to grow non-GM crops.

Farmer Y was concerned that pollen from farmer X's GM crop could fertilise her non-GM plants, causing the next generation of Farmer Y's crops to produce the insect-poisoning protein.

The farmers agreed to carry out field trials to establish whether leaving a gap between crops reduced the likelihood of cross-pollination. A number of trials were planted so that the results of one trial did not interfere in any way with the results of another. The percentage of seeds produced at various positions as a result of cross-pollination was measured for each trial. The outline of these trials and the results gathered are shown in the following table.

	Percentage of cross-pollination	
	at edge of non-GM crop	10 metres into non-GM crop
Trial 1 GM non-GM, no gap between plots	10	2
Trial 2 GM non-GM, 5 metres between plots	1	0.5
Trial 3 GM non-GM, 7 metres between plots	1	0.3

a State the independent and dependent variables in the field trial. (1 MARK)

b Was a control group used in this experiment? Explain your response and, if not present, describe what a control group would consist of. (2 MARKS)

c From the data, what conclusions can be drawn about cross-pollination and the gap between crops? (2 MARKS)

d Farmer X was dissatisfied with the results of the trial, and insisted that they undertake another trial with replication.

i Explain why this is a good suggestion. (1 MARK)

ii Draw and explain an experimental setup the farmers could use in a field trial with replication. (2 MARKS)

e In an attempt to minimise error, a number of trials were planted at different times so that the results of one trial did not interfere in any way with the results of another. Explain one potential problem with this experimental design. (2 MARKS)

f Eventually, the farmers decided to plant their crops 5m away from each other, agreeing that this should keep the amount of cross-pollination low. After a few years, Farmer Y's initially non-GM crops were 50% GM. Despite this, Farmer Y was not displeased because her crops were growing far better than usual. Referring to an ethical principle, identify one ethical issue with the situation. (1 MARK)

Adapted from VCAA 2003 Exam 2 Section B Q4h

Question 15 (7 MARKS)

Before a drug is used for human therapy it is usually tested on animals. This is because results for animals often give some indication of how effective a drug may be in humans, and any potential side effects of the drug.

a Design an experiment, using mice, to test the effectiveness of a drug that targets viruses. (3 MARKS)

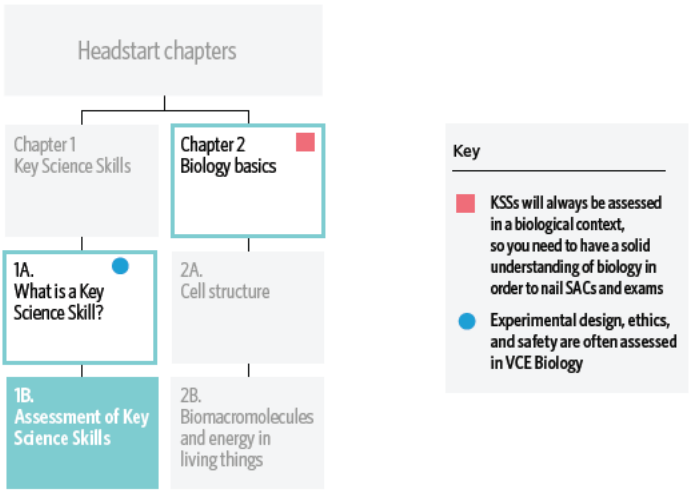
b Identify two ethical considerations the scientists should discuss before proceeding with the experiment. Suggest how they might be overcome. (2 MARKS)

c Identify two precautions the scientists should take to ensure the experiment is safe. (2 MARKS)

Adapted from VCAA 2006 Exam 1 Section B Q3c

1B ASSESSMENT OF KEY SCIENCE SKILLS

When analysing graphs and tables, make sure your conclusions are limited by, and do not go beyond, the data available. To assume anything more makes an 'ass' out of 'u' and 'me'.



In this lesson you will learn how to demonstrate your KSSs in School Assessed Coursework (SACs). In particular, you'll learn how to present your data.

Study design dot points

- the biological concepts specific to the investigation and their significance, including definitions of key terms, and biological representations
- the characteristics of scientific research methodologies and techniques of primary qualitative and quantitative data collection relevant to the selected investigation, including laboratory work (biochemistry, cytology, immunology) and/or fieldwork (geomorphology); precision, accuracy, reliability, and validity of data; and minimisation of experimental bias
- methods of organising, analysing, and evaluating primary data to identify patterns and relationships including sources of error and limitations of data and methodologies
- the nature of evidence that supports or refutes a hypothesis, model, or theory
- the key findings of the selected investigation and their relationship to cytological, biochemical, and/or evolutionary concepts
- the conventions of scientific report writing and scientific poster presentation including biological terminology and representations, standard abbreviations, units of measurement, and acknowledgment of references

Key knowledge units

Overview of assessment in Units 3 & 4 VCE Biology	4.3.4
The logbook	4.3.5
Practical reports	4.3.6
Poster presentation of a scientific investigation	4.3.7
How to present and analyse data	4.3.8

Overview of assessment in Units 3 & 4 VCE Biology 4.3.4

OVERVIEW

SACs make up 40% of your VCE Biology mark, and the exam makes up the remaining 60%. To be successful at these assessments, you need to revise the set theory, develop KSSs, and record all your practical activities in a logbook.

THEORY DETAILS

VCE Biology assesses students in a number of ways. Most of your marks are derived from your exam performance (60%), and the rest (40%) come from a variety of teacher-chosen tasks set for **School Assessed Coursework (SACs)**. Most of the time, SACs will involve collecting **primary** or **secondary data** and preparing practical reports, but they may also be tests, media responses, posters, and other activities. While your exam is marked externally, your teacher marks your SACs (although these can be moderated externally). Additionally, you are required to maintain a **logbook** throughout Unit 3 & 4 Biology.
In all of these assessments, you may be tested on both your theory knowledge and KSSs.

School Assessed Coursework (SAC) an internally-marked assessment (e.g. practical report, test, media response) that contributes to your overall study score in VCE Biology

primary data results collected from experiments, interviews, or surveys undertaken by the researcher

secondary data results from sources other than the researcher's own investigations

logbook a record of all your practical investigations. Maintaining a logbook is a compulsory component of VCE Biology

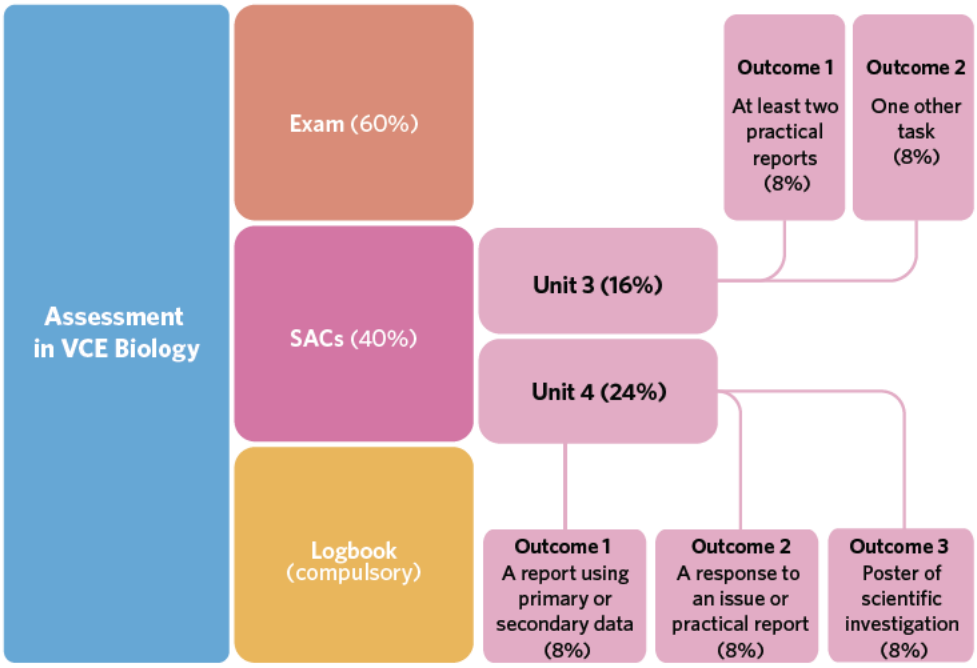


Figure 1 The components of your VCE Biology course that contribute to your final score

The logbook 4.3.5

OVERVIEW

Logbooks are a requirement of VCE Biology and are comprised of results from the investigations you undertake during the course.

What is a logbook?

Scientists don't need to have excellent memories. Instead, they keep a meticulous and organised record of their observations, discussions, experiments, analyses, and conclusions. Keeping a logbook should help you practise writing down and articulating your thoughts about biology. It will also mean that you won't break into a cold sweat when your teacher or lab partner asks you, 'Did the *Elodea* in the negative control group displace the water by 1.5 mL or 1.6 mL?' You can just flick back to your notes.

Logbooks can be digital and/or paper-based. While there is no set format for a logbook, VCAA emphasise that the logbook is a record of all your practical activities and investigations over Units 3 & 4 Biology. This means that formal practical reports and SACs are typically recorded in your logbook. Your logbook may also contain:

- Surveys
- Interviews
- Reflections
- Results of simulations
- Qualitative and quantitative data
- Planning notes for experiments
- Responses to questions in a worksheet
- Results from activities or investigations
- Simple observations made during class
- Notes, images, or data from excursions
- Web-based investigations and research
- Notes of additional work completed outside of class
- Links to spreadsheet calculations or other digital records.

The purpose of collating all this in the logbook is to provide a basis for further learning. In particular, the logbook should help you:

- contribute to class discussions
- report back to class on activities
- reflect and draw conclusions from experiments and discussions
- record data and observations in an accurate and timely manner.

Tip Make sure you acknowledge or reference investigation partners, expert advice, secondary data sources, and any assistance you received. Also, write the date at the top of each entry.

Practical reports 4.3.6

OVERVIEW

Some of your SACs will be formal practical reports of experiments. The recommended structure for a practical report is title, abstract, introduction, methodology, results, discussion, conclusion, acknowledgements, then references.

THEORY DETAILS

Figure 1 shows that many of your SACs involve writing a practical report. You may also conduct experiments that do not contribute to your final marks but give you a chance to practise or explore a concept. In total, VCAA recommend that classes devote 3.5-5 hours of class time to practical work per Outcome, but 7-10 hours for Unit 4 Outcome 3. Typically, you will be asked to describe and discuss any experimental work in a **practical report.**

practical report a structured record of an experiment

raw data results that have not been processed, manipulated, or formatted for use

transformed data results that have been converted from their raw format into a more visually sensible presentation that is easier to analyse

In this section, we will describe the main parts of a practical report. Reports are typically written in third person (e.g. 'This study investigated...' or 'The results indicate that...') but some journals prefer first person (e.g. 'We found that...' or 'Our research shows...'). You should note that your teacher may have additional or different requirements for you to follow.

Table 1 The components of a practical report, including suggested length and tense of each section

Section	Suggested length	Suggested tense
Title The title may be written as a question or statement that describes the main thing you are trying to determine. Examples include: • How does light intensity affect the rate of photosynthesis? • Does the theory of natural selection explain the increasing carp (*Cyprinus carpio*) population in the Murray River? • The impact of pH on the rate of enzyme-catalysed reactions. • The isolation and characterisation of spermatogonial stem cells in the fat-tailed dunnart (*Sminthopsis crassicaudata*). • What does medical student study behaviour look like, and is it effective? • Bathing salmon in cold water is an effective treatment for removing skin parasites. Note that if you are investigating a particular species you may wish to include the species name in the title.	One sentence	Present
Abstract Abstracts are optional but recommended. In essence, the abstract is a short overview of the entire experiment. One formula you could use for writing an abstract is answering each of these questions in one sentence, then using linking words to make the paragraph flow: • What is the significance of the experiment? • What was the aim of the experiment? • What was your method? • What were your results? • Why are your results important? • Given these results, what should be researched next? Or, what are the broader implications of these results?	100-300 words	Past

cont'd

Introduction The purpose of the introduction is to justify why you needed to perform your experiment. Introductions generally contain the following information (not necessarily in this order). • Background information. This may include: – Why the system or model is important to study – For example, photosynthesis is important to study as it plays a major role in controlling the levels of different gasses in our atmosphere – The broader implications of answering your particular question – Any prior research that has been undertaken › This may include pilot studies your class undertook or research by other sources › You may also wish to point out weaknesses with prior studies - these could be grounds for your research › Be sure to reference any secondary sources – Any gaps in knowledge, and how your experiment could fill that gap • The aim of the experiment • The variables tested • The hypothesis – As well as a justification for your prediction • The final sentence of the introduction is typically 'big picture', suggesting how what you discover could help the world or influence future research.	Variable - check with your teacher, but usually one to four paragraphs	Past
Methodology The purpose of a method is to outline all the materials and steps you took during an experiment. Like a cooking recipe, it must be very detailed so that someone else could read it and follow your steps exactly. You can usually write the method in steps and in third person. We recommend using short sentences and removing all flowery language so that it is easy to understand. Make sure you: • Write the steps in order • Name any equipment used – You may wish to outline if/how the equipment was maintained or calibrated • Draw and label any complex experimental setups • State what you measured and when.	Usually no longer than half a page	Past
Results The purpose of the results section is to present the key findings of the study in a clear and honest manner. You do not usually present **raw data** in the results section, but manipulate it into **transformed data** (e.g. table, line graph, bar graph) that best shows any trend, patterns, or relationships that exist (see the next section in this lesson for more on presenting data). Each figure is accompanied by a brief (2-3 sentence) description of the key finding. If statistical analyses have been performed, they are presented here as well. Do not interpret or explain your findings in this section.	Variable — it depends on the number of figures and tables	Past

Tip Some instruments are more precise than others. For instance, the screen height of an iPhone X could be 14.9 cm (ruler), 14.86 cm (vernier calipers), or 14.859 cm (micrometre screw gauge). Clearly, there is more uncertainty associated with the ruler measurement than with the micrometre screw gauge measurement.

You may wish to quantify the uncertainty associated with measuring instruments in your methods. Digital devices like scales typically state the uncertainty on a sticker somewhere. For analogue instruments like rulers and measuring cylinders, uncertainty is a bit trickier.

If you have to set up the instrument before measuring (e.g. with a ruler, you need to put it in place before measuring), then the uncertainty is the smallest measurement. On the ruler shown in Figure 2, the uncertainty is ± 1 mm.

If you don't need to set the instrument up before measuring (e.g. a measuring cylinder, a thermometer), then the uncertainty is half of the smallest measurement.
In the measuring cylinder as shown in Figure 3 the smallest measurement is 1 mL, so the uncertainty is ± 0.5 mL.

Note that the uncertainty assigned to standard digital stopwatches is ± 0.1 second due to human reaction time.

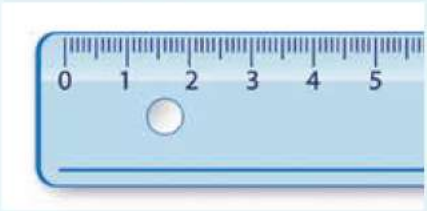


Image: Dragance137/Shutterstock.com

Figure 2 A section of a ruler that has an uncertainty of ± 1 mm

Image: oFFsoRRy/Shutterstock.com

Figure 3 A measuring cylinder that has an uncertainty of ± 0.5 mL

Discussion The purpose of the discussion is to determine if the data obtained support the hypothesis and to explore the implications of the findings. It is very important that you highlight any problems that arose during the experiment in the discussion, as well as any limitations of the data. One way you could structure a paragraph in your discussion would be to include: • Restate one key result (e.g. the result from one figure) • State if the result supports or refutes the hypothesis • Discuss if your findings support or differ from prior research – Be sure to reference sources • Weigh up the strengths and weaknesses of the data to determine if the result can be trusted – Identify reasons why this result may be invalid or unreliable. Here, you could refer to: › Personal, systematic, or random errors › Precision, accuracy, and uncertainty of data › Problems with the experimental design › Other studies that contradict your data – Identify reasons why the results may be limited - what is the data not telling us that would be useful to know? – Suggest how the method could be changed to overcome any problems – Identify any strengths that support the validity, reliability, and scope of the results.	At least one paragraph — usually three or four	Mostly present
Conclusions The purpose of this section is to summarise your study. Generally, conclusions begin by stating whether the hypothesis was supported. They also may include: • Justification of why the hypothesis is supported/rejected • Summary of limitations and improvements • The broader implications of the results, for example – Future research – The impact on scientific knowledge – The impact on society/environment.	One paragraph	A mix, but mostly present
Acknowledgements Individuals involved in the experiment should be recognised for specific contributions.	One to three sentences (not included in word count)	Present
References A list of references in a standard style (e.g. Harvard or APA) should be included.	Anywhere from 2 — 20 references (not included in word count)	N/A

Poster presentation of a scientific investigation 4.3.7

OVERVIEW

The poster presentation has the same sections as a practical report, but you must change your communication style so that information is transmitted more concisely and visually.

THEORY DETAILS

At scientific conferences, halls are filled with posters showing the latest research (Figure 4). As a result, it is important to develop your skills at making posters. In particular, they are different from reports in that:

- written sections are short and direct
- the results section is usually front and centre
- images can be included
- figures should be large and easy to read.

Remember that, for scientists, eye-catching and visually pleasant presentations mean more people will look at your poster as opposed to the hundreds of others up on the walls. This gives you a greater chance of sharing your results, meeting potential collaborators, receiving feedback, and advancing your career. The skills you use to make this poster - namely, being concise and presenting work clearly - are valued across all disciplines, not just science.

Because poster presentations are so important for scientists, for VCE Biology you will spend seven to ten hours creating a poster that presents an investigation of any topic from Units 3 & 4. The investigation may take place anytime during the year, and must involve the collection of primary data.

The scientific investigation

The poster presents information about a scientific investigation that you undertake largely independently. This means that you will not be given a question or a prescribed procedure, as in a **structured inquiry.** Specifically, VCAA recommend you undertake either a **coupled** or **open inquiry**. In coupled inquiries, your teacher may choose an initial question to investigate, then you must build on and design a linked investigation. For example, your teacher might demonstrate how to measure the rate of photosynthesis. From there, you could design an experiment that tests the rate of photosynthesis in native plants compared to introduced species or you could test how changing pH affects photosynthesis in marine plants (a problem many will face due to ocean acidification). You decide upon the variables that you wish to investigate, within a predetermined framework.

structured inquiry an investigation in which students explore a teacher-proposed question through a prescribed procedure

coupled inquiry an investigation in which students extend or build upon an initial, teacher-proposed question

open inquiry an investigation that is student-centred, whereby students develop their own question and experiment

In an open inquiry, you choose your own question and design your investigation. In this scenario, you may deep dive into any topic from Units 3 & 4 Biology or even design an experiment that explores multiple topics at once. Open enquiries are entirely based off student curiosity and interests, but your teacher can support you where necessary.

A potential way to start with an open inquiry is to think about your hobbies - perhaps you have a passion for music, art, or sport. How might aspects of these disciplines interact with cellular respiration, enzyme-catalysed reactions, plant hormones, evolution, or antibiotics? For example, do different brands of sports drinks affect osmosis across plasma membranes? Or respiration rate in yeast cells? Alternatively, you could begin an open inquiry by considering current issues the world, or your hometown, is facing. For example, salt tolerance and drought tolerance are increasingly important for plants in a world affected by global warming. You could manipulate levels of water or salt and measure germination, growth, or photosynthesis in a local plant species.

Figure 4 An example of a poster presentation at a scientific conference

Tip Be really careful when writing your question! Table 2 outlines some common problems with research questions.

Table 2 Suggested solutions for common mistakes with research questions

Poorly worded question	Problem	Improved question
Is it best to grow plants with natural or artificial light during the Australian winter?	The question is vague: what do the students mean by 'best'? Which plant species did they test?	Do snow pea plants (*Pisum sativum*) grow more with natural or artificial light during the Australian winter?
How does garlic inhibit the growth of *S. epidermis*?	Using 'How' questions suggest you need to explain the mechanism of action of garlic. This is not investigable with standard school equipment in less than ten hours. Also you should use the full scientific name, not an abbreviation.	What is the effect of garlic on the growth of *Staphylococcus epidermis*?

Creating the poster

The poster sections are the same as the sections of a practical report. However, there are some key differences in what is included in each section. Figure 5 shows a suggested layout of the poster, and explanations of how to approach each section. Note that VCAA mandate a word limit of 1000 (excluding references and acknowledgements) for this assessment.

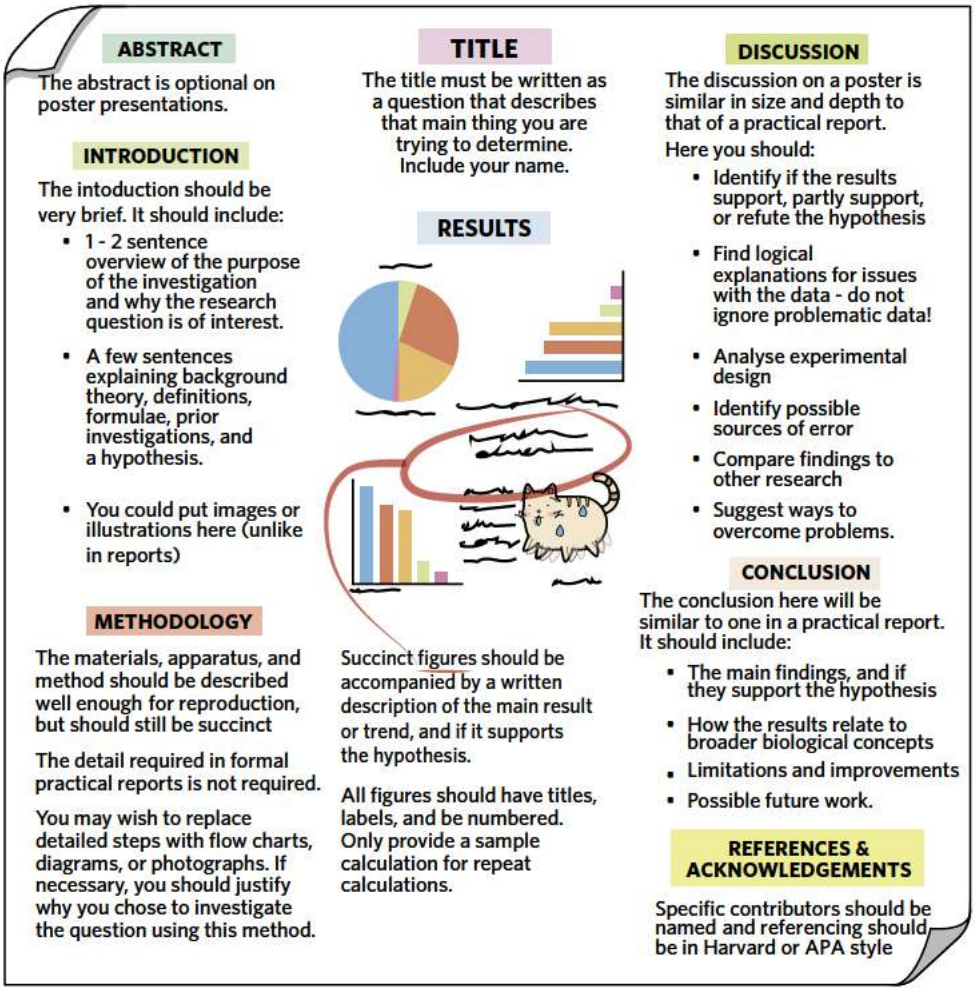


Figure 5 A suggested layout for the poster presentation, and descriptions of what to include in each section

When creating your poster, you must think carefully about your communication style. Some guidelines for effective scientific communication on your poster include:

- Logical sequencing
- Signposting key parts, such as the hypothesis, question, aim, and conclusion
- Reduce complexity
  - Inclusion of only the essential details
  - Use (defined) acronyms
  - Use dot points
- Using a range of visual aids to avoid overcrowding with text - some scientists recommend that at least 50% of the poster space is photos and figures.
- Use of font, font size, and colour to ensure the poster is easy to read (even from a distance)
- Correct spelling and grammar
- Test if someone with no background knowledge can understand it
- Label figures, images, and tables.

How to present and analyse data 4.3.8

OVERVIEW

In practical reports, posters, and exams you may need to present and interpret data.

Figure 6 The process of analysing, presenting, and discussing data

THEORY DETAILS

Imagine that it's the last period on a Friday. It's hot. Over the past hour and a half, you and your laboratory partner have managed to design a valid and repeatable experiment, thanks to lesson 1A. You've sweated over Bunsen burners, made precise measurements and battled to minimise error and bias during data collection. You're proud of yourselves. Very little went wrong, so you should have reliable data from which you can draw meaningful, reasonable conclusions. Right? But, as you look down at the scrimmage of numbers and letters in your logbook, you realise that you actually have no idea what it all means.

A crucial part of being a scientist is communicating your results clearly and honestly. In practical reports and posters, raw data is not usually presented because it can be hard to read, repetitive, irrelevant, or messy. Instead, data is manipulated so that the main result, pattern, or trend is obvious. Tables are not always the best way to show trends, so results sections will typically include graphs and charts.

Types of graphs

The type of graph you choose depends on the type of data that you have collected. Table 3 outlines the different types of data you may collect, and how you can represent that type of data.

Table 3 Type of data you may collect about variables and how they are best graphed

Type of variable		Explanation	Typically graphed using a...
Numerical	**Continuous**	Data that can take any value between a set of real numbers e.g. height, age, mass, volume	**Line graph** or **scatter plot**
	Discrete	Data that take a particular value, and cannot take a fraction of that value e.g. count of individuals	
Categorical	**Ordinal**	Data that can be logically ordered e.g. size (small, medium, large), fin health score (1 = no fin damage, 2 = some fin damage, 3 = most of fin surface damaged), attitudes (agree, neutral, disagree)	**Bar graph** or pie chart
	Nominal	Data that cannot be organised in a logical sequence, e.g. gender, nationality, hair colour	

numerical variables factors that are measured as a number such as height, count of population, and age

scatter plot a graph in which the relationship between variables is plotted using dots, through which a trendline may reveal correlation. Also known as a **scattergram**

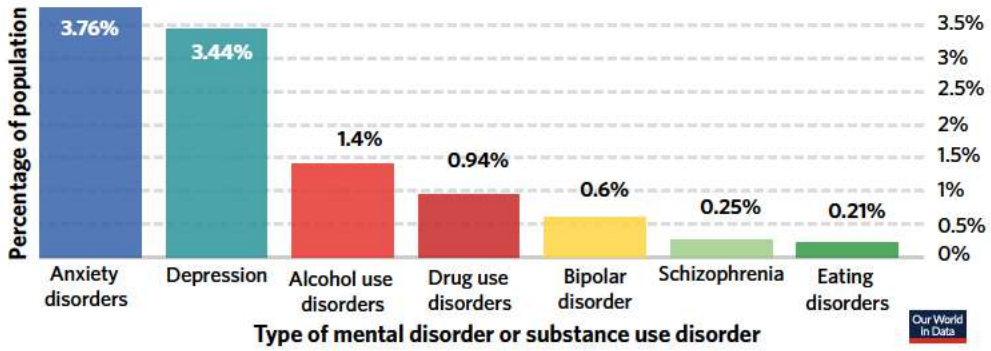
categorical variables factors that are qualitative, typically describing a characteristic such as gender, birth order (1st, 2nd, 3rd), or nationality

bar graph a graph that shows changes in categorical variables using filled rectangles

dependent variable (DV) the factor(s) changed by the manipulation of the IV

independent variable (IV) the factor(s) that is manipulated in an experiment

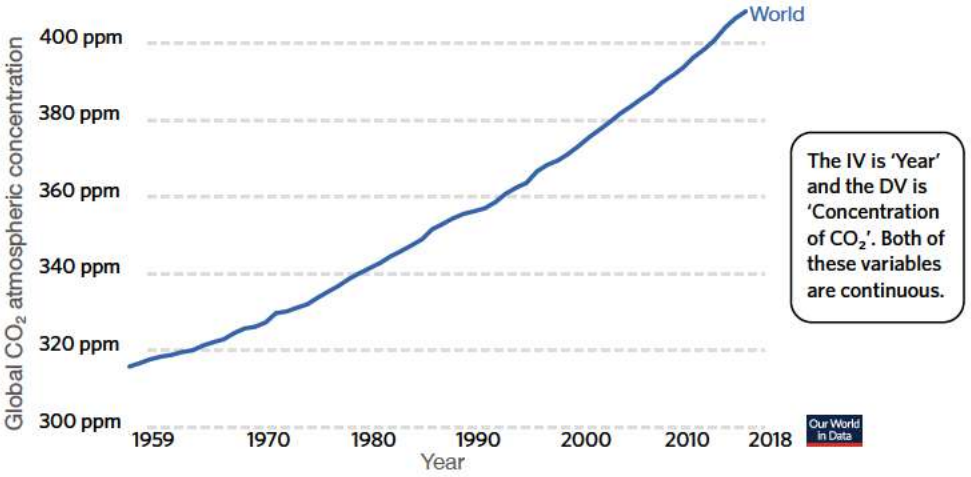
Bar charts (Figure 7) and pie graphs typically graph categorical data, whereas line graphs (Figure 8) and scatter plots (Figure 9) represent numerical data well. Scatter plots are particularly useful if you wish to compare two variables (e.g. the salary of women compared to the salary of men). If one variable is categorical but the other is continuous, bar graphs usually work well.



The categorical variable in this bar graph is the IV: Type of mental and substance use disorder

Source: Global Burden of Disease Collaborative Network (2017) adapted by Ritchie and Roser (2019)

Figure 7 Bar graph showing the prevalence of mental disorders and substance use disorders in 2017



Source: Keeling (1974) and the National Oceanic and Atmospheric Administration (2018) adapted by Ritchie and Roser (2019)

Figure 8 Line graph showing the change in global carbon dioxide atmospheric concentration over the past 60 years

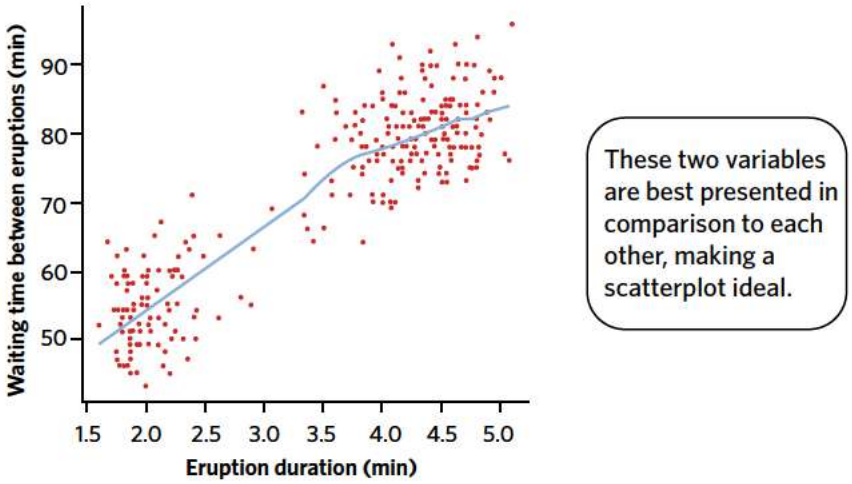


Figure 9 Scatter plot showing that the longer the wait time between eruptions of the geyser Old Faithful, the longer the duration of the next eruption

During experiments, you may record points within a range of continuous data, creating a scatterplot. For example, you may record the oxygen concentration in a sealed jar with a plant inside every five minutes. Oxygen concentration is continuous data, so you can draw a 'line of best fit' to show the general relationship between the variables. A line of best fit may pass through all the points, some of the points, or none of the points (Figure 10). A good rule of thumb when drawing a line of best fit is to ensure the number of points above and below the line are equal.

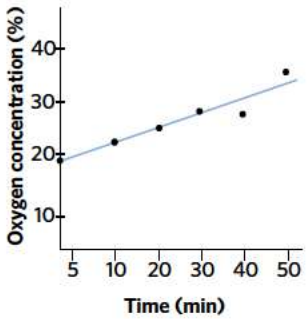


Figure 10 The line of best fit showing the general trend between two variables on a scatterplot

Formatting of results

Once you've drawn up your graph on paper or on the computer, you need to format it to maximise clarity and to ensure it fits scientific conventions. Some guidelines for formatting are:

- Ensure the graphics are clear and easily read
- The scale should be appropriate for the data, and labelled clearly
- Ensure the graphs do not have coloured backgrounds or grid lines, unless required to present results clearly
- Axis labels should be formatted in sentence case (Not in Title Case and NOT ALL CAPS). Only the first letter of the first word should be capitalised, as well as any proper nouns.
- Any calculations should be presented in a clear, non-repetitive manner (e.g. by using one sample calculation)
- Each graph should have a figure number and title underneath
- Each table should have a table number and title above
- The results section also includes text. The text should summarise the key finding for each graph in 1-2 sentences, including if the result supports the hypothesis.

Tip In most cases, the IV is represented on the horizontal axis and the DV is on the vertical axis.

Interpreting data

As a budding scientist, you should be able to draw sound conclusions from reliable evidence. Of course, first you need to confirm that your evidence is reliable - by checking if the data is accurate, precise, and valid (as explored in 1A). If you decide that any issues with the data collection do not undermine the overall result, you can then start to interpret data and draw conclusions. Here, we will investigate two common problems students have when interpreting data.

1 Correlation does not mean **causation**

Not all experiments will reveal a correlation between two variables (Figure 11). You may find that the DV and the IV are unrelated. Furthermore, even if your data indicate that your IV affects your DV in a consistent and measurable manner (e.g. if you increase the IV, the DV increases), this doesn't necessarily mean that the IV causes the change in DV. In other words, correlation of two variables does not mean that one causes the other.

An example of the correlation/causation problem can be observed when measuring the number of ice cream sales and the number of shark attacks. Looking at Figure 12, it would appear that high ice cream sales cause many shark attacks. However, the tight correlation of the variables does not rule out the possibility that something other than ice cream consumption is causing shark attacks. In fact, it seems much more likely that a confounding variable - hot weather making people cool off at the beach and/or buy ice cream - explains the relationship more clearly.

Even if you understand a system very well, there is always a possibility that you have overlooked a confounding factor or that the hypothesis is only supported in a controlled experimental context. Higher replication or an improved experimental design may produce different results. Consequently, scientists tend to use language that is not definitive when explaining their data in the discussion and conclusion. Instead of saying 'Without a doubt, the results clearly prove that...' they might say 'The results suggest... ' or 'The hypothesis was supported by...'. It is important to apply the same level of scrutiny when examining other people's results or secondary data.

2 Conclusions must be limited by, and not go beyond, the data available

Any conclusions drawn from data must be limited by, and not go beyond, the data available. For example, when drawing a line of best fit it is important not to force your line through zero. Consider Figure 13. Here, the scientists measured the height of a seedling every day since germination, but not on the day of germination. Although the seedling height is logically zero at day zero, as it has not grown at all, drawing a **trendline** that is forced through zero results in a different slope (red dotted line) to the trendline that actually best fits their data (blue line). In summary, draw trendlines that fit the data you collect, rather than the data that doesn't exist.

Additionally, the scientists stopped collecting data after ten days. Therefore, it is not correct to state that 'it will take the seedlings 20 more days to reach 9 cm', because we have no idea what happens to the rate of growth of seedlings after day ten. One could, however, say that 'if the rate of growth continues in the manner indicated by the results, then it will take the seedlings 20 more days to reach 9 cm'.

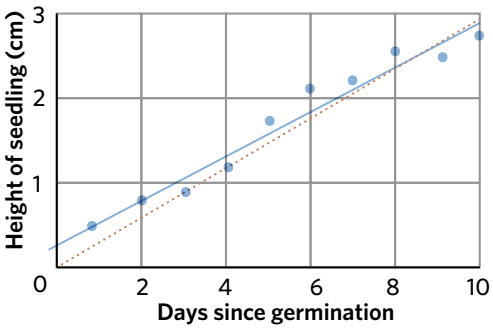


Figure 13 When drawing a trendline, avoid forcing your data through zero (red dotted line) as you end up with a different slope that doesn't accurately represent the data you collected (blue)

correlation demonstrated when there is a statistical relationship between two variables

causation demonstrated when change in one variable leads to reliable change in another

trendline a line that shows the main pattern followed by a set of points on a graph. Also known as a **line of best fit**

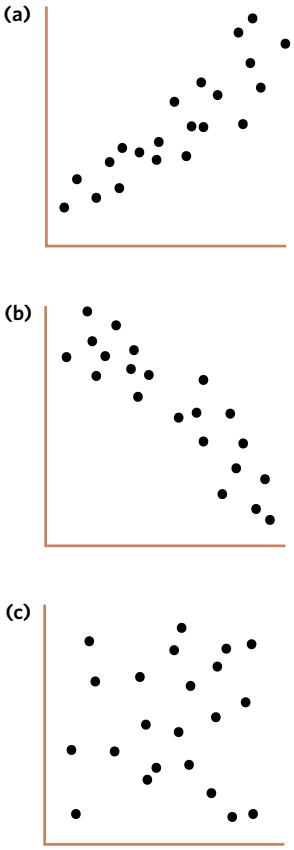


Figure 11 Scatter plot examples of **(a)** positive correlation, **(b)** negative correlation, and **(c)** no correlation

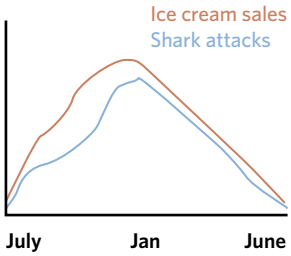
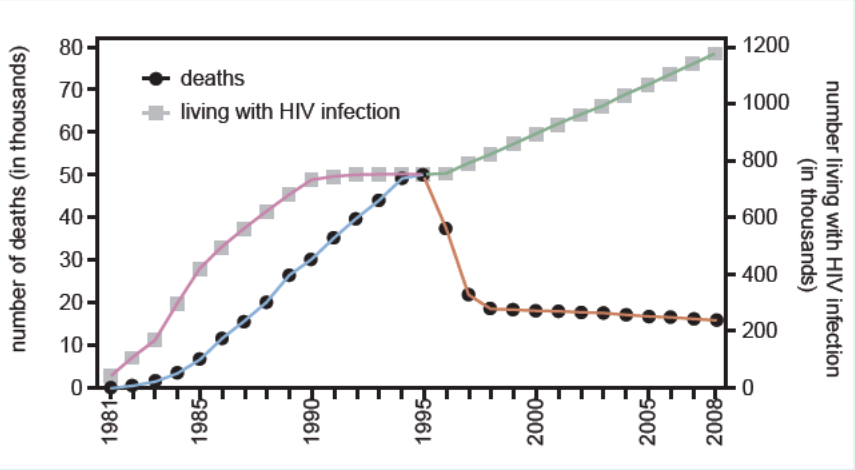


Figure 12 The number of ice cream sales and shark attacks are correlated, but one does not cause the other

Tip On exams, you may be asked to *describe* data before you then explain it. A good plan of attack to describe data is to divide the graph into different sections.

For example, in this graph from the 2018 exam, it would be difficult to describe everything that is happening all at once. But we have superimposed colour over sections of the data that actually would be easy to describe.



Source: adapted from National Institute on Drug Abuse (2012)

Figure 14 An exam question that requires students to interpret a line graph

Here is an example of how you could describe this data:

The number of deaths from HIV rose steadily from 1981, reaching a peak in 1995 at 50 000. This was followed by a sharp decline in deaths from 1995–1997, until plateauing around 20 000 for the next ten years. Meanwhile, the number of people living with HIV rose from close to zero to 800 000 between 1981 and 1990. It stayed at approximately 800 000 for five years, then the number increased linearly to 1 200 000 by 2008.

Note that the description includes numbers from the x and y axis to contextualise the overall pattern.

Theory summary

In VCE Biology, your understanding of theory and application of KSSs are tested during SACs (40%), the exam (60%), and by maintaining a logbook (hurdle requirement). During SACs, you will often be assessed in the format of practical reports. Each part of a practical report requires you to include particular information. Another major piece of assessment is the scientific poster of an investigation. Although it has similar sections to a practical report, the investigation must be independent and the poster requires succinct communication and a greater use of graphics.

1B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the section of a practical report that requires a high level of detail, so others can reproduce your experiment

b _____ the variable that is usually plotted on the x axis

c _____ the matching or relatedness of two variables

d _____ the type of numerical data that takes a particular value, such as count of frequency

e _____ the type of data that is best plotted on line graphs or scatterplot

f _____ a type of inquiry style where students choose and design their own investigation autonomously

g _____ the section of a practical report that ensures anyone who contributed to the investigation is recognised

h _____ a line that shows that general pattern of data on a scatterplot

i _____ non-numerical data whereby variables may be grouped by qualitative characteristics

j _____ results that have just been collected and not manipulated in any way

Question 2

Each part of a practical report fulfils a particular function. Identify which section of the report match the following descriptions.
NOTE: a single description can match with multiple or no report sections

I The aim and hypothesis are outlined for the first time.

II Previous research on the topic is explored.

III Graphs and tables are presented.

IV Relevant photos should be displayed.

V Instruments and their uncertainties are described here.

VI The degree to which the results support the hypothesis is described.

VII The limitations of the data are explored.

VIII The broader implications of the experiment are discussed.

	Introduction	Method	Results	Discussion
A	I, II, IV	V, IV	III, IV	II, IV, VI, VII, VIII
B	I, II, VIII	V	III, IV	II, VI, VII, VIII
C	I, II, III, VIII	V	III	II, VI, VII, VIII
D	I, II, VIII	V	III, IV	VI, VII, VIII

Question 3

Which of the following options contains all true statements regarding the communication style required in practical reports compared to scientific posters?

	Practical report	Poster
A	Concise but formal text, accompanied by clear raw data. Images not required.	Detailed and lengthy text for thoroughness. Results and images very important.
B	Detailed, informal, but thorough text accompanied with clear transformed data. Images not required.	Concise and direct text. Eye-catching images and graphs.
C	Detailed, formal, and thorough text accompanied with clear transformed data. Images not required.	Concise and direct text. Eye-catching images and graphs. Can exclude references for brevity.
D	Detailed, formal, and thorough text accompanied with clear transformed data. Images not required.	Concise and direct text. Eye-catching images and graphs.

Question 4

Which of the following correctly explains the difference between structured, coupled, and open inquiries?

A Unlike coupled and open inquires, students receive teacher feedback in structured inquiries.

B Unlike coupled and open inquires, students undertake an independent investigation in structured inquiries.

C Unlike structured and coupled inquiries, students follow a prescribed method in open inquiries.

D Unlike structured inquiries, students decide upon their own research question in coupled and open inquiries.

Question 5

Identify if the following variables are examples of continuous, discrete, ordinal, or nominal data.

I Mass of seed

II Population of sugar gliders

III Percentage of the population that is under 20 years old

IV Species

V Order of finishing a race

VI Number of petals on a flower

VII Likelihood of going to the gym on a given day (unlikely, 50-50, likely)

VIII Eye colour

	Continuous	Discrete	Ordinal	Nominal
A	I, III	II, VI	V, VII	IV, VIII
B	II, VI	I, III	V, VII	IV, VIII
C	I, III	II, VI	IV, VIII	V, VII
D	II, VI	I, III	IV, VIII	V, VII

Question 6

Fill in the blanks in the following sentences.

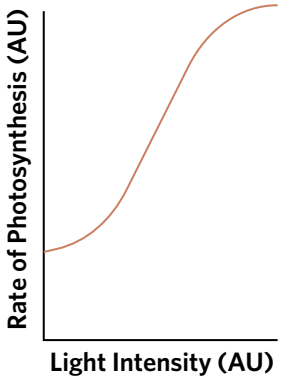
Bar graphs are best used for representing _____**I**_____ data, whereas line graphs or scatterplots can represent _____**II**_____ data. Generally, the _____**III**_____ is plotted on the x axis, and the _____ **IV**_____ is plotted on the y axis.

	I	II	III	IV
A	categorical	numerical	dependent variable	independent variable
B	numerical	categorical	dependent variable	independent variable
C	numerical	categorical	independent variable	dependent variable
D	categorical	numerical	independent variable	dependent variable

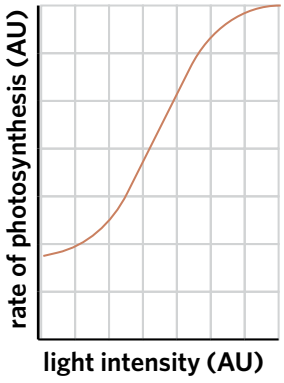
Question 7

Which of the following graphs has been formatted correctly?

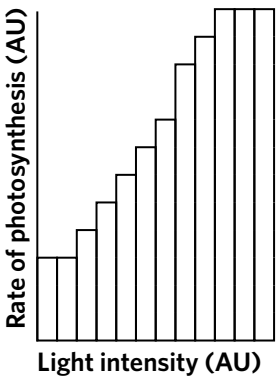
A



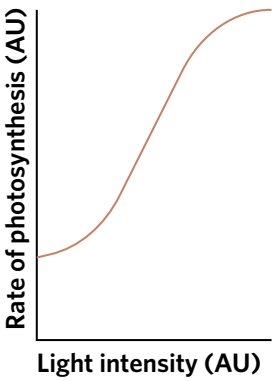
B



C



D



Question 8

Scientists need to examine their own, and others', data critically. Which of the following would not make a scientist doubt the reliability and validity of the results?

A A sentence in the discussion that states 'These results provide undeniable evidence that our hypothesis is true.'

B A scatterplot with a trendline that is not forced through zero.

C A description of an instrument used to measure the length of a bird's beak with an uncertainty of ± 3 cm.

D Results that show a correlation between the IV and DV without any discussion of potential causes.

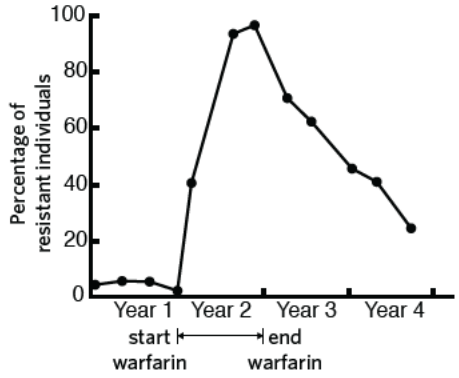
Exam-style questions

Key science skills

Use the following information to answer Questions 9 and 10.

Warfarin is a poison used to control rat populations. The graph shows changes in the proportion of rats resistant to warfarin in a particular population over a period of about 4 years.

High levels of warfarin were used on this population during Year 2 but poisoning stopped at the end of this period. Rats are reproductively mature at an age of three months and can breed about every three weeks.



Question 9 (1 MARK)

Which of the following options best describes the data in the graph?

A The percentage of resistant individuals increases with time up to nearly 100%.

B The percentage of resistant individuals is less than 10% in Year 1, but rises sharply to around 95% in Year 2.

C The percentage of resistant individuals is initially low, then rises sharply in Year 2 to 95%, then falls again to around 25% in Year 4.

D The count of resistant individuals is low in Year 1, then rises sharply in Year 2 to reach a peak of around 98, then falls again to 60 in Year 3 and 25 in Year 4.

Adapted from VCAA 2002 Exam 2 Section B Q7

Question 10 (1 MARK)

A line graph was used to represent this data because

A the independent variable is on the x axis and the dependent variable is on the y axis.

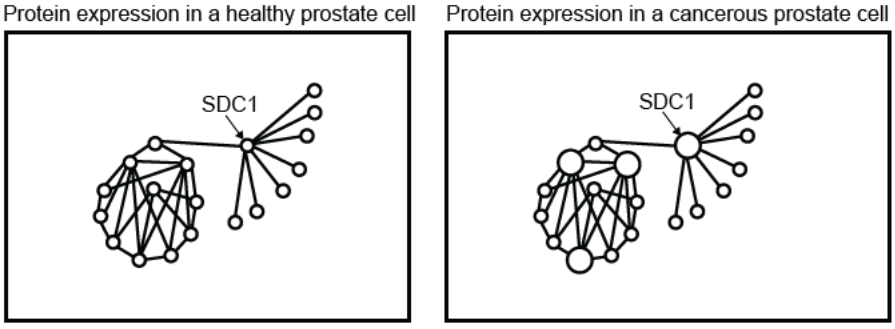
B the dependent variable is continuous but the independent variable is ordinal.

C both variables are continuous.

D both variables are categorical.

Question 11 (1 MARK)

The diagrams show some of the interactions between the proteins found in healthy prostate cells compared to the interactions between the proteins found in cancerous prostate cells.



Source: adapted from Heath, Davis, & Hood (2009)

From the diagrams, it is reasonable to say that

A protein expression is the same in both healthy and cancerous prostate cells.

B SDC1 protein expression does not affect other proteins when expressed in healthy prostate cells.

C SDC1 protein expression is greater in cancerous prostate cells than in healthy prostate cells.

D There are no proteins expressed in healthy prostate cells, and four proteins expressed in cancerous prostate cells.

Adapted from VCAA 2017 Sample Exam Section B Q6f

Use the following information to answer Questions 12 and 13.

Four groups of students carried out an experiment in which the effect of glucose concentration on the fermentation rate of yeast was measured. The fermentation rate was determined by the rate of temperature change of the fermenting mixture. Before beginning the experiment, each group practised measuring the temperature of water and checked the group's thermometer against an electronic thermometer that gave a true measure of temperature. The following results were obtained during the practice.

Group	Each group's thermometer readings (°C)			Electronic thermometer reading (°C)
	1st measurement	2nd measurement	3rd measurement	
1	18.0	18.0	18.5	19.0
2	18.5	19.0	19.5	19.0
3	17.0	20.3	21.1	19.0
4	17.0	16.0	16.0	20.1

Question 12 (1 MARK)

Which one of the following statements is correct?

A Group 3's measurements are the least accurate.

B Group 1's measurements are the most accurate and most precise.

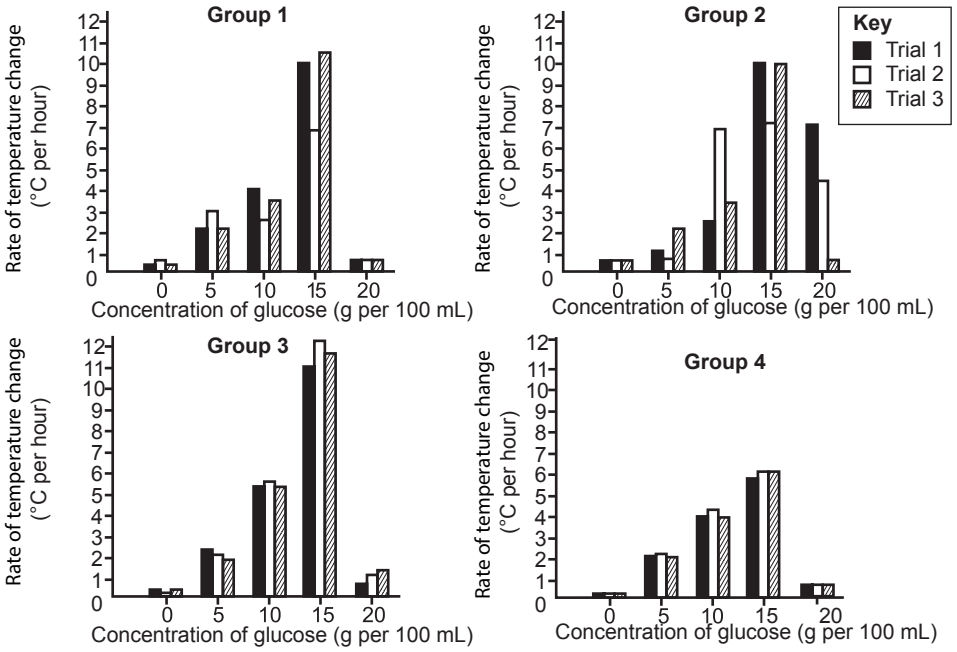
C Group 4's measurements are the least accurate and the least precise.

D Group 2's measurements are the most accurate but not the most precise.

Adapted from VCAA 2018 Section A Q11

Question 13 (1 MARK)

Each group conducted the experiment three times (Trial 1, Trial 2, Trial 3). Five different concentrations of glucose were used in each trial. Each group plotted its results on a graph. The black bar represents Trial 1, the white bar represents Trial 2 and the striped bar represents Trial 3.



Which one of the following statements about the experiment's results cannot be concluded from the graphs?

A All the groups have equally valid results because they followed the same method.

B Group 4's results are more reliable than the other groups'.

C Group 3's data is more reliable than Group 1's data.

D Group 2's data is inaccurate.

Adapted from VCAA 2018 Section A Q12

Question 14 (15 MARKS)

Ibrahim wanted to investigate the effectiveness of an antifungal medication against the common house hold fungi *Aspergillus niger*. He prepared five different concentrations of the antifungal. He wrote the following method:

1. Collect ten agar plates containing Sabouraud dextrose agar.
2. Label two agar plates with one of the five different concentrations of the antifungal. Repeat for every concentration.
3. Put on a pair of disposable gloves.
4. With tweezers, collect 0.2 g of the *A. niger* spores from the culture and place them in the centre of the first agar plate.
5. Spread the spores over the agar plate with the spreader provided.
6. Place a drop of the antifungal in the centre of the agar plate.
7. Close the lid of the agar plate and tape the lid to the bottom of the agar plate with sticky tape.
8. Repeat steps 6 to 8 with the second agar plate labelled with that concentration, and the other four concentrations of the antifungal. Use separate sterile spreaders and tweezers for each agar plate.
9. Place the agar plates on the side bench and leave overnight.
10. Wash your hands and dispose of the gloves.

Ibrahim collected the following results.

Concentration of antifungal (µg/mL)	Mean diameter of fungal colony (cm)
5	3.2
10	0.8
15	1.0
20	0.2
25	0.0

Adapted from VCAA 2017 Sample Exam Section B Q11

a Name the independent and dependent variables. (2 MARKS)

b Define the term 'sterile' and explain why Ibrahim used sterile tools in this experiment. (2 MARKS)

c Identify if Ibrahim has replicated the experiment. Justify your answer. (2 MARKS)

d Identify and explain one poor experimental decision in this investigation, then suggest how the experimental design could be changed to reduce the effect of this error. (3 MARKS)

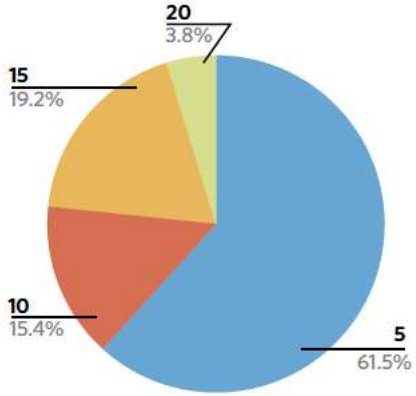
e Consider Ibrahim's results.

I Describe Ibrahim's results. (1 MARK)

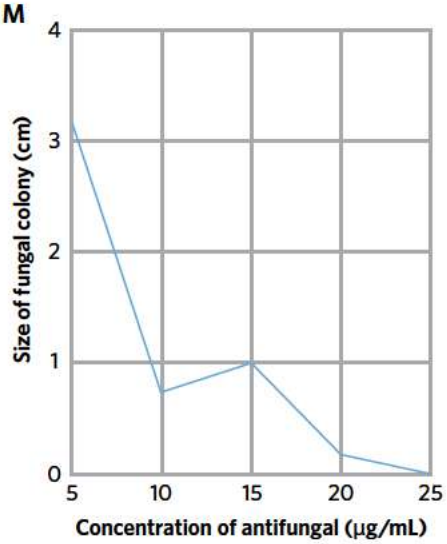
II Explain whether these results would support Ibrahim's hypothesis. (3 MARKS)

III Ibrahim tried manipulating his data in a number of ways, making the following three graphs. Which one of the graphs (L-N) is the best representation of Ibrahim's data? Justify your response. (2 MARKS)

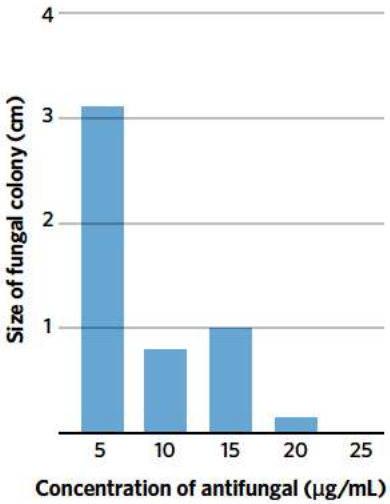
L



M



N



ACTIVITY

Decoding experiments

In each of the three experiments outlined below, identify:

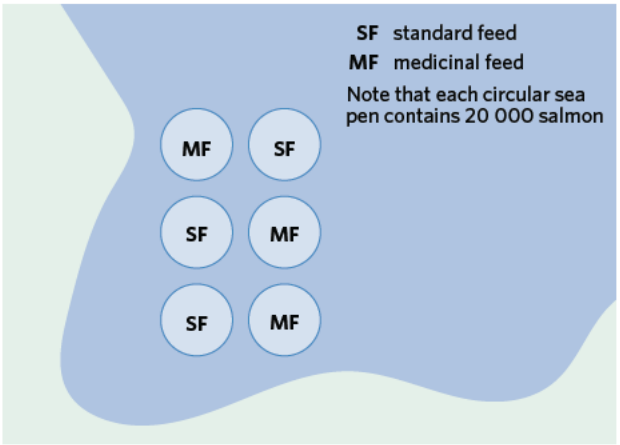
1. A hypothesis for the experiment
2. The control group/s
3. The experimental (or treatment) group/s
4. The independent variable
5. The dependent variable
6. Any constant or controlled variables described
7. Any potentially uncontrolled variables that are not described
8. A safety or ethical consideration
9. Any replication in the experiment
10. A possible improvement in the experimental design.

Experiment 1

Students wanted to determine if common home remedies for colds had antibacterial properties. To test this, 20 Petri dishes were cultured with a non-pathogenic strain of *E. coli* bacteria. Four dishes were then covered in lemon juice, another four covered in saltwater, four were covered with a steaming hot cloth, four were covered in antibiotics, and four were exposed to nothing. The Petri dishes were all exposed to the treatment for 60 minutes. Once the treatment was removed, the bacteria were incubated at 37.5 °C for 24 hours. The amount of bacterial growth on each plate was recorded.

Experiment 2

Scientists at an aquaculture research institute wanted to find out if farmed Atlantic salmon (*Salmo salar*) fed specialised feeds would be more resistant to skin parasite infestation. They designed an experiment where three groups of 20 000 salmon were fed standard industrial fish feed and another three groups of 20 000 salmon were fed the medicinal feed with an additive that helped salmon develop a thicker mucous layer around their scales. The six groups of salmon lived in sea pens in the same fjord. Every fortnight for a year, the scientists collected 20 salmon from each group and recorded the number of skin parasites.



Experiment 3

An experiment was conducted to determine the ideal amount of water and fertilizer for wheat (*T. aestivum*) germination and seedling growth over eight months. Fifteen wheat seeds were grown with no water, 15 were grown in low amounts of watering, and 15 were grown with high amounts of watering. Of the 15 grown under each condition, five were provided with no fertilizer, five were provided with a small amount of fertilizer, and five were provided with a large amount of fertilizer. The seeds were planted in the same soil, grown in the same laboratory, and the scientists ensured that light conditions were equal across treatments.

CHAPTER SUMMARY

Rotate page

Experiments must be **valid**, **reproducible**, and **repeatable**

It is NOT valid if it does not measure what it claims to be measuring. Some ways to make an experiment invalid include:
- measuring inaccurately
- not using a control for comparison
- using an inappropriate indicator for the DV (e.g. measuring the growth of a plant by counting the number of flowers produced)

It is NOT reproducible if the method and results cannot be replicated by another scientist. Some ways to make an experiment unreproducible include:
- communicating incoherently
- being imprecise and inaccurate
- designing an unethical experiment
- letting uncontrolled factors influence results

It is NOT repeatable if you cannot get the same results over and over again. Some ways to make an experiment unrepeatable include:
- not replicating experimental and control groups
- being imprecise and inaccurate
- using broken instruments
- letting uncontrolled factors influence results

So how do I make an experiment **valid**, **reproducible**, and **repeatable**?

Before the experiment

Set up scientifically
- Have an **IV** and a **DV**
  - Write a testable hypothesis that states how your IV will affect your DV
- Ensure your experiment is **safe** and **ethical**
- Include a control treatment
  - *This means you can compare the results of the control to those in experimental groups*

Maximise accuracy
- Ensure sample is **unbiased**
- Reduce **systematic error**
  - Calibrate instruments
  - Use sophisticated and functional instruments
- Identify & control potential **confounding factors**
- Minimize **personal error**
  - Practice
  - Focus
  - Label everything correctly
  - Take detailed notes

Maximise precision
- Minimize **random error**
  - Get a large sample size
  - Use high levels of **replication**
  - *This means you can take an average and reduce the impact of **outliers***
- Use instruments with appropriate **uncertainty**

After the experiment

Analyse and present data accurately
- Choose the appropriate graph for your variables (categorical or numerical)
- Do not force a line of best fit through zero
- Do not assume correlation means causation
- Ensure your conclusions are limited to, and do not go beyond, the results you collected

Categorical variables are best depicted on bar and pie graphs

Numerical variables are best depicted on line and scatter graphs

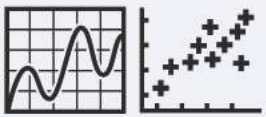
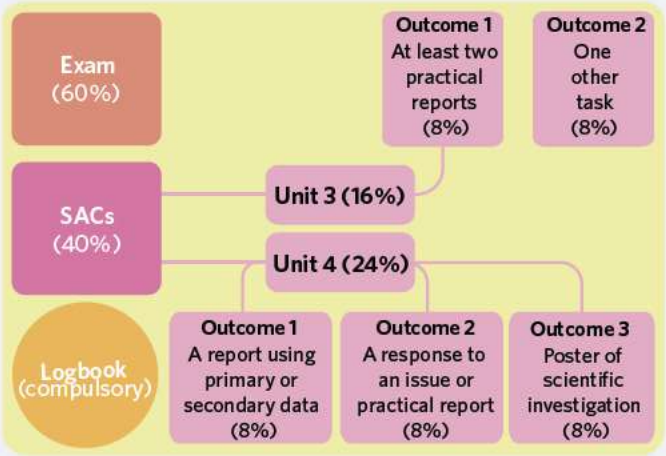


Image: graphixmania/Shutterstock.com

Communicate honestly, clearly, and concisely
- Practical reports require high level of detail and formal language
- Scientific posters require concise explanations and lots of large images and graphs to simplify key concepts
- Poster and report sections are: Title, introduction, abstract (optional), methodology, results, discussion, conclusion, references, and acknowledgements
- Ensure that you identify and explain anything that may have affected the accuracy, precision, and validity of your results in the discussion section
- Format your results with care, so that the main result is obvious
- Follow formatting rules for graphs e.g. Not All Caps, only use necessary gridlines, include detailed figure titles



CHAPTER REVIEW QUESTIONS

SECTION A (10 MARKS)

Question 1 (1 MARK)

Doctors tested a new medication, Medi-X, that controls blood pressure in pregnant women. A hundred pregnant women aged between 25 and 35 years were divided into two groups of 50 patients. The first group received a pill containing Medi-X and the second group received an identical looking pill to Medi-X but it had no active medicinal ingredients.

Each patient was given one pill per day. All pills were the same colour and of equal mass.

The dependent variable in this experiment was

A the composition of the given pill.

B the pregnant women aged 25–35 years.

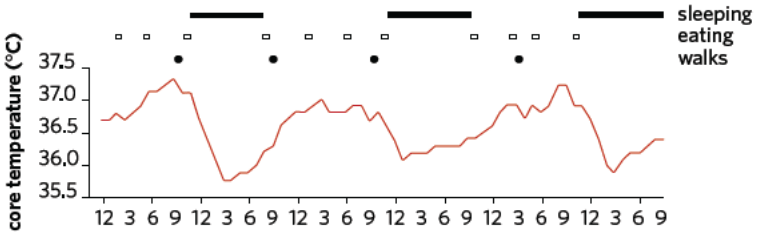
C the blood pressures of the pregnant women.

D being given a pill of the same mass each day.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q27

Use the following information to answer Questions 2 and 3.

An experiment on the control of body temperature recorded the core temperature of one human subject, Jonah, living in one room for three days. The room temperature was kept constant at 20 °C. The results of the experiment are shown on the graph.



Question 2 (1 MARK)

The dependent variable in this experiment is

A time.

B Jonah.

C the activity of Jonah.

D the core body temperature of Jonah.

Adapted from VCAA 2012 Exam 1 Section A Q15

Question 3 (1 MARK)

From the graph, it can be concluded that

A Jonah always sleeps for the same duration each night.

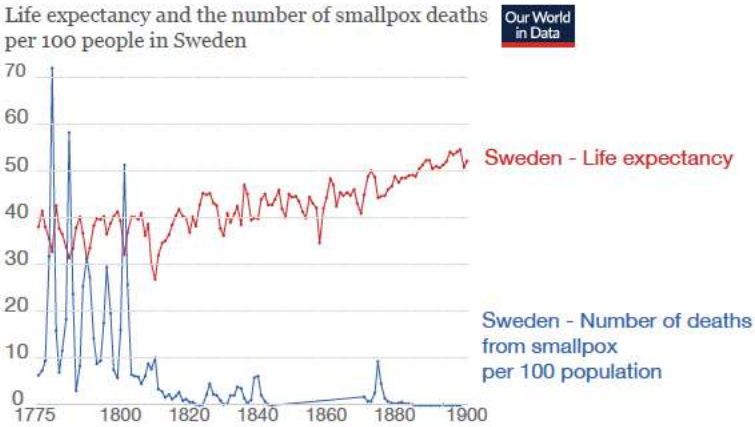
B Jonah's core body temperature decreases during sleep.

C after eating, Jonah's core body temperature reaches its highest peaks.

D core body temperature is exclusively affected by the environmental temperature.

Question 4 (1 MARK)

Smallpox is a disease caused by the variola virus. The World Health Organisation (WHO) has officially declared it has been eradicated. Data from Sweden displays the number of deaths per 100 people in the population and the life expectancy between 1775 and 1900.



Source: Edwardes (1902), Riley (2015), Zijdeman and Ribeira da Silva (2015), and United Nations, Department of Economic and Social Affairs, Population Division (2019) adapted by Ochmann and Roser (2019)

It can be concluded from the data that

A in 1800, approximately 52 people died in Sweden from smallpox.

B before 1900, the greatest life expectancy for Swedish people was 55 years.

C overall life expectancy is dependent upon the number of smallpox infections.

D smallpox deaths reached its lowest point of 28 deaths per 100 people in 1807.

Adapted from VCAA 2016 Section A Q22

Use the following information to answer Questions 5 and 6.

An experiment was conducted to test the following three hypotheses about the effect of the plant growth regulator indoleacetic acid (IAA).

- Hypothesis 1 - High concentrations of IAA inhibit shoot growth and stimulate root growth.
- Hypothesis 2 - Concentrations of IAA below 0.0001 parts per million stimulate shoot and root growth.
- Hypothesis 3 - High concentrations of IAA inhibit both shoot and root growth.

In the experiment, radish seedlings were grown in different concentrations of IAA, as indicated in the table.

Concentration of IAA (parts per million)	Stimulation (+)/ inhibition (-) of shoot growth (%)	Stimulation (+)/ inhibition (-) of root growth (%)
0	0	0
0.00001	+0.10	-30
0.0001	+6	-50
0.001	-20	-70
0.01	-60	-85
1	-70	-90
10	-80	-95
100	-90	-100

Question 5 (1 MARK)

Which one of the following is a reasonable conclusion to draw from the results of the experiment?

A Only Hypothesis 1 is supported.

B Only Hypothesis 3 is supported.

C Hypotheses 2 and 3 are both supported.

D Hypotheses 1, 2, and 3 are all not supported.

Adapted from VCAA 2016 Section A Q15

Question 6 (1 MARK)

Which sample serves as the experimental control?

A 1 part per million of IAA
B 0 parts per million of IAA
C 0.1 parts per million of IAA
D 100 parts per million of IAA

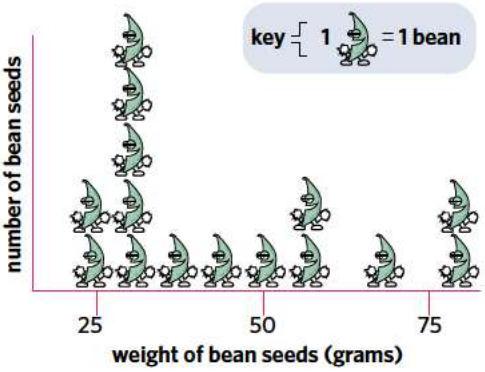
Question 7 (1 MARK)

Danielle performed an experiment on a stick of celery to see whether it needed light to grow. Each piece of celery was watered with 5 mL every day. Under these conditions, the amount of water provided to each celery is referred to as a

A control.
B controlled variable.
C dependent variable.
D independent variable.

Question 8 (1 MARK)

Farah recorded the weight of 15 bean seeds and graphically presented the data as shown.



The seeds came from bean plants grown in identical environmental conditions.

What conclusion can be drawn from these results?

A There is a spread of bean weight due to different growing conditions.
B The average bean seed weight is close to 40 grams.
C The largest bean weighed greater than 100 grams.
D The beans at 80 grams are outliers.

Adapted from VCAA 2014 Section A Q26

Question 9 (1 MARK)

Tatiana set up an experiment in her school science laboratory to test the effect of wavelength on photosynthesis. Part of the experimental method directed Tatiana to 'add a few bunches of leaves' of an aquatic plant, *Elodea*, to a number of different test tubes. *Elodea* leaves naturally vary in size.

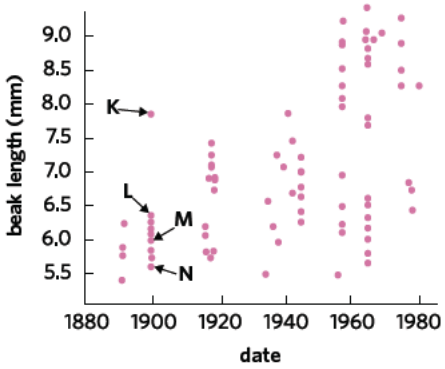
This experiment would be

A repeatable only.
B reproducible only.
C repeatable and reproducible.
D neither repeatable or reproducible.

Adapted from VCAA 2014 Section A Q26

Question 10 (1 MARK)

Scientists have measured the beak length of the soapberry bug, *Jadera haematoloma*, over time. Their results are shown in the graph.



Which of the following points is most likely considered to be an outlier?

A Point K
B Point L
C Point M
D Point N

SECTION B (30 MARKS)

Question 11 (10 MARKS)

Four groups of students carried out an experiment testing the effect of glucose concentration on the fermentation rate of yeast. Higher temperature indicates higher rates of fermentation.

NOTE: glucose is an input in the fermentation reaction.

a Identify the independent and dependent variable. (2 MARKS)

b Define the purpose of a control and outline a possible control for this experiment. (2 MARKS)

c Before beginning the experiment, each group practised measuring the temperature of water and checked the group's thermometer against an electronic thermometer that gave a true measure of temperature.

The following results were obtained during the practice.

Group	Thermometer readings (°C)			Electronic thermometer readings (°C)
	1st measurement	2nd measurement	3rd measurement	
1	18.0	16.5	17.5	20.1
2	19.0	18.0	18.5	20.5
3	21.0	21.0	20.5	19.9
4	20.0	19.0	21.0	20.0

i Identify which group has the most precise results. Justify your response. (2 MARKS)

ii Identify which group has the most accurate results. Justify your response. (2 MARKS)

iii Explain how testing the thermometers increases the reliability of the experimental results. (2 MARKS)

Adapted from VCAA 2018 Section A Q11

Question 12 (11 MARKS)

The effect of different concentrations of sucrose solution on the average height of groups of tomato plants was tested. Six groups containing 40 plants each were left to grow for 20 days. Each plant had an initial height of approximately 2 cm. Each group was watered daily with 5 mL of water.

a Identify the independent and dependent variables. (2 MARKS)

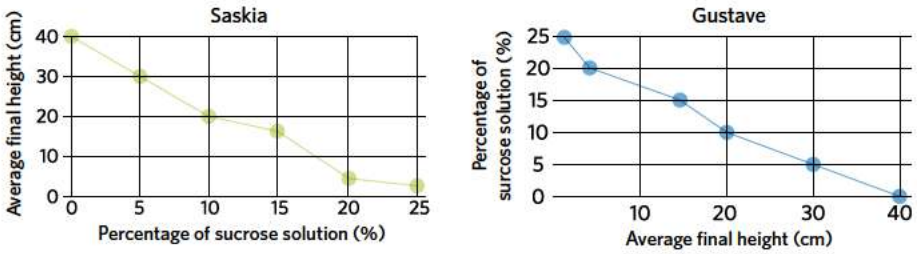
b List three variables that were controlled to ensure the experiment produced valid results. (3 MARKS)

c The concentration of sucrose solution for each group is shown in the table. The heights of the plants were measured and averaged for each group.

Plant group	Percentage of sucrose solution (%)	Average final height (cm)
A	0	40
B	5	30
C	10	20
D	15	15
E	20	5
F	25	2

i Saskia and Gustave both attempted to graph their results.

Effect of sucrose solution on the height of tomato plants



Identify who has created the more correct graph. Justify your response. (2 MARKS)

ii Explain why groups of plants were used in the experiment rather than individuals and their height was averaged to form the results. (2 MARKS)

d Consider any experiment. Explain the difference between the accuracy and validity of measurements. (2 MARKS)

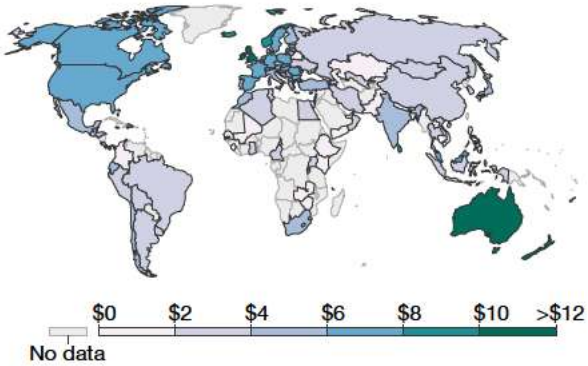
VCAA 2018 Northern Hemisphere Exam Section A Q36

Question 13 (9 MARKS)

The World Health Organisation (WHO) has released a report on the dangers of smoking tobacco. Over time, the WHO has encouraged countries to increase the price of cigarettes.

The graph displays the average price of a pack of 20 cigarettes measured in international dollars. The average price is calculated based on the prices of three brands of cigarettes known to be the most sold in the country. The average price is weighted by the market share of each of the three brands.

Average price of a pack of cigarettes, 2014



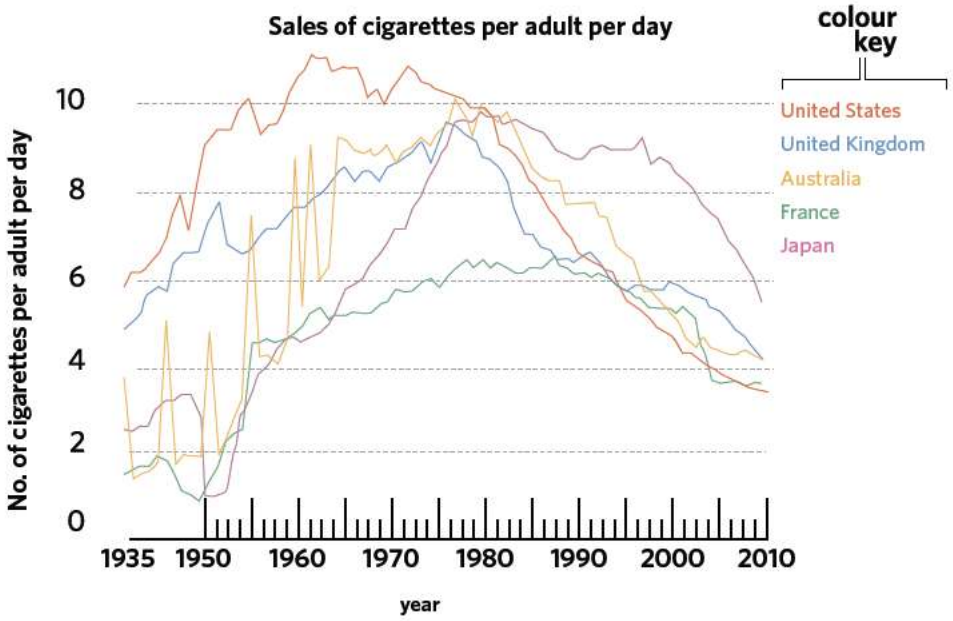
Source: World Health Organization Global Observatory (2014) adapted by Ritchie and Rosie (2019)

a Identify one country that charges more than $10 for a pack of cigarettes. (1 MARK)

b Explain why the WHO would encourage countries to increase the price of cigarettes. (1 MARK)

c In 1980, it was estimated that 30.5% of the Australian population smoked daily when the population size was just under 15 million. This number decreased to 16.3% of the population in 2012 when the population was almost 23 million. Explain why these percentages were estimations rather than a true value. (2 MARKS)

d The graph displays the amount of cigarettes sold per adult per day in Australia, France, Japan, the United Kingdom, and the United States.



Source: Forey, Hamling Hamling and Lee (2015) adapted by Ritchie and Roser (2019)

i State which country had the highest average sales of cigarettes per adult per day. Identify when this occurred. (1 MARK)

ii Describe the trend in the sale of cigarettes per adult per day in Australia from 1935 to 2010. Include data in your response. (2 MARKS)

iii Compare the trend between Japan and France in the sale of cigarettes per adult per day from 1935 to 2010. Include data in your response. (2 MARKS)

CHAPTER 2

Biology basics

02

2A Cell structure

2B Biomacromolecules and energy in living things

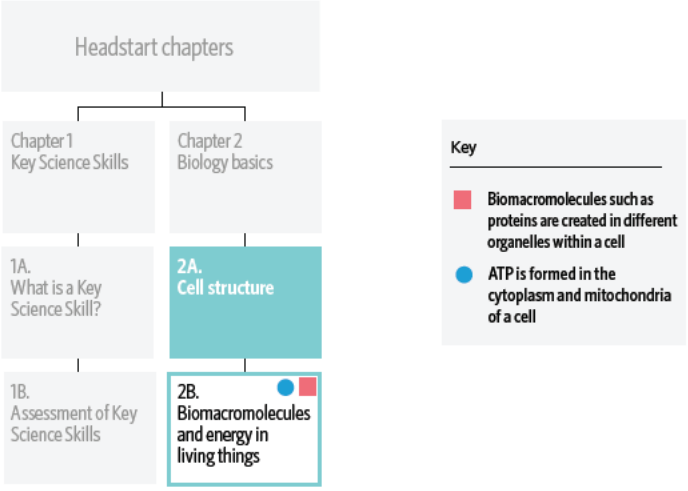
This chapter will help you revise content you learnt in Unit 1 & 2 to provide a foundational level of knowledge prior to starting the course. The topics that you will cover include:

- types of cells
- organelles
- biochemistry
- biomacromolecules
- energy in living things.

Image: Kateryna Kon/Shutterstock.com

2A CELL STRUCTURE

Instead of telling your date how great their hair looks or how beautiful their eyes are, compliment how great their 37.2 trillion cells are functioning today, and don't forget to admire the 40 - 400 trillion prokaryotic cells that also make up the brilliant specimen standing in front of you.



In this lesson you will learn that all living things are made of cells. These cells contain different organelles, depending on the type of organism.

Key knowledge units

Types of cells	0.1
Organelle structure and function	0.2

Types of cells 0.1

OVERVIEW

Living things are either prokaryotic or eukaryotic. Sometimes one cell can make up an entire organism. At other times, it can be one of many trillions in a larger organism.

THEORY DETAILS

Cells are the building blocks of all living things, including you. In fact, scientists have predicted that the average adult human is made up of 30 - 40 trillion cells. But humans are very different from plants, and even more different to bacteria. This means our fundamental building blocks must be distinct from that of a plant or a bacterium, as we all have different requirements for survival.

Organisms can be categorised as either **prokaryotic** or **eukaryotic** depending on their cellular structure. From there, living things are classified into the six kingdoms of life: Animalia, Archaea, Bacteria, Fungi, Plantae, and Protista.

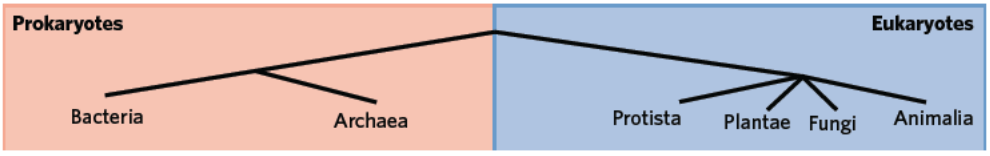


Figure 1 The classification of prokaryotes and eukaryotes

cell the smallest functional unit of a living organism

prokaryote a group of single-celled organisms with no nucleus and a circular loop of DNA. Bacteria and archaea are both prokaryotic

eukaryote a group of single and multi-celled organisms with a nucleus and linear strands of DNA. Animals, plants, fungi, and protists are eukaryotic

membrane-bound organelles structures within a cell that are enclosed by a membrane

Prokaryotes vs eukaryotes

Eukaryotes contain many **membrane-bound organelles**, multiple strands of linear DNA packed in a nucleus, and tend to be larger than prokaryotes. Prokaryotes lack a nucleus, have a single loop of DNA, and may contain some smaller circular units of DNA called plasmids. Table 1 summarises the differences between the two cell types. Figure 3 is a visual representation of how the cells differ structurally.

Table 1 Comparison between eukaryotic and prokaryotic cells

	Eukaryotes	Prokaryotes
Membrane-bound organelles	Present	Absent (except vesicles)
DNA organisation	More than one linear strand of DNA packaged in a nucleus	One circular chromosome and additional plasmids
Organism nature	Can be unicellular or multicellular	Unicellular
Size	Larger	Smaller
Method of cell replication	Mitosis and meiosis	Binary fission

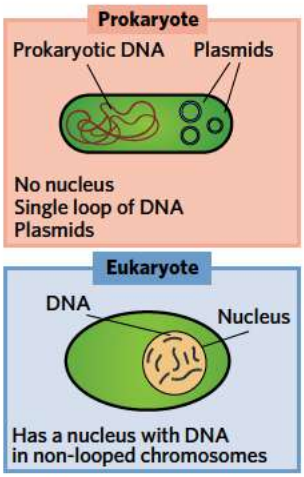


Figure 2 Comparison between prokaryotic and eukaryotic DNA organisation

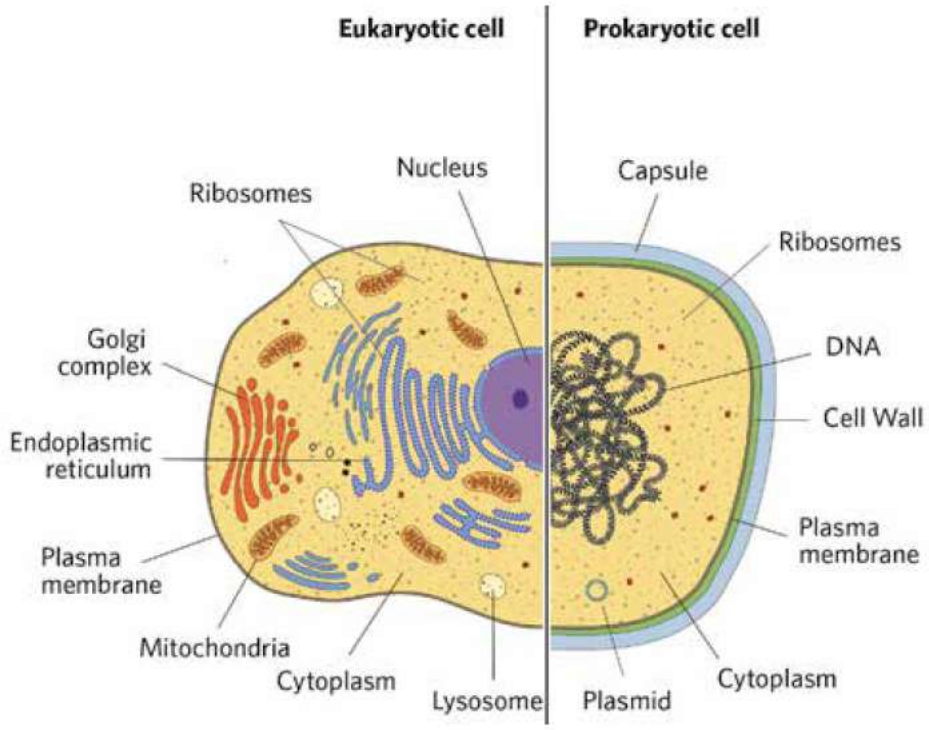


Image: Aldona Griskeviciene/Shutterstock.com

Figure 3 Comparison between prokaryotic and eukaryotic cell structure. Note: these cells are not drawn to scale as prokaryotic cells are usually smaller than eukaryotic cells.

Finally, the mode of cell replication is different between prokaryotes and eukaryotes. Due to the presence of a nucleus, eukaryotic cells replicate through the processes of mitosis and meiosis. In contrast, prokaryotic cells perform a simpler process known as binary fission.

Animal vs plant cells

Eukaryotic cells can be further divided into fungi, protist, **animal**, and **plant cells**, according to **organelle** composition and overall organism structure. VCE Biology mostly focuses on animal and plant cells, so we will deep dive on them here. There are three key factors that distinguish plant and animal cells:

1. The **cell wall** is present in plant cells but not animal cells.
2. **Chloroplasts** are present in plant cells but not animal cells.
3. **Vacuoles** in animal cells are small and there can be many or none, whereas plant cells tend to have one large vacuole.

There are a few reasons for these differences:

1. Unlike plants, most animals have a skeleton which provides structural support for the organism. Plants rely on their strong cell walls to perform the same function.
2. Chloroplasts are found in plants (except plant root cells) as they are required for photosynthesis, a process which animals do not perform.
3. Finally, vacuoles in plants are used to provide further support for the organism. They must be full to prevent wilting, whereas their role is less structurally important in animal cells.

animal cell eukaryotic cells that do not contain a cell wall or chloroplasts and are found in organisms in the kingdom Animalia

plant cell eukaryotic cells that contain a cell wall or chloroplasts and are found in organisms in the kingdom Plantae

organelle cellular structures that perform specific cellular functions

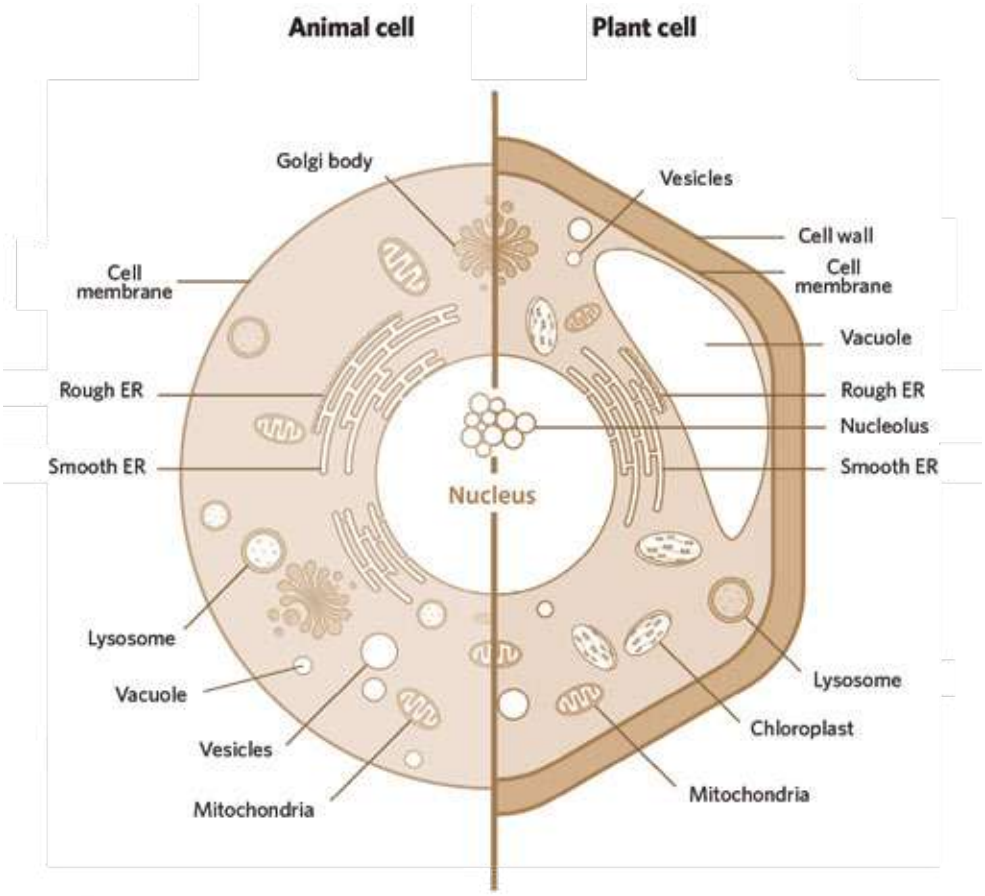


Image: Molecular Sensei/Shutterstock.com

Figure 4 The differences between animal and plant cells.

Organelle structure and function 0.2

OVERVIEW

Organelles are the subunits of our cells. Each organelle performs a specific function in the cell.

THEORY DETAILS

Each organelle serves a specific purpose in a cell. This increases cell efficiency as it allows many different metabolic processes to occur simultaneously. The functionality of an organelle is heavily dependent upon its structure (Table 2).

All cells are contained by a plasma membrane, which creates a spherical boundary that contains the liquid **cytosol.** The organelles float in the cytosol. All the organelles (except the nucleus) and the cytosol in which they float make up the **cytoplasm.**

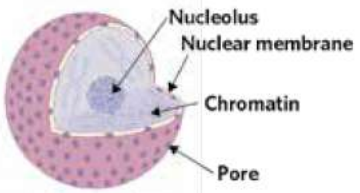
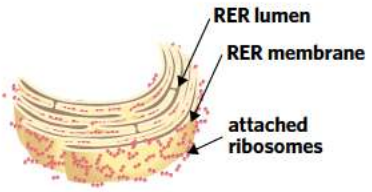
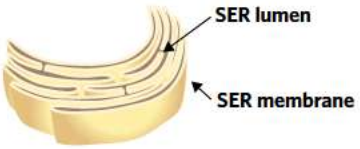
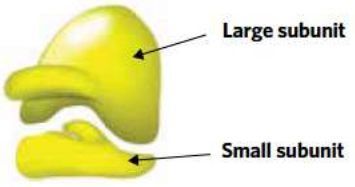
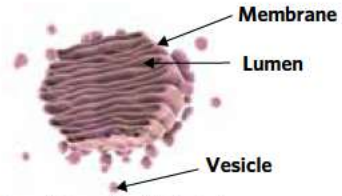
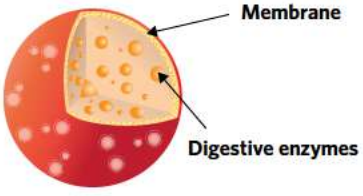
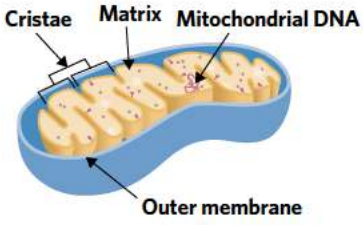
The cell types explored in the first KU can be identified by the organelles in their cells.

cytosol the aqueous fluid that surrounds the organelles inside the plasma membrane

cytoplasm the cytosol and organelles inside the plasma membrane, excluding the nucleus

lumen the space contained within a tubular or circular membrane

Table 2 A diagrammatic representation of different organelles, and their structure and function

Organelle	Structure and function	Diagram
Nucleus	It is surrounded by a double membrane. Its role is to protect and confine the genetic information (DNA) of the cell. Inside the nucleus is a smaller structure known as the nucleolus which is the site of ribosome production.	 Image: Soleil Nordic/Shutterstock.com
Rough endoplasmic reticulum (RER)	A membranous chain of connected and flattened sacs which are coated with ribosomes on their outer surface. This allows them to synthesise and modify proteins. It typically surrounds, or is close to, the nucleus.	 Image: Designincolorc/Shutterstock.com
Smooth endoplasmic reticulum (SER)	A membranous chain of connected and flattened sacs which are not coated with ribosomes. They are responsible for the production of lipids in a cell.	 Image: Designincolorc/Shutterstock.com
Ribosomes	Ribosomes are tiny structures made of ribosomal RNA and proteins that fold into a large and small subunit. Cells have many ribosomes, which either float freely in the cytoplasm or are attached to RER. Ribosomes assemble polypeptide chains to create proteins.	 Image: Designua/Shutterstock.com
Golgi body (also known as the Golgi apparatus or Golgi complex)	Stacked flattened sacs that are the site of protein sorting, packaging, and modifying. Protein-filled vesicles often fuse with or bud off the Golgi body.	 Image: Kateryna Kon/Shutterstock.com
Lysosome	A membrane-bound vesicle that contains digestive enzymes. Is responsible for breaking down cell waste, acting like a garbage disposal.	 Image: Akarat Phasura/Shutterstock.com
Mitochondrion	An organelle with a highly folded inner membrane surrounded by a second outer membrane. Mitochondria are the site of aerobic cellular respiration which produces the ATP required to power cellular processes. They also contain their own DNA and ribosomes.	

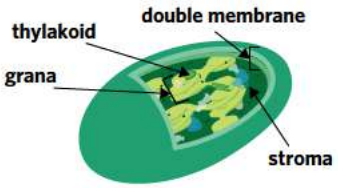
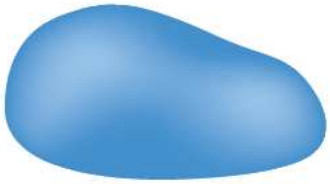
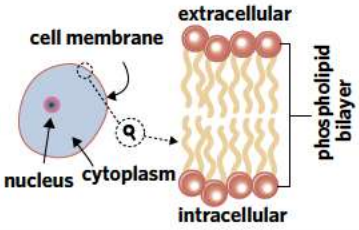
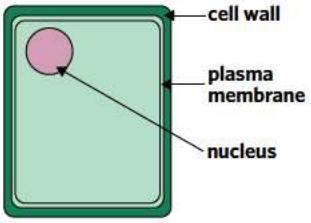
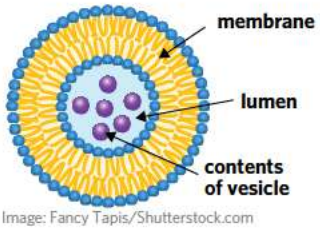
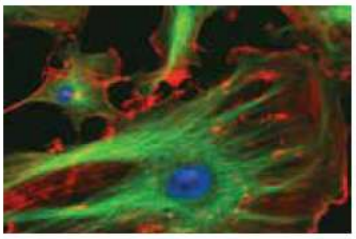
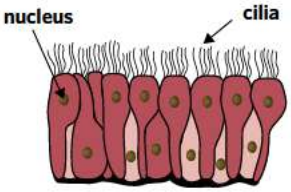
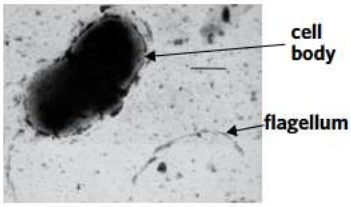
Chloroplast	A double membrane-bound organelle that contains flattened, fluid-filled sacs that allow the process of photosynthesis to take place. Chloroplasts also contain their own DNA and ribosomes.	
Vacuoles	A membrane-bound sac that is used for water and solute storage. It can also play a role in maintaining plant cell structure.	 Image: Designincolor/Shutterstock.com
Plasma membrane	The plasma membrane is a selectively permeable barrier between the intracellular and the extracellular environment. It is made of a phospholipid bilayer which is studded with many molecules.	
Cell wall	A sturdy border outside the plasma membrane that provides strength and structure to plant, bacterial, and fungal cells.	
Vesicle	A small membrane-bound sac that transports substances into or out of a cell, or stores substances within a cell.	 Image: Fancy Tapis/Shutterstock.com
Cytoskeleton	A dynamic linkage of many protein filaments that start at the nucleus and reach out to the plasma membrane. It is critical for maintaining shape and transporting vesicles around the cell. In the fluorescence microscopy photo, the green represents the cytoskeleton.	
Cilium (pl. cilia)	Small hair-like structures on the outside of the plasma membrane that perform a rhythmic waving to help move substances through tubes, such as clearing mucus and dirt from airways. Also involved in locomotion in eukaryotic single-celled organisms.	 Image: Timonina/Shutterstock.com
Flagellum (pl. flagella)	A tail-like structure that attaches to the side of the cell body and is used for locomotion on single-celled organisms.	

Table 3 Types of organisms that contain each organelle

	Is the organelle membrane-bound?	Prokaryotes?	Eukaryotes	
			Plant?	Animal?
Nucleus	✓	✗	✓	✓
Rough endoplasmic reticulum (RER)	✓	✗	✓	✓
Smooth endoplasmic reticulum (SER)	✓	✗	✓	✓
Ribosomes	✗	✓	✓	✓
Golgi apparatus	✓	✗	✓	✓
Lysosome	✓	✗	✓	✓
Mitochondria	✓	✗	✓	✓
Chloroplast	✓	✗	✓	✗
Vacuoles	✓	✗	✓	✓
Plasma membrane	✗	✓	✓	✓
Cell wall	✗	✓	✓	✗
Vesicle	✓	✓	✓	✓
Cytoskeleton	✗	✓	✓	✓
Cilia	✗	✗	✓	✓
Flagella	✗	✓	✓	✓

VCAA often ask questions about organelles by providing electron micrograph images. Figure 5 has labelled an electron micrograph image of some common structures within a cell.

Theory summary

Cells are the smallest fundamental unit of life. Organisms can be classified as prokaryotic or eukaryotic depending on whether their cells contain a nucleus. Eukaryotic cells can be further broken down into animal, fungi, protist, and plant cells. All organisms contain ribosomes, a plasma membrane, cytoplasm, and a DNA-containing region.

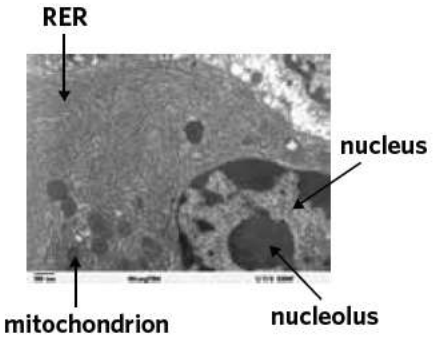


Figure 5 Electron micrograph image of part of an animal cell

2A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ membrane-enclosed structure that contains genetic material

b _____ specialised structures within a cell that serve specific functions to increase cell efficiency

c _____ protein production factories within the cell

d _____ organisms that do not contain membrane-bound organelles

e _____ space within the plasma membrane including the fluid and the organelles

f _____ structure responsible for cell movement that is attached to bacteria

g _____ eukaryotic cell type that contains chloroplasts

Question 2

Identify the labelled structures in the diagram.

	K	L	M	N
A	Golgi body	Chloroplast	RER	SER
B	RER	Mitochondrion	SER	Golgi body
C	RER	Chloroplast	SER	Golgi body
D	Golgi body	Mitochondrion	RER	SER

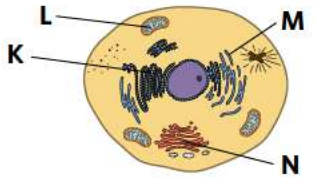


Image: Aldona Griskev c ne/Shutterstock.com

Question 3

Identify the labelled structures in the diagram.

	W	X	Y	Z
A	Plasma membrane	Cytosol	Chloroplast	Vacuole
B	Plasma membrane	Nucleus	Mitochondrion	Vacuole
C	Cell wall	Vacuole	Chloroplast	Nucleus
D	Cell wall	Cytoplasm	Mitochondrion	Nucleus

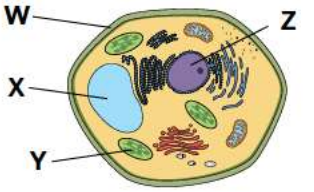


Image: Aldona Griskeviciene/Shutterstock.com

Question 4

The diagram displays a unicellular organism.

Which of the following kingdoms does this organism belong to?

A Bacteria
B Animalia
C Plantae
D Protista

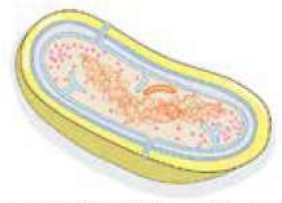
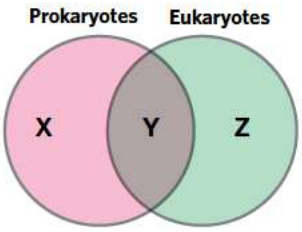


Image: Soleil Nordic/Shutterstock.com

Question 5

Complete the following Venn diagram.

	X	Y	Z
A	Only unicellular	Living organisms	Only multicellular
B	Contain cell walls	Contain a nucleus	Contain ribosomes
C	Do not contain cilia	Contain mitochondria	Do not contain a flagellum
D	Do not contain a nucleus	Contain a plasma membrane	Contain mitochondria



Exam-style questions

Within lesson

Question 6 (1 MARK)

The genetic material in prokaryotes is found in the

A mitochondria.
B flagellum.
C nucleus.
D cytosol.

Question 7 (1 MARK)

The membrane-bound organelle that contains digestive enzymes to break down waste products in a cell is a

A ribosome.
B lysosome.

C Golgi body.
D smooth endoplasmic reticulum.

Question 8 (1 MARK)

A circular molecule of DNA is the main form of DNA found in

A bacteria.
B animals.
C plants.
D fungi.

Adapted from VCAA 2016 Section A Q12

Question 9 (1 MARK)

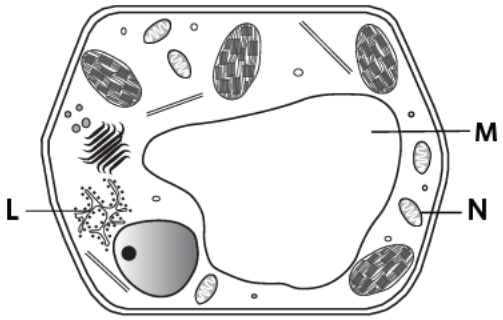
The genetic material of eukaryotic cells is contained in

A a circular chromosome and many small plasmids.
B a linear chromosome and many small plasmids.
C many circular chromosomes.
D many linear chromosomes.

Adapted from VCAA 2012 Exam 2 Section A Q4

Question 10 (9 MARKS)

Ms Norbury's biology class at Northshore High School were learning about the structure of a cell. She showed her class the following diagram and asked them to analyse it.



a Name the term given to the sub-structures within a cell. (1 MARK)
b Identify whether this cell is prokaryotic or eukaryotic. Justify your response. (2 MARKS)
c Regina believes this is an animal cell, whilst Cady thinks it is a plant cell. Identify who is correct and provide one reason to justify your response. (2 MARKS)
d Name and describe the function of structure L. (2 MARKS)
e Identify whether structure M or N is the site of aerobic cellular respiration. Justify your response by explaining the function of each structure. (2 MARKS)

Key science skills

Question 11 (7 MARKS)

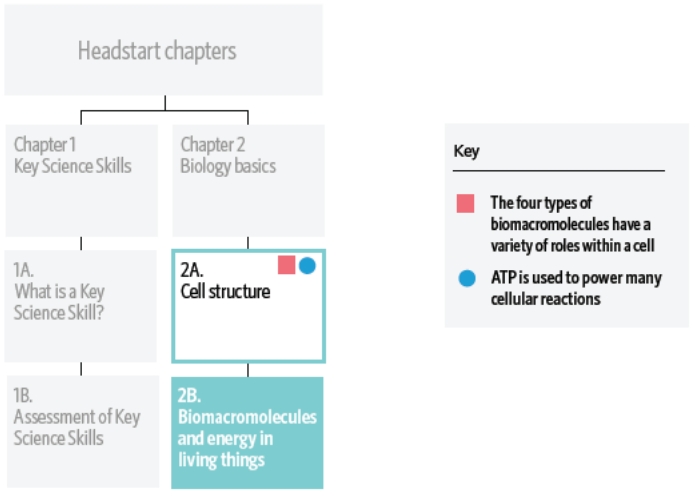
A rover went on an exploration to an asteroid where it found signs of life. Scientists discovered some unicellular organisms and studied their structure and biochemical processes. The organism had the following traits:

- single-stranded circular DNA
- flagellum
- chloroplasts
- ribosomes
- plasma membrane
- cell wall
- one large vacuole
- no mitochondria
- no nucleus

a Explain whether this organism would be able to move freely. (1 MARK)
b Identify whether this organism contains membrane-bound organelles. (1 MARK)
c It was observed that the organism reproduces in the same way as bacteria. Name this process of reproduction. (1 MARK)
d Scientists concluded that this organism was neither eukaryotic or prokaryotic. Critically evaluate the evidence to determine if the conclusion is correct. (4 MARKS)

2B BIOMACROMOLECULES AND ENERGY IN LIVING THINGS

You are what you eat: sugars, fats, proteins, and nucleic acids are the biomacromolecules that make up your cells.



In this lesson you will learn the basic chemistry underpinning biological processes, what the four types of biomacromolecules are, and how energy is transferred in a chemical reaction.

Key knowledge units

Chemistry for biologists	0.3
Biomacromolecules	0.4
Energy and reactions	0.5

Chemistry for biologists 0.3

OVERVIEW

Chemistry and biology are heavily intertwined. To understand biological systems and living organisms it is important to know the underlying chemistry.

THEORY DETAILS

Atoms and elements

Atoms are the building blocks of all matter; they make up everything around us and in us. Atoms themselves are made up of particles called protons, neutrons, and **electrons.** Protons have a positive charge, neutrons have no charge, and electrons are negatively charged.

Atoms differ in the number of protons, neutrons, and electrons they contain. Elements are defined by the number of protons they contain. For example, one element, carbon (C), typically consists of 6 protons, 6 neutrons, and 6 electrons, whereas the element oxygen (O) consists of 8 protons, 8 neutrons, and 8 electrons. All of the elements are displayed on the periodic table. A few elements integral to biology are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), calcium (Ca), sulphur (S), and potassium (K).

electron a negatively charged component of atoms

covalent bond a chemical bond formed by sharing electrons between two non-metal atoms

molecule two or more atoms joined by covalent bonds to form a single chemical entity

ionic bond a chemical bond formed by donating and accepting electrons

ion a charged atom or group that has lost or gained electrons

Molecules and bonding

Atoms join together in specific ways. The most relevant bond types to know about for VCE Biology are:

1 **covalent bonds.** These occur when nonmetal atoms share electrons between them, forming a **molecule** (e.g. H_2O, O_2).

2 **ionic bonds.** These occur when atoms donate or receive electrons to become strongly charged atoms (known as **ions**) that can combine to form lattice structures (e.g. NaCl).

Collectively, we call at least two atoms of different elements that have bonded together compounds. Therefore, molecules such as H_2O (water), NH_3 (ammonia), and NaCl (salt) are compounds, but O_2 (oxygen) is not.

You will notice that certain elements often pair together - this is because they have the right number of electrons to 'balance' each other out. Carbon dioxide (CO_2), for example, pairs one carbon with two oxygens to be stable.

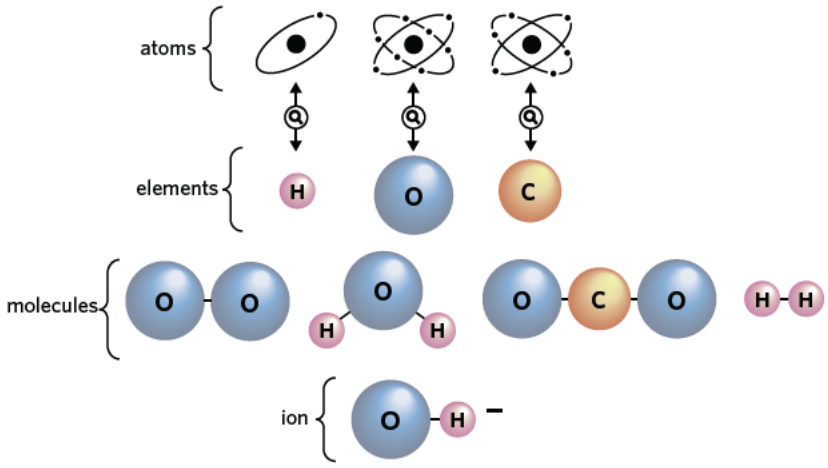


Figure 1 Atoms make up molecules

The covalent or ionic bonds within a molecule are **intramolecular** bonds, meaning within the molecule. Molecules interact with each other in a number of ways, including forming **intermolecular forces** between molecules ('inter-' meaning between). A key type of intermolecular force is **hydrogen bonding**, which can occur when a hydrogen (H) bound to oxygen (O) or nitrogen (N) is attracted to an oxygen or nitrogen on another molecule. Intermolecular bonds are not usually as strong as intramolecular bonds.

intramolecular force a bond that joins together the atoms within a molecule

intermolecular force an attraction or repulsion that exists between molecules

hydrogen bonds an intermolecular bond between a hydrogen of one molecule and an electronegative atom in another

polar describes a molecule with both a positive end and negative end. These tend to be hydrophilic

nonpolar describes a molecule without a clearly positive or negative end. These tend to be hydrophobic

lesson link In ***chapter 4***, you will come across peptide bonds (in proteins) and phosphodiester bonds (in DNA and RNA). These are types of covalent bonds.

Charge and polarity

Sometimes, atoms and molecules can carry a charge, meaning that they can be positive or negative. This can affect the way they interact with other substances. There are two types of charged particles you should know about for VCE Biology: highly charged ions and weakly charged **polar** molecules.

Ions are charged atoms or groups that have lost or gained electrons. You can recognise them as they will have a + or - in superscript next to the molecular formula (e.g. H^+, Mg^{2+}, Cl^-, OH^-).

Atoms themselves are made from positively and negatively charged particles (protons and electrons). So, charges exist within the atoms and the bonds of neutrally charged molecules, even when they haven't lost or gained electrons. Sometimes, the shared electrons within a molecule are more attracted to certain atoms and more electrons can be found closer to those atoms. The regions with more electrons become negatively charged and the regions with fewer electrons become positively charged. When charges are different at each end, we say the molecule is polar. If a molecule has an even charge distribution, so the ends are not differently charged, they are **nonpolar.** Polarity allows for intermolecular forces such as hydrogen bonding. However, compared to ions, polar molecules are less charged so we don't write a + or - next to the molecular formula.

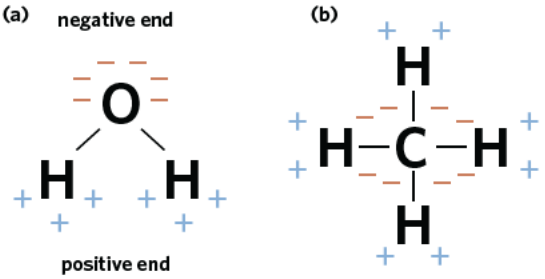


Figure 3 **(a)** Water is a polar molecule **(b)** methane is nonpolar

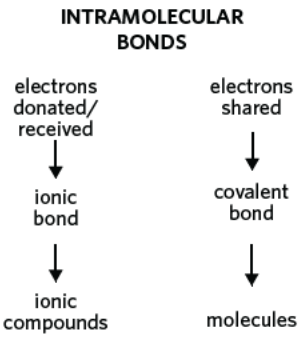


Figure 2 Intramolecular bonding

As water is polar, it readily interacts with other polar molecules but not with nonpolar molecules. Polar substances that readily interact with and dissolve in water are hydrophilic (water-loving). Nonpolar substances that tend to repel or fail to mix with water are hydrophobic (water-hating). Similarly, a lipophilic substance tends to combine with or dissolve in lipids or fats, whereas lipophobic ones do not. We call this the 'like dissolves like' rule.

hydrophilic having a tendency to be attracted to and dissolve in water

hydrophobic having a tendency to repel from and be insoluble in water

Case study

No matter how much you mix oil and water, they separate. Adding oil to water will result in a layer of oil sitting on top of the water. This is due to the polarity of the substances. Water is polar and does not mix with or dissolve the nonpolar oil.

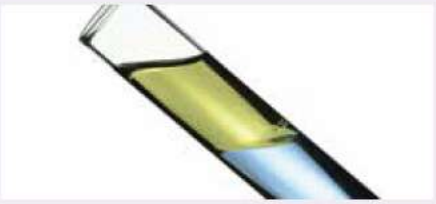


Image: Artography/Shutterstock.com

Figure 4 Water and oil do not mix due to their polarities

Tip The word hydrophobic is related to the word 'phobia', meaning the molecules have a fear of water.

lesson link A great example of the tendencies of hydrophobic and hydrophilic molecules is phospholipids, covered in ***3A***.

Biomacromolecules 0.4

OVERVIEW

The four basic biomacromolecules integral to life are carbohydrates, proteins, lipids, and nucleic acids. While they all contain carbon, hydrogen, and oxygen, they have very different structures and functions.

THEORY DETAILS

Monomers and polymers

Large **organic** biological molecules that make up living organisms are called biomacromolecules, sometimes referred to as biomolecules. Biomacromolecules are made from chains of **monomers** (the building blocks) that form **polymers** (the product). There are four types of biomacromolecules which have their own specific monomer: **carbohydrates, proteins, lipids,** and **nucleic acids.** The four classes of biomacromolecules are summarised in Table 1.

Biomacromolecules are called 'macro' because they can be very large: the polymers may be made of hundreds of thousands of monomers, folded and twisted into complex shapes. Multiple polymers can even combine to form larger compounds. For example, if a single DNA molecule (of which you have trillions) was unwrapped, it would be about three centimetres long.

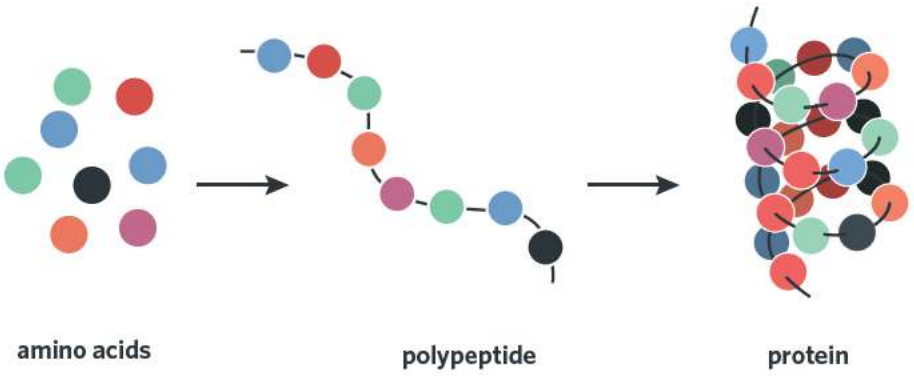


Figure 5 A protein biomacromolecule is a polymer of amino acid monomers linked by bonds called peptide bonds

organic a molecule containing covalently linked carbon

monomer a molecule that forms the smallest basic unit of a polymer

polymer a large molecule that is made up of small, repeated monomer subunits

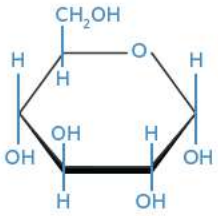
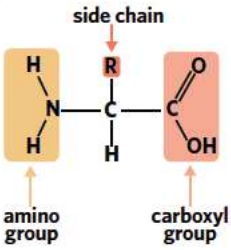
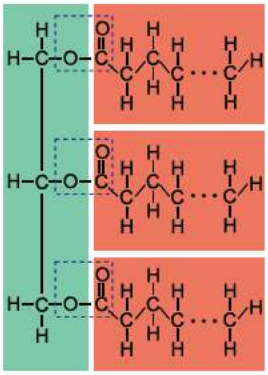
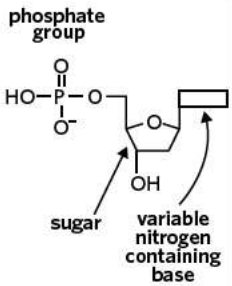
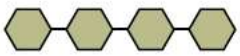
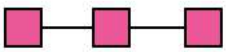
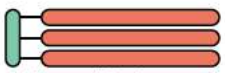
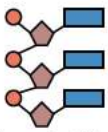
carbohydrate the class of biomacromolecules made from monosaccharide monomers consisting of C, H, and O. Also known as **saccharides** or **sugars**

protein a type of biomacromolecule made of amino acid chains folded into a 3D shape

lipid the class of biomacromolecules typically made from fatty acids and glycerol monomers consisting of C, H, and O. Characterised by their nonpolar nature. Examples include fats, oils, and waxes

nucleic acid the class of macromolecules that includes DNA and RNA. All nucleic acids are polymers made out of nucleotide monomers

Table 1 Summary of the different biomacromolecules

	Carbohydrates	Proteins	Lipids	Nucleic acids
Function examples	Energy storage Components in DNA, RNA, ATP Structure	Muscle movement Cell membrane transport Signalling Structure Enzymes Antibodies	Cell membrane structure and fluidity Energy storage Signalling	Genetic information storage Instructions for protein synthesis
Common examples	Glucose ($C_6H_{12}O_6$) Sucrose Starch Glycogen	Collagen Elastin Keratin Amylase	Oil Waxes Steroids	DNA RNA
Contains the elements	C,H,O	C,H,O,N,S	C,H,O	C,H,O,N,P
Monomer	Monosaccharides/sugars	Amino acids	Typically glycerol and fatty acids	Nucleotides
Polymer	Polysaccharide	Polypeptide	Lipid/fat	Nucleic acid
Polarity	Polar	Either polar or nonpolar	Nonpolar	Polar
Relevant lessons	6A, 7A	4A, 4C, 5A, 9D	3A, 8B	4B, 4C, 11A, 15C, 15D
Monomer diagram	 The monosaccharide glucose	 Amino acid	 Glycerol and fatty acids	 Nucleotide
Basic polymer diagram	 4x monosaccharides Carbohydrates are made from monosaccharide monomers	 3x amino acids Proteins are made from amino acid monomers	 1x glycerol, 3x fatty acids Lipids are typically made from glycerol and fatty acid monomers. This lipid is a triglyceride, which is made of a glycerol molecule and three fatty acids	 3x nucleotides Nucleic acids are made from nucleotide monomers

Energy and reactions 0.5

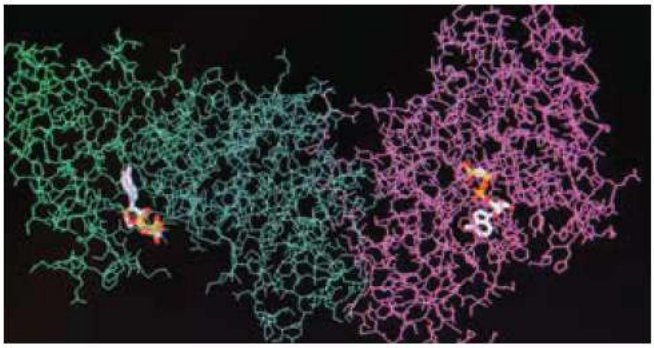


Image: Sergei Drozd/Shutterstock.com

Figure 6 The structure of biomacromolecules can be very complex. This computer generated image of a protein displays carbon atoms as a bend in the line.

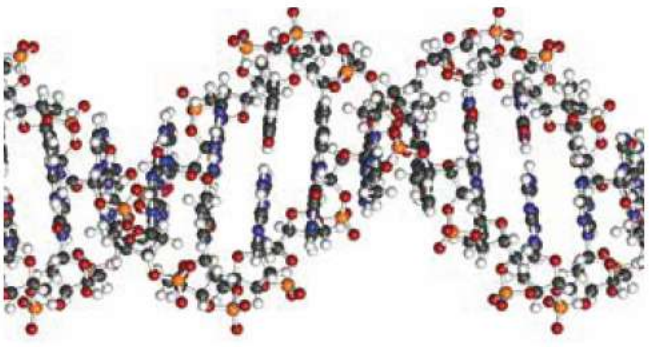


Image: StudioMolekuul/Shutterstock.com

Figure 7 Two polynucleotide chains can come together to form DNA

OVERVIEW

Countless chemical reactions take place within cells every second. In chemical reactions, bonds are broken and formed, which involves a transfer of energy.

THEORY DETAILS

Types of reactions

In an **exergonic** reaction, energy is released into the environment. In an **endergonic** reaction, energy is absorbed from the environment. For example, during cellular respiration the sugar glucose ($C_6H_{12}O_6$) is broken down into the smaller molecules of CO_2 and H_2O. During this process a large amount of energy is released, so it is an exergonic reaction. Conversely, when amino acid monomers link to form a larger polypeptide, energy is stored within the new bonds and so the reaction is endergonic.

Tip You may also come across the terms exothermic and endothermic reactions. These terms refer to the release or absorption of energy in the form of heat.

An exothermic reaction increases the temperature of the environment (releases energy like exergonic). An endothermic reaction decreases the temperature of the environment (endergonic).

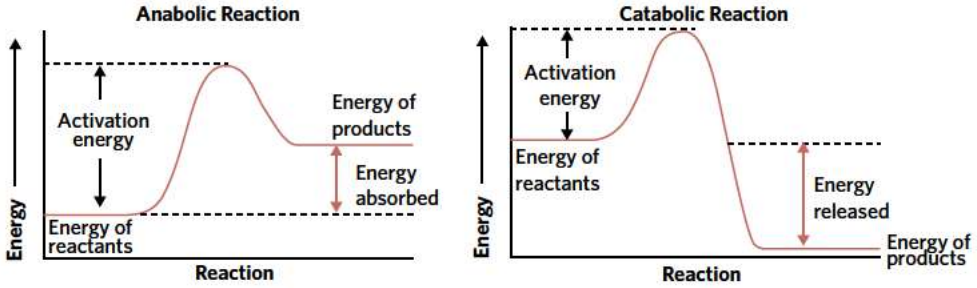


Figure 8 The transfer of energy in anabolic and catabolic reactions

Reactions can also be classified by whether they create larger molecules or break larger molecules into smaller ones. **Anabolic** reactions 'build-up' larger molecules by using energy (endergonic). **Catabolic** reactions break down larger molecules, releasing energy (exergonic).

Notice in Figure 8 that both anabolic and catabolic reactions must get over a 'hump' before completing the reaction. This hump is the energy input required to get the reaction started, and is called the **activation energy.** If a reaction has a low activation energy, it is more likely to occur. Cells can use special proteins called enzymes to lower the activation energy of specific reactions, increasing cell efficiency.

Condensation reactions are a type of anabolic reaction that form water as a by-product. Condensation reactions are the mechanism for turning a biomacromolecule monomer into a polymer. Hydrolysis is a type of catabolism that consumes water when polymers are broken down into monomers.

ATP

Recall that cells undergo a process called cellular respiration to produce a high energy molecule called adenosine triphosphate (**ATP**). Cells use ATP to carry energy between reactions, and when it is broken down it releases energy for use. During an endergonic reaction, ATP would be used to provide the required energy. Upon being broken into ADP, it can easily be remade, or cycled back to ATP to be used again. Because it is used so often, it is sometimes referred to as the 'energy currency' of life.

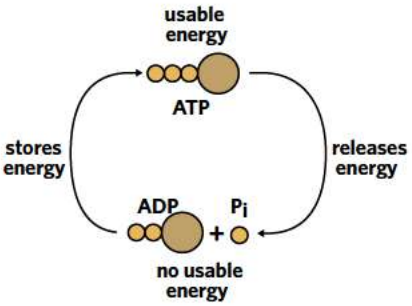


Figure 10 ATP cycles to ADP releasing energy

Theory summary

Atoms are the building blocks of matter. Polar substances have charged ends and are typically hydrophilic; nonpolar substances have no overall charge and are typically hydrophobic. The four biomacromolecule groups (carbohydrates, proteins, lipids, and nucleic acids) are polymers made from specific monomers. Anabolic and endergonic reactions store energy and build up larger molecules, catabolic and exergonic reactions release energy by breaking molecules down.

exergonic a reaction that releases energy, the products have less energy than reactants

endergonic a reaction that stores energy, the products have a greater energy than reactants

anabolic an endergonic reaction where larger molecules are formed from smaller molecules

catabolic an exergonic reaction where larger molecules are broken down into smaller molecules

activation energy the energy required to initiate a reaction

condensation reaction a reaction where two small molecules join to form one larger molecule, producing water as a by-product in the process

ATP adenosine triphosphate, a high energy molecule that, when broken down, provides energy for cellular processes

Memory device One way to remember the similarities between reaction types is EXERHYDROCAT, which highlights that exergonic reactions are catabolic and include hydrolysis. The alternative combination would be endergonic, anabolic, condensation reactions.

Figure 9 Over-exercising cat says 'me-ow'

2B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ describes a molecule with a positive and negatively charged end that tends to be hydrophilic
b _____ the type of bonding where electrons are shared
c _____ small, identical subunits of a given biomolecule group that bind together
d _____ the biomacromolecule produced when amino acids join
e _____ describes a molecule without a positive and negatively charged end that tends to be hydrophobic
f _____ a high energy molecule used to power reactions within a cell
g _____ the biomacromolecule made from monosaccharides
h _____ the biomacromolecule that are sometimes called fats and oils
i _____ a large molecule produced when biomolecule subunits link together
j _____ a reaction that releases energy
k _____ a reaction that absorbs energy
l _____ the biomacromolecule that is responsible for storing genetic information

Question 2

Which of the following are all true of proteins?

A	Made from amino acids	Peptide bond formed between monomers	Also known as saccharides
B	Made from amino acids	Peptide bond formed between monomers	Also known as polypeptides
C	Made from amino acids	Ionic bond formed between monomers	Also known as polypeptides
D	Made from nucleic acids	Peptide bond formed between monomers	Also known as saccharides

Question 3

Which of the following statements about endergonic reactions is false?

A Endergonic reactions absorb energy, similar to hydrolysis reactions.
B Endergonic reactions are anabolic reactions that build up larger molecules.
C In endergonic reactions, the energy of the products is greater than the reactants.
D Endergonic reactions require an initial input of energy, known as activation energy, to start the reaction.

Question 4

Fill in the blanks in the following sentences.

The building blocks of all matter are _____**I**____, which are made up of protons, neutrons and _____**II**_____. Nitrogen is a(n) _____**III**_____ on the periodic table. When nitrogen shares electrons with three hydrogen ions, it forms ammonia (NH_3). The ammonia molecule is held together by _____**IV**_____ bonds and is a polar molecule, meaning that it is likely _____**V**_____.

	I	**II**	**III**	**IV**	**V**
A	atoms	electrons	element	covalent	hydrophobic
B	atoms	electrons	molecule	ionic	hydrophilic
C	molecules	atoms	element	ionic	hydrophobic
D	atoms	electrons	element	covalent	hydrophilic

Question 5

Which of the following statements about carbohydrates is false?

A also known as polysaccharides

B found in both plants and animals

C made up of only three elements: C, H, and N

D simple carbohydrates are known as sugars and often used as energy sources

Question 6

What belongs in the spaces X, Y, and Z in the table?

Monomer	**Biomacromolecule**
Amino acid	Protein
Glycerol and fatty acids	**X**
Y	**Z**
Monosaccharide	Carbohydrate

	X	**Y**	**Z**
A	Nucleotide	Nucleic acid	Lipid
B	Lipid	Nucleic acid	Nucleotide
C	Nucleic acid	Lipid	Nucleotide
D	Lipid	Nucleotide	Nucleic acid

Question 7

Which of the following correctly lists terms that are commonly related?

A Endergonic, exothermic, hydrolysis, anabolic

B Exergonic, endothermic, hydrolysis, catabolic

C Exergonic, exothermic, condensation, catabolic

D Endergonic, endothermic, condensation, anabolic

Question 8

Classify each of the following statements as relating to either carbohydrates, lipids, nucleic acids, or proteins in the table. NOTE: some statements can be classified into multiple groups.

1 Made up of subunits called monomers

2 Monomer is amino acids

3 Made from only three elements: C, H, and O

4 Also known as fats

5 Glucose is an example

6 A peptide bond is formed between monomers

7 Carry genetic information

8 Is a biomacromolecule

9 Also known as saccharides

	Carbohydrate	**Lipid**	**Nucleic acid**	**Protein**
A	1, 3, 5, 7, 8	1, 2, 4, 8, 9	1, 7, 9	1, 2, 3, 8
B	1, 5, 7, 9	1, 3, 8	1, 8	1, 3, 8
C	1, 3, 5, 8, 9	1, 3, 4, 8	1, 7, 8	1, 2, 6, 8
D	1, 5, 8, 9	1, 3, 4, 8	1, 3, 8	1, 3, 6, 8

Exam-style questions

Within lesson

Question 9 (1 MARK)

Which of the following is an anabolic process?

A the conversion of glycogen into glucose
B the breakdown of starch into smaller saccharides
C using ATP in a chemical reaction, converting it to ADP
D the formation of triglyceride from glycerol and fatty acids

Adapted from VCAA 2016 Section A Q16

Question 10 (1 MARK)

ATP is

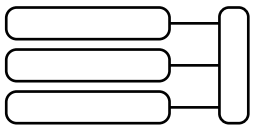
A a high energy molecule.
B a diphosphate molecule.
C an input in cellular respiration.
D made from removing a phosphate group from ADP.

Adapted from VCAA 2016 Section A Q9

Use the following information to answer Questions 11 — 14.

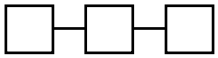
Consider the following diagrams showing structural subunits of three types of biomolecules. The subunits are named in the order shown in each diagram.

W



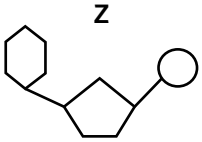
3 **X**, 1 glycerol

protein



3Y

Z



1 nitrogen base, 1 sugar, 1 phosphate group

Question 11 (1 MARK)

Biomolecule W is a

A lipid.
B protein.
C nucleic acid.
D carbohydrate.

Question 12 (1 MARK)

The three subunits denoted by X are

A glycerols.
B fatty acids.
C nucleotides.
D amino acids.

Question 13 (1 MARK)

Subunit Y is a

A monosaccharide.
B amino acid.
C nucleotide.
D glycerol.

Question 14 (1 MARK)

Biomolecule Z is a monomer of a

A fat.

B protein.

C nucleic acid.

D carbohydrate.

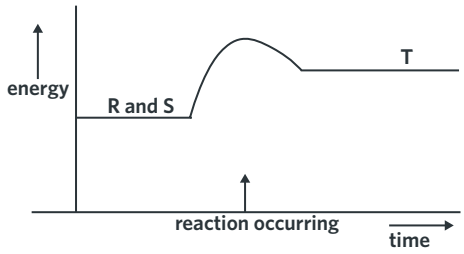
Adapted from VCAA 2013 Section A Q2

Question 15 (4 MARKS)

The following reaction occurs within a cell where molecules R and S and converted into molecule T.

R + S → T

The energy of the reaction can be graphed as follows.



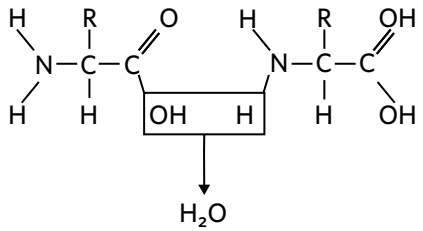
a Does this reaction release or absorb energy? Justify your response. (2 MARKS)

b State whether this reaction is anabolic or catabolic. (1 MARK)

c It was found that ATP was used to produce molecule T. What is the role of ATP in biological systems? (1 MARK)

Question 16 (5 MARKS)

The following diagram represents the joining of monomers to produce one of the four major classes of biomolecules.



a Identify the name of the monomers undergoing the reaction. (1 MARK)

b What type of biomacromolecule is produced in this reaction? (1 MARK)

c Give an example of a molecule that falls into this biomacromolecule group. (1 MARK)

d Hydrolysis is the chemical breakdown of a compound due to reaction with water.
Is this reaction an example of hydrolysis? Justify your response. (2 MARKS)

Key science skills

Question 17 (5 MARKS)

Two students, Jed and Ava, were designing an experiment to investigate what happens when oil is added to water. They set up a beaker of water as shown, and prepared to deliver oil into the beaker.

Image: Pat_Hastings/Shutterstock.com

a Devise a hypothesis the students could be testing. (1 MARK)

b Oil is an example of one of the four classes of macromolecules.

i What kind of biomacromolecule is oil? (1 MARK)

ii Identify the typical polarity of this group of biomacromolecule. (1 MARK)

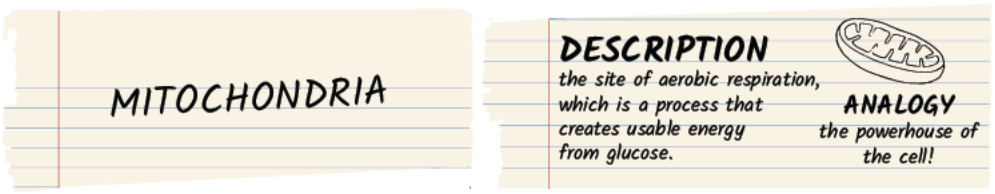
c When the oil was added to the water the two substances did not mix, instead the oil formed a layer above the water. Ava stated that this was because the nonpolar water could not dissolve the nonpolar oil as the pair were too similar. Jed believed that it was because the nonpolar oil could not dissolve in the polar water because of their differences in polarity. Which student is correct? Justify your response. (2 MARKS)

ACTIVITIES

Cue card challenges

Do you organ-know your organelles?

Make a deck of organelle-themed cue cards. On one side, write the name of the organelle. Then, flip the card over and write a full description of its role, followed by an analogy and a small image or drawing. For example, your cards may look like this:



Make sure your deck includes:

- Nucleus
- Mitochondria
- Chloroplast
- Cell wall
- Plasma membrane
- Ribosome
- Rough endoplasmic reticulum
- Smooth endoplasmic reticulum
- Golgi body
- Lysosome
- Vacuole
- Cytoplasm

Once your deck has been made, get your friend to test you! Start by getting them to show you the back and guess which organelle it is. Then switch it up and describe each organelle after being shown the front.

Ultimate Biology Snap

Find another stack of cue cards now to set up for the ultimate game of snap!

Grab a card and write a key biological term on it. Now grab a different card and write the definition for it. Next, grab another card and write a fun fact on it. Finally, on the fourth card, draw a diagram or symbol to represent the key term. This means there are more combinations to snap. Spice it up a little! Below is a list of key terms you can use in your game.

- Cell
- Eukaryote
- Prokaryote
- Plant cell
- Animal cell
- Carbohydrates
- Lipids
- Proteins
- ATP
- Hydrophobic
- Hydrophilic

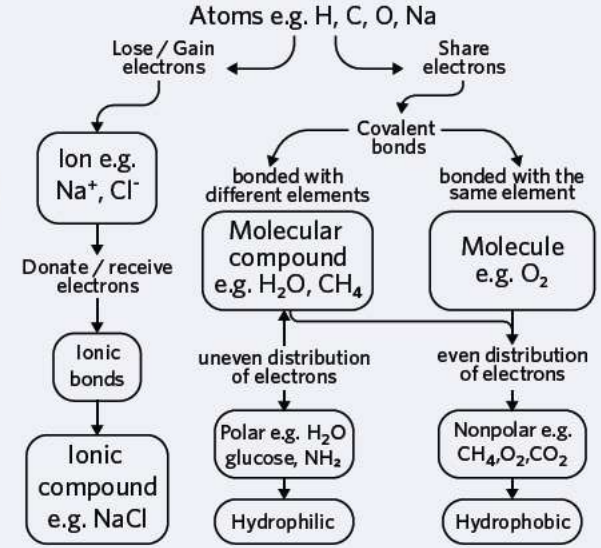
Feel free to add some of your own terms or your organelle cue cards to beef the deck up.

Rules of Snap

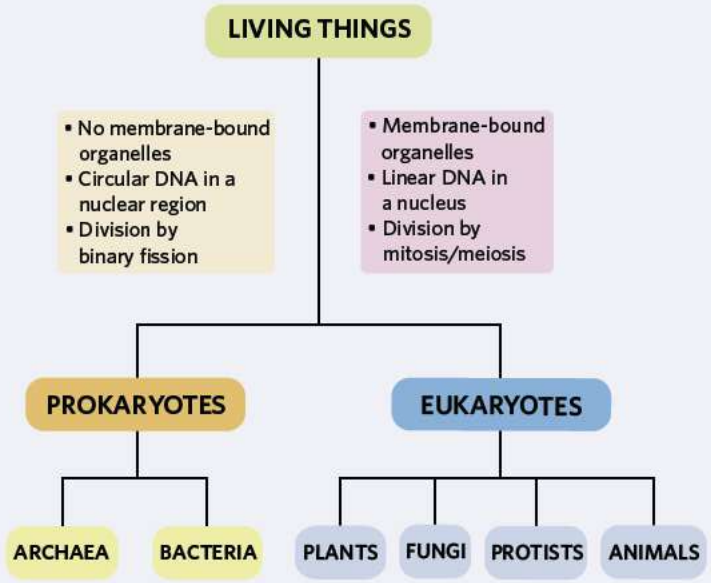
The deck is shuffled, then all the cards in the deck are dealt out evenly among the players. Each player holds their cards in a pile face down. The first player flips their first card and places it face up in the middle of the playing space. Then the next player does the same.

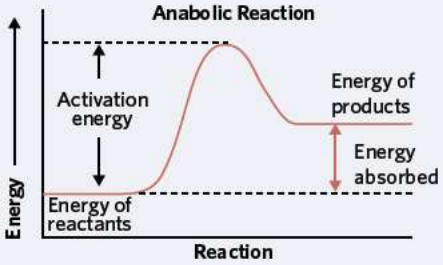
When two consecutive cards match, the first person to notice calls out snap and places their hand on top of the pack. They then collect the pile and place it at the bottom of their hand of cards. This continues until one player has won all the cards. They are deemed the winner of the game.

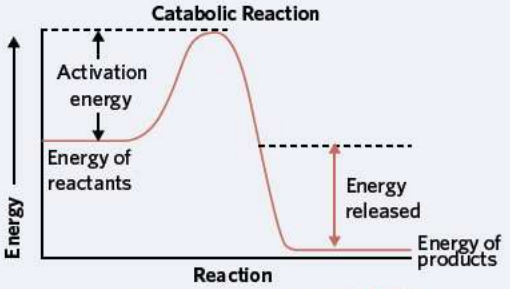
CHAPTER SUMMARY



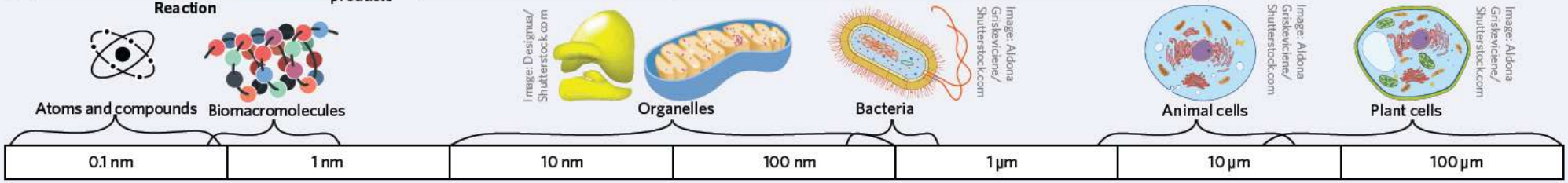
Organelle	Function	Plants (P), animals (A), or bacteria (B)
Nucleus	Stores DNA	P, A
Mitochondrion	Site of cellular respiration and ATP synthesis	P, A
Cell wall	Protection and support	P, B
Chloroplast	Site of photosynthesis	P
Ribosome	Protein synthesis	P, A, B
Plasma membrane	Regulates transport in and out of cell	P, A, B
Golgi body	Packages and modifies protein	P, A







	Carbohydrates	Proteins	Lipids	Nucleic acids
Function examples	Energy storage Components in DNA, RNA, ATP Structure	Muscle movement Cell membrane transport Signalling Structure Enzymes Antibodies	Cell membrane structure and fluidity Energy storage Signalling	Genetic information storage Instructions for protein synthesis
Monomer	Monosaccharides/ sugars	Amino acids	Typically glycerol and fatty acids	Nucleotides
Polymer	Polysaccharide	Polypeptide	Lipid/fat	Nucleic acid



CHAPTER REVIEW QUESTIONS

SECTION A (12 MARKS)

Question 1 (1 MARK)

ATP is

A a nucleic acid.
B a lipid monomer.
C required for active transport.
D used as a building block in protein synthesis.

Question 2 (1 MARK)

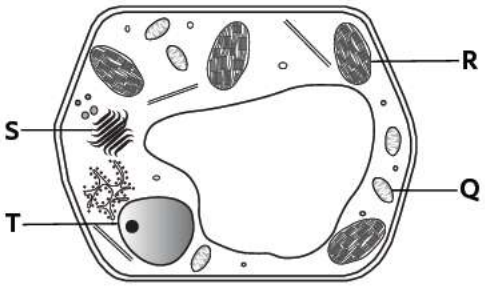
The lysosome is responsible for the

A destruction of toxins.
B manufacture of lipids.
C production of energy for the cell.
D modification and packaging of protein molecules.

Adapted from VCAA 2011 Exam 1 Section A Q14

Use the following information to answer Questions 3–5.

Consider the following cell.



Question 3 (1 MARK)

Which of the following statements is correct?

A The cell is an animal cell.
B The cell is a red blood cell.
C The cell is a prokaryotic organism.
D The cell can undergo photosynthesis.

Question 4 (1 MARK)

Structure T

A is the site of glucose synthesis.
B is the site of aerobic respiration.
C stores the cell's water and nutrients.
D contains genetic material that carries the instructions for protein synthesis.

Question 5 (1 MARK)

Which of the following structures is responsible for trapping sunlight energy to produce glucose?

A R
B S

C T

D Q

Question 6 (1 MARK)

The diagram shows the structure of an organelle in a cell.

This organelle

A contains genetic material that carries the instructions for protein synthesis.

B modifies, sorts, and packages protein molecules.

C is the site of aerobic respiration to produce ATP.

D is the site of protein production.

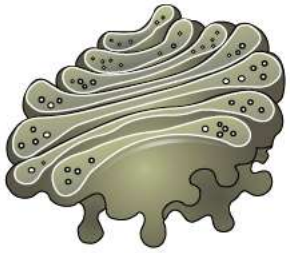


Image: Tefi/Shutterstock.com

Adapted from VCAA 2011 Exam 1 Section A Q10

Question 7 (1 MARK)

Which one of the following processes produces energy?

A The formation of triglycerides from glycerol and fatty acids.

B The breakdown of glucose in cellular respiration.

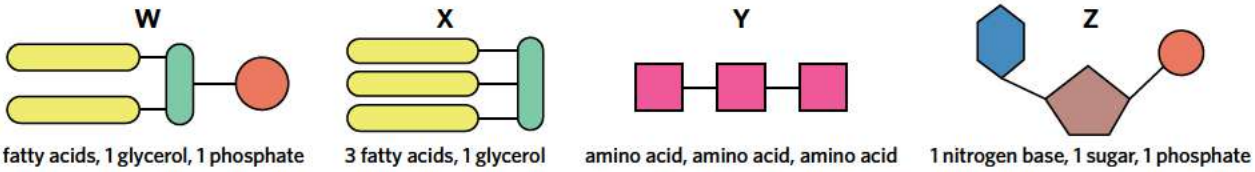
C The synthesis of polypeptides from amino acids.

D The conversion of glucose to glycogen.

Adapted from VCAA 2016 Section A Q16

Use the following information to answer Questions 8 and 9.

Consider the diagrams showing structural sub-units of four types of biomolecules. The sub-units are named in the order shown in each diagram.



2 fatty acids, 1 glycerol, 1 phosphate | **3 fatty acids, 1 glycerol** | **amino acid, amino acid, amino acid** | **1 nitrogen base, 1 sugar, 1 phosphate**

Question 8 (1 MARK)

The class of biomolecules called proteins includes

A W only.

B Y only.

C W and X only.

D W and Y only.

Question 9 (1 MARK)

Which of the molecules would be stored in the nucleus of a cell?

A X only

B Z only

C X and Z only

D W, X, Y, and Z

Adapted from VCAA 2013 Section A Q2

Question 10 (1 MARK)

Which of the following processes consumes energy?

A The breakdown of ATP into ADP and P_i

B The breakdown of glucose in cellular respiration

C The hydrolysis of a polypeptide into amino acids

D The synthesis of glycogen from glucose monomers

Adapted from VCAA 2016 Section A Q16

Question 11 (1 MARK)

A hydrophobic molecule

A is lipophilic.

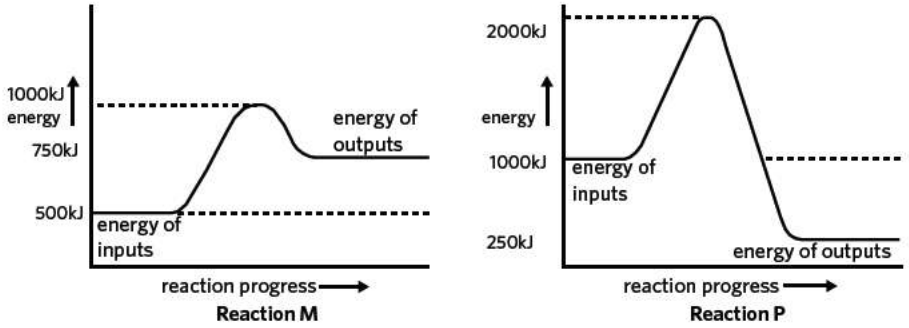
B dissolves in water.

C can be a carbohydrate.

D cannot diffuse through the plasma membrane.

Question 12 (1 MARK)

The following graphs depict two different reactions.



From the two graphs, it is reasonable to conclude that

A in reaction M, the energy level of the inputs is greater than that of the outputs.

B the activation energy of reaction P is greater than that of reaction M.

C both graph M and P represent reactions that release energy.

D the energy is absorbed in reaction P.

Adapted from VCAA 2011 Exam 1 Section A Q23

SECTION B (18 MARKS)

Question 13 (10 MARKS)

The diagram shows the structure of a cell.

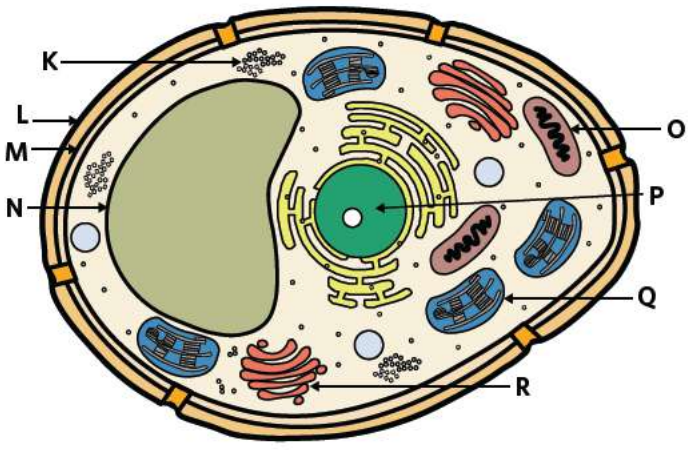


Image: KazakovaMaryia/Shutterstock.com

a Complete the following table. (5 MARKS)

Structure	Name	Role
		uses solar energy to produce glucose
	ribosomes	
		controls all cellular processes
N		stores fluids, water, and waste within the cell
		modifies, sorts, and packages protein molecules
L		
		converts glucose into energy
	plasma membrane	

b Describe the difference between the cytosol and the cytoplasm of a cell. (2 MARKS)

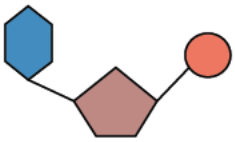
c Clara states that this is a prokaryotic plant cell. Evaluate her statement and state how this cell would be categorised. (3 MARKS)

Adapted from VCAA 2012 Exam 1 Section B Q1

Question 14 (8 MARKS)

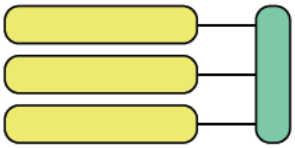
Consider each of the four diagrams of different biomolecules.

T



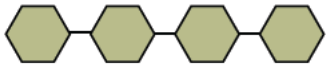
1 nitrogen base, 1 sugar, 1 phosphate

U



3 fatty acids, 1 glycerol

V



glucose, glucose, glucose, glucose

W

amino acid, amino acid, amino acid

Dylan and Tèa are comparing the properties and functions of different biomolecules in the diagram.

a State what type of biomolecule each diagram belongs to. (2 MARKS)

b Tèa believes that all of the pictured biomolecules are made up of the carbon, hydrogen, nitrogen, and oxygen. Explain whether she is correct. (2 MARKS)

c Dylan believes all four biomolecules are synthesised in different places in a cell.

i Identify where polymers of biomolecule U are produced. (1 MARK)

ii Identify where polymers of biomolecule W are produced. (1 MARK)

d With reference to the interactions with water

i identify the nature of structure V. (1 MARK)

ii identify the nature of fatty acid tails in structure U. (1 MARK)

UNIT

3 How do cells maintain life?

The cell is a dynamic system of interacting molecules that define life. An understanding of the workings of the cell enables an appreciation of both the capabilities and the limitations of living organisms whether animal, plant, fungus, or microorganism. The convergence of cytology, genetics, and biochemistry makes cell biology one of the most rapidly evolving disciplines in contemporary biology.

In this unit students investigate the workings of the cell from several perspectives. They explore the importance of the insolubility of the plasma membrane in water and its differential permeability to specific solutes in defining the cell, its internal spaces, and the control of the movement of molecules and ions in and out of such spaces. Students consider base pairing specificity, the binding of enzymes and substrates, the response of receptors to signalling molecules, and reactions between antigens and antibodies to highlight the importance of molecular interactions based on the complementary nature of specific molecules.

Students study the synthesis, structure, and function of nucleic acids and proteins as key molecules in cellular processes. They explore the chemistry of cells by examining the nature of biochemical pathways, their components, and energy transformations. Cells communicate with each other using a variety of signalling molecules. Students consider the types of signals, the transduction of information within the cell, and cellular responses. At this molecular level students study the human immune system and the interactions between its components to provide immunity to a specific antigen.

Image: vitstudio/Shutterstock.com

UNIT 3

AOS1

How do cellular processes work?

In this area of study students focus on the cell as a complex chemical system. They examine the chemical nature of the plasma membrane to compare how hydrophilic and hydrophobic substances move across it. They model the formation of DNA and proteins from their respective subunits. The expression of the information encoded in a sequence of DNA to form a protein is explored and the nature of the genetic code outlined. Students use the *lac* operon to explain prokaryotic gene regulation in terms of the 'switching on' and 'switching off' of genes.

Students learn why the chemistry of the cell usually takes place at relatively low, and within a narrow range of, temperatures. They examine how reactions, including photosynthesis and cellular respiration, are made up of many steps that are controlled by enzymes and assisted by coenzymes. Students explain the mode of action of enzymes and the role of coenzymes in the reactions of the cell and investigate the factors that affect the rate of cellular reactions.

Outcome 1

On completion of this unit the student should be able to explain the dynamic nature of the cell in terms of key cellular processes including regulation, photosynthesis, and cellular respiration, and analyse factors that affect the rate of biochemical reactions.

Image: Kateryna Kon/Shutterstock.com

UNIT 3 AOS 1, CHAPTER 3

Plasma membrane

03

3A The structure of the plasma membrane

3B Transport across membranes

3C Bulk transport

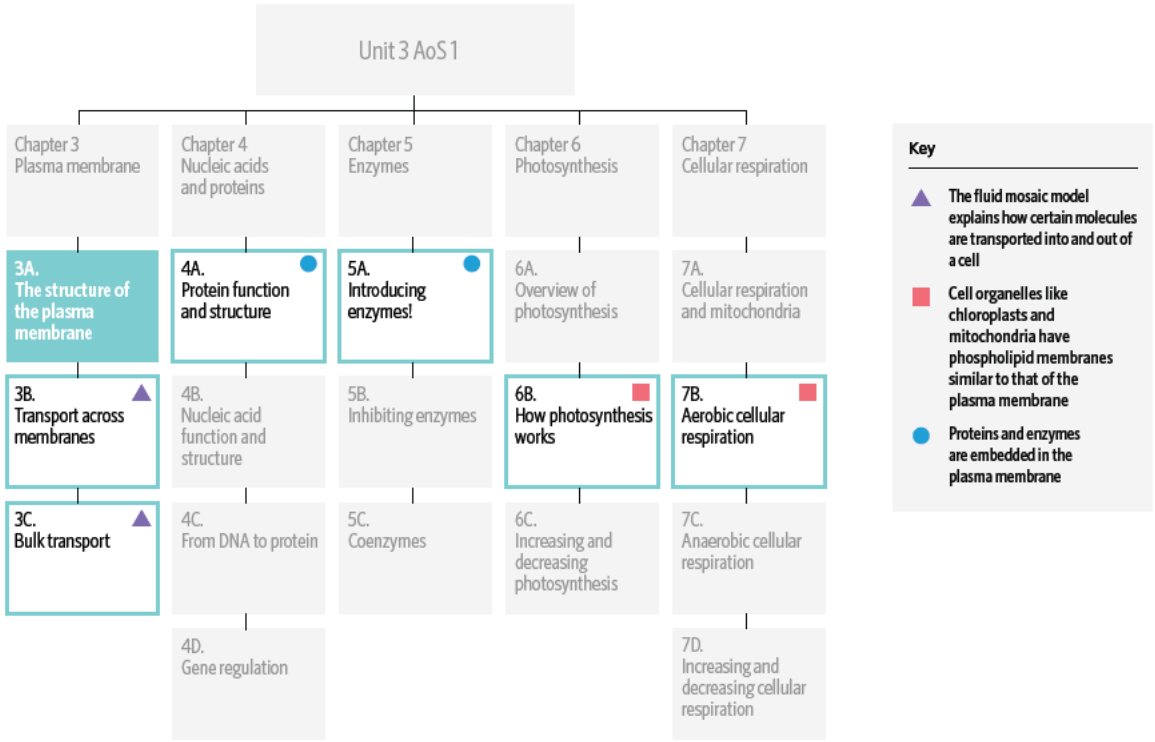
Key knowledge

- the fluid mosaic model of the structure of the plasma membrane and the movement of hydrophilic and hydrophobic substances across it based on their size and polarity
- the role of different organelles including ribosomes, endoplasmic reticulum, Golgi apparatus, and associated vesicles in the export of a protein product from the cell through exocytosis
- cellular engulfment of material by endocytosis

Image: Lebendkulturen.de/Shutterstock.com

3A THE STRUCTURE OF THE PLASMA MEMBRANE

The only thing keeping all the components of a cell together is the plasma membrane. Without it, we'd all just be puddles of organelle soup!



In this lesson you will learn about the fluid mosaic model of the plasma membrane.

Study design dot point

- the fluid mosaic model of the structure of the plasma membrane and the movement of hydrophilic and hydrophobic substances across it based on their size and polarity

Key knowledge unit

What the plasma membrane looks like	3.1.1.1

What the plasma membrane looks like 3.1.1.1

OVERVIEW

The plasma membrane is composed of a phospholipid bilayer that is embedded with cholesterol to regulate fluidity, carbohydrates for cell signalling, and multi-functional proteins.

THEORY DETAILS

All cells have a **plasma membrane**. It is the thin, fatty boundary of the cell that separates the intracellular and extracellular environments and controls which molecules enter and exit. As a result of having a plasma membrane, a cell can have a specialised internal environment.

plasma membrane the phospholipid bilayer and embedded proteins which separate the intracellular environment from the extracellular environment

Phospholipids, proteins, carbohydrates, and cholesterol

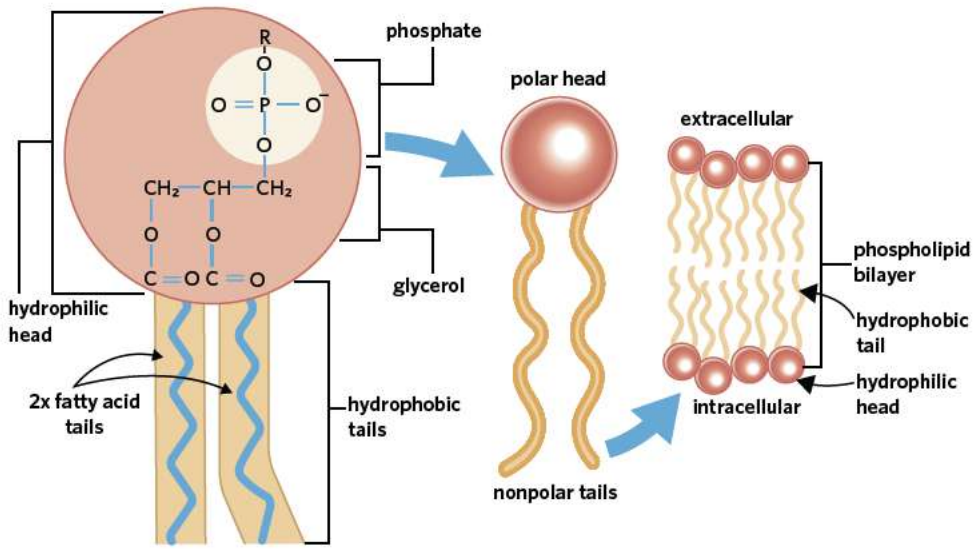


Figure 1 The structure of a phospholipid and the phospholipid bilayer

The main components of the plasma membrane are **phospholipids** (Figure 1). They are arranged in a film called a **phospholipid bilayer**, that consists of two layers of phospholipids. Phospholipids have a **phosphate head** and two **fatty acid tails.** The phosphate head is made of a glycerol and phosphate group, and it has a negative charge that makes it 'water-loving' or **hydrophilic.** This means it is attracted to, and orients itself towards, the aqueous intra- and extracellular environments. The fatty acid tails are made of long chains of carbon and hydrogen. They are uncharged and **hydrophobic** ('water-fearing'), so orient themselves away from the intra- and extracellular fluid to form the middle portion of the membrane. Because phospholipids have both hydrophilic and hydrophobic parts, they are **amphipathic** molecules. This amphipathic nature makes the plasma membrane stable: the fatty acids are repelled from water whilst the phosphate heads are attracted to water, so a bilayer naturally forms.

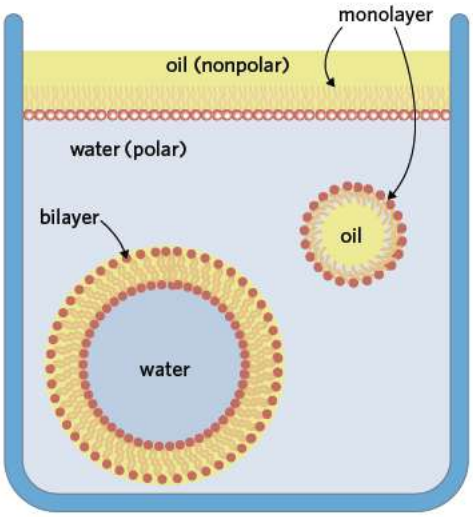


Figure 2 The natural formation of phospholipids in hydrophilic and hydrophobic environments

Tip Most polar molecules are hydrophilic, which means they can interact and bond with water. Chemically, all hydrophilic molecules have an uneven charge distribution over the molecule.

In contrast, hydrophobic molecules are not very reactive, have an even charge distribution across the molecule, and cannot bond with water. They are attracted to other hydrophobic molecules. So, the fatty acid tails of phospholipids are attracted to each other, stabilising the membrane.

phospholipid the main molecule of which membranes are composed. They have a phosphate head and two fatty acid tails

phospholipid bilayer a double layer of amphiphilic molecules that forms the primary component of cell membranes

phosphate head the hydrophilic subunit of a phospholipid

fatty acid tail the hydrophobic lipid subunit of a phospholipid

hydrophilic having a tendency to be attracted to and dissolve in water

hydrophobic having a tendency to repel from and be insoluble in water

amphipathic describes molecules with both hydrophilic and hydrophobic components. Also known as **amphiphilic**

Tip The carbons in fatty acid tails of phospholipids can be joined by one bond (saturated) or double/triple bonds (unsaturated). When carbon chains are unsaturated, kinks and bends occur. This makes it harder to pack phospholipids tight against each other and increases the fluidity of the plasma membrane. Phospholipids made of saturated fatty acids can be packed neatly next to each other, decreasing the fluidity of the plasma membrane.

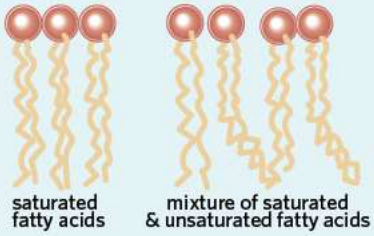


Figure 3 Saturated (left) fatty acids mean phospholipids can pack tightly, unsaturated (right) fatty acids on phospholipids can lead to more fluid membranes.

Cholesterol, carbohydrates, and proteins are attached to and embedded in the phospholipid bilayer (see Figure 4). Their structures and functions are summarised in Table 1.

Table 1 The structure and function of cholesterol, carbohydrates, and proteins in membranes

Membrane molecule	Structure	Functions
Cholesterol	A lipid steroid that embeds itself between the fatty acid tails of the phospholipid bilayer in animal cells (Figure 4). Cholesterol is replaced with different sterols in other kingdoms, but all are functionally similar.	Regulates the fluidity of the membrane. At higher temperatures, the cholesterol keeps phospholipids bound together, preventing unwanted substances from slipping through holes. At lower temperatures, the cholesterol disrupts the fatty acid tails, stopping phospholipids from becoming a solid boundary.
Carbohydrates	Usually in chains outside the cell, rooted in the membrane to lipids (**glycolipids**) or proteins (**glycoproteins**).	Aid with cell-cell communication, signalling, recognition of self or non-self (foreign) molecules, and adhesion.
Proteins	**Integral** – proteins that are a permanent part of the membrane **Transmembrane** – integral proteins that span from the inside to the outside of the bilayer **Peripheral** – temporary proteins that attach to the outside of the membrane	Transport – channels or pumps that control what enters and exits the cell, making the plasma membrane **selectively permeable** Enzymes – catalyse chemical reactions Communication – receive signals or recognise cells and molecules. Often attached to the **cytoskeleton** to transmit signals into the cell Adhesion – stick to other cells, the extracellular matrix, or the cytoskeleton

cholesterol a steroid alcohol that regulates fluidity in plasma membranes

glycolipid a phospholipid bound to a carbohydrate

glycoprotein a protein bound to a carbohydrate

integral protein a protein that is permanently secured to the plasma membrane

transmembrane protein an integral protein that spans from the intracellular to the extracellular side of the plasma membrane

peripheral protein a protein that is temporarily secured to the plasma membrane

selectively permeable a property of cell membranes that ensures only specific substances pass across them. Also known as **semipermeable**

cytoskeleton the microscopic web of protein filaments in the cytoplasm. It provides structure, support, and transports products around the cell

Tip Note that the structure of the plasma membrane is similar across many organisms. Remember that the cell wall of plants, bacteria, and fungi is located outside the plasma membrane. The cell wall provides strength, protection, and structure, but the plasma membrane controls transport into and out of the cell.

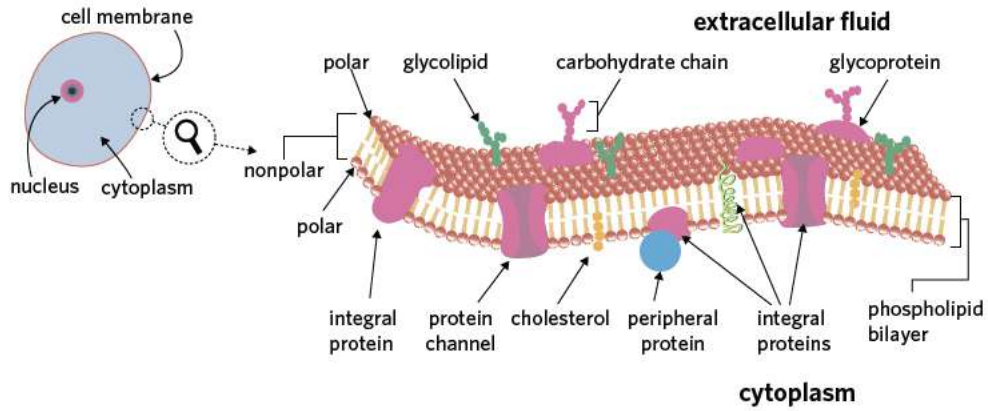


Image: Kallayanee Naloka/shutterstock.com

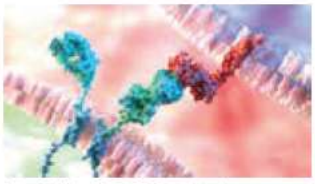


Image: Alpha Tauri 3D Graphics/ Shutterstock.com

Figure 5 A depiction of receptor protein (blue) binding to a protein (red) on another cell

Figure 4 The structure of the plasma membrane, with proteins, glycoproteins, glycolipids, and cholesterol

The fluid mosaic model

Our current understanding of the structure of the plasma membrane is described by the '**fluid mosaic model**'. The plasma membrane is fluid because its main component, phospholipids, continually move laterally (side to side) in the membrane. Occasionally, phospholipids may 'flip-flop' between the two layers of the plasma membrane.

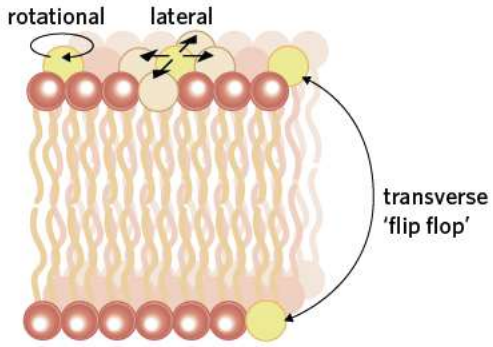


Figure 6 The ways that phospholipids can move in a fluid plasma membrane

To demonstrate the fluidity of the plasma membrane, consider the following scenario: when scientists want to enucleate (remove the nucleus) an egg cell, they pierce the cell membrane with a microscopic needle. The membrane reforms around the needle, with little cytoplasmic leakage. Then, when the scientists remove the needle, the phospholipids move again to fill the gap.

The 'mosaic' component of the model comes from the proteins and carbohydrates embedded in the membrane. These molecules can move around the bilayer, like ice floating in a glass of water. When looking down at the membrane, scientists imagine that they would see a variety of molecules of different shapes and sizes.

fluid mosaic model the theory of how the plasma membrane is structured

polar describes a molecule with both a positive end and negative end. These tend to be hydrophilic

nonpolar describes a molecule without a clearly positive or negative end. These tend to be hydrophobic

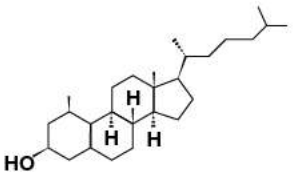


Figure 7 The chemical structure of cholesterol

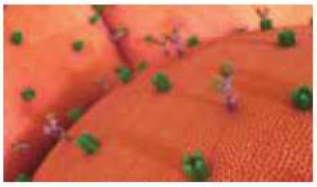


Image: sciencepics/Shutterstock.com

Figure 8 Proteins (green) and carbohydrate (purple) embedded in a membrane (red) like a mosaic

Theory summary

The plasma membrane is the selectively permeable barrier between the cell and its environment. Its structure is described by the fluid mosaic model, in which molecules within the membrane can move around and it is embedded with a myriad of proteins and other molecules.

The membrane is made up of a phospholipid bilayer. Phospholipids have a **polar**/hydrophilic phosphate head and two **nonpolar**/hydrophobic fatty acid tails. Cholesterol regulates fluidity in the membrane, carbohydrates attached to phospholipids and proteins play a role in cell signalling and adhesion, and proteins are involved in transport and enzymatic reactions.

3A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a molecule that has an uneven charge distribution

b _____ a molecule that is attracted to water

c _____ the hydrophilic part of a phospholipid

d _____ a molecule that regulates fluidity in animal cell membranes

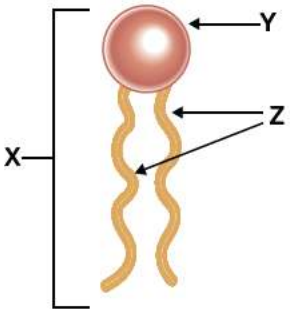
e _____ molecules that can create transport channels in the membrane

f _____ a molecule that is polar at one end and nonpolar at the other end

Question 2

Which of the options correctly describes the structures X, Y, and Z?

	X	Y	Z
A	Phospholipid, amphipathic	Phosphate head, hydrophilic	2 x fatty acid tails, nonpolar
B	Phospholipid, amphiphilic	Phosphate head, hydrophilic	1 x fatty acid tail, hydrophobic
C	Phospholipid bilayer, amphipathic	Phosphate head, hydrophilic	2 x fatty acid tails, nonpolar
D	Phospholipid, amphipathic	Phosphate head, hydrophobic	2 x fatty acid tails, hydrophilic



Question 3

Fill in the blanks in the following sentences.

Many different proteins are associated with the plasma membrane. They have many functions including _____**I**_____. Integral proteins are permanent parts of the membrane, but _____**II**_____ proteins are not. _____**III**_____ proteins are integral proteins that span the whole membrane bilayer.

	I	II	III
A	catalysing chemical reactions, transport across the membrane, cell-cell communication, or adhesion	peripheral	Transmembrane
B	creating a mosaic across the plasma membrane	peripheral	Transmembrane
C	enzymatic functions, transport, communication, or adhesion	channel	Transmembrane
D	enzymatic functions, storage, fluidity regulation, transport, communication, or adhesion	peripheral	Cross-membrane

Question 4

Examine the diagram.

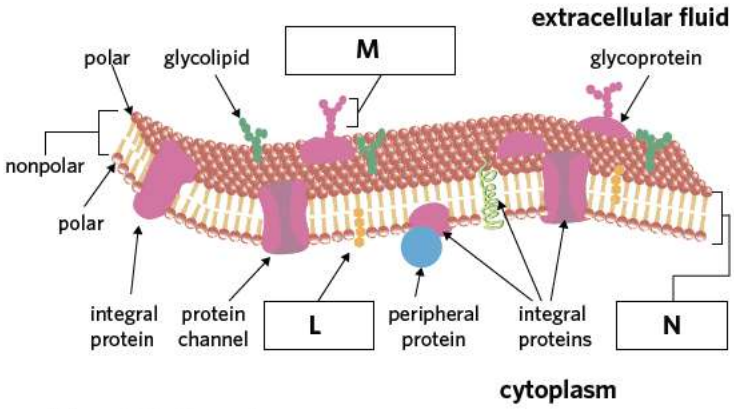


Image: Kallayanee Naloka/shutterstock.com

Which of the following options correctly identifies and explains the function of molecules L, M, and N?

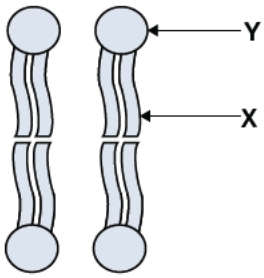
	L	M	N
A	cholesterol, regulates fluidity	carbohydrate chain, cell signalling and adhesion	phospholipid bilayer, makes ATP for the cell
B	cholesterol, stores energy	carbohydrate chain, cell communication and adhesion	phospholipid bilayer, regulates fluidity
C	cholesterol, regulates fluidity	glycolipid, cell signalling and adhesion	phospholipid bilayer, stable boundary between cell and environment
D	cholesterol, regulates fluidity	carbohydrate chain, cell signalling and adhesion	phospholipid bilayer, stable boundary between cell and environment

Exam-style questions

Within lesson

Use the following information to answer Questions 5–7.

The diagram represents the arrangement of a type of molecule found in the plasma membrane.



Question 5 (1 MARK)

The structure labelled X in the molecule is

A polar.
B ionised.
C amphiphilic.
D hydrophobic.

Adapted from VCAA 2015 Section A Q2

Question 6 (1 MARK)

The structure labelled Y in the molecule is

A a cell.
B a protein.
C a monosaccharide.
D a phosphate head.

Adapted from VCAA 2015 Section A Q2

Question 7 (1 MARK)

Together, the structures labelled X and Y

A form part of a phospholipid bilayer that is fully permeable.
B form part of a phospholipid bilayer that is selectively permeable.
C form part of a phospholipid bilayer that is not selectively permeable.
D form part of a phospholipid monolayer that is selectively permeable.

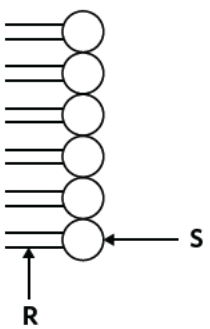
Adapted from VCAA 2015 Section A Q2

Question 8 (1 MARK)

Six molecules that form part of the plasma membrane of an animal cell are shown.

Which one of the following statements is false?

A S and R are separate molecules.
B The S portions of the molecules represent the hydrophilic phosphate heads.
C The S and R portions of the molecules together form an amphipathic molecule.
D The R portions of the molecules would not be in contact with the interior of the cell or the extracellular environment.



Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q4

Question 9 (1 MARK)

Both plant and animal cells have plasma membranes. Consider the structure of the plasma membrane of animal cells.
The plasma membranes of animal cells

A contain mainly cellulose.

B are more fluid than plant plasma membranes.

C are made up of mainly cholesterol and carbohydrates.

D have a hydrophobic region similar to the plant plasma membrane.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q3

Question 10 (5 MARKS)

All cells have a plasma membrane.

a On a sheet of paper, draw a labelled diagram of the arrangement of phospholipids in the plasma membrane. (2 MARKS)

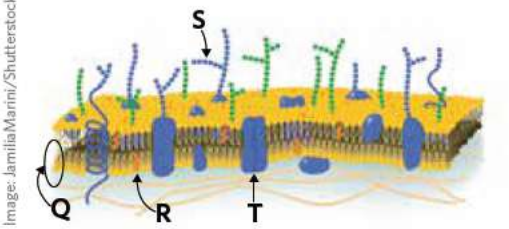
b Identify the charge(s) of the molecule(s) that you have drawn. (2 MARKS)

c Cholesterol is found embedded in the plasma membrane. Explain the role of cholesterol in plasma membranes and describe how it performs this role. (1 MARK)

Adapted from VCAA 2011 Exam 1 Section B Q4a

Question 11 (9 MARKS)

Consider the diagram of a plasma membrane.



a Identify and outline the functions of Molecules Q, R, S, and T. (4 MARKS)

Molecule	Name	Function
Q		
R		
S		
T		

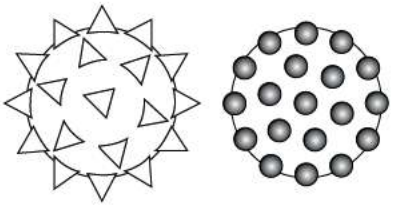
b Both Molecules R and T are embedded in the plasma membrane. With reference to charge, explain why this is possible for each molecule. (3 MARKS)

c Scientists currently describe the plasma membrane as 'fluid mosaic'. Outline the fluid mosaic model. (2 MARKS)

Key science skills

Question 12 (6 MARKS)

Many eukaryotic cells have proteins as part of their plasma membranes. An experiment was performed on different animal cells. The diagrams show the positions and shapes of two proteins on the plasma membranes of two different cells.



These cells were then fused, and scientists observed the plasma membranes after one hour.

a Using your understanding of the fluid mosaic model of the plasma membrane, draw the changed positions of the proteins one hour after fusion. (2 MARKS)

b Suggest a hypothesis the scientists could have been testing in this experiment. (1 MARK)

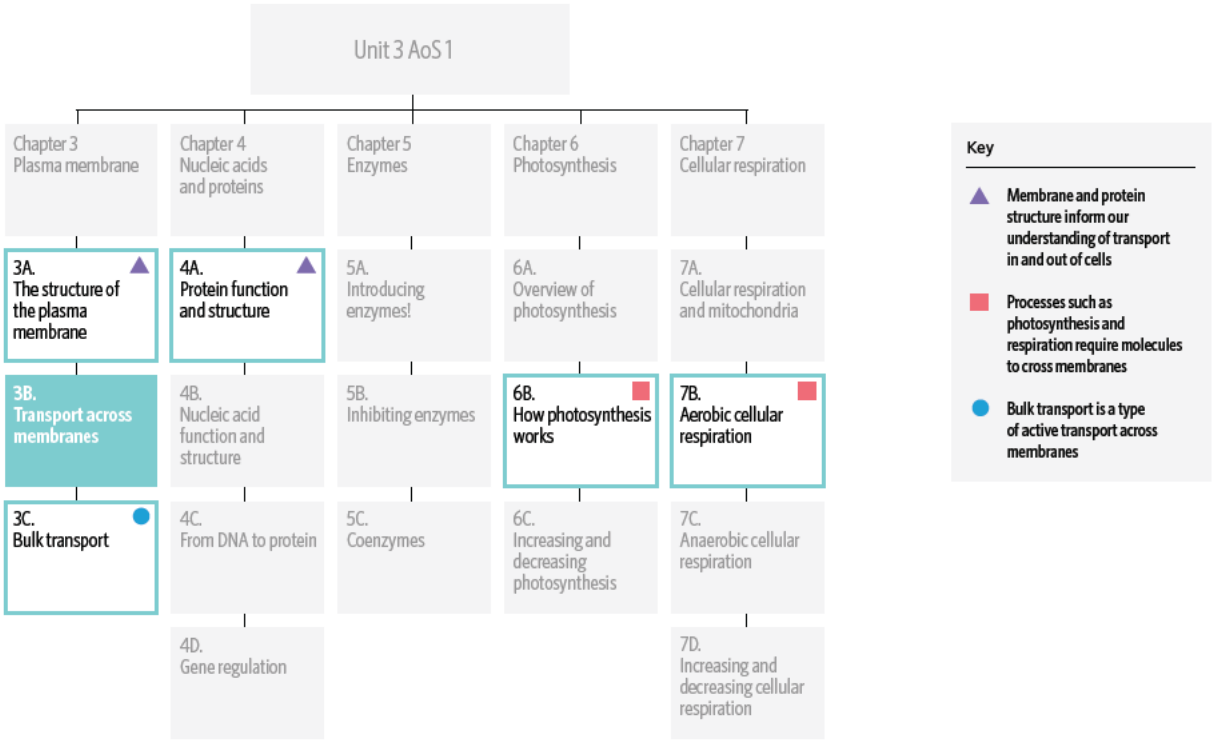
c Identify two factors in the experiment that would have been important to control. (2 MARKS)

d Identify one way to improve the reliability of the scientists' results. (1 MARK)

Adapted from VCAA 2016 Section A Q6

3B TRANSPORT ACROSS MEMBRANES

The plasma membrane is like border control – it ensures only particular molecules enter and exit the cell.



In this lesson you will learn how molecules can be transported across the plasma membrane.

Study design dot point

- the fluid mosaic model of the structure of the plasma membrane and **the movement of hydrophilic and hydrophobic substances across it based on their size and polarity**

Key knowledge units

Passive transport	3.1.1.2
Active transport	3.1.1.3

Passive transport 3.1.1.2

OVERVIEW

Passive transport is the movement of molecules across a membrane without the use of energy. Diffusion, facilitated diffusion, and osmosis are the three types of passive transport.

passive transport the movement of molecules through a semipermeable membrane and down the concentration gradient, without an input of energy

selectively permeable a property of cell membranes that ensures only specific substances pass across them. Also known as **semipermeable**

diffusion the passive movement of molecules from areas of high concentration to areas of low concentration (down the concentration gradient)

THEORY DETAILS

A cell's plasma membrane is **selectively permeable**. This means that only certain substances can cross it, depending on their polarity, size, and concentration on either side of the membrane. This is important so that the cytosol can preserve an internal environment separately from the extracellular fluid.

Diffusion

Diffusion is the passive movement of molecules from an area of high concentration to an area of low concentration. If a molecule is very small (e.g. H_2O) and/or nonpolar (e.g. O_2, H_2, or CO_2) it can move freely across the plasma membrane via diffusion. Most of the plasma membrane is also nonpolar (in the form of fatty acid tails of phospholipids) so small, nonpolar molecules can slip through the phosphate heads and easily pass to the other side.

Molecules diffuse into or out of the cell depending on their concentration either side of the plasma membrane. Let's use O_2 as an example. If the extracellular fluid has a higher concentration of O_2 than the cytosol, then O_2 will diffuse into the cell. But, if the concentration of O_2 is higher inside the cell than outside the cell, O_2 will diffuse out of the cell into the extracellular fluid. As these small, nonpolar molecules always diffuse from areas of high to low concentration, we say they are moving 'down' their **concentration gradient**.

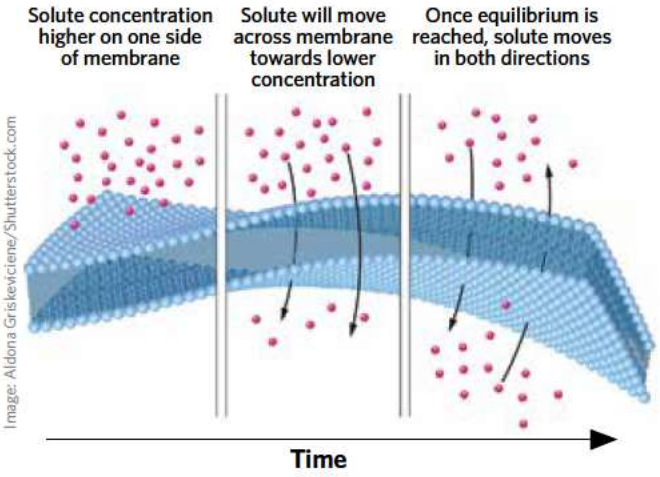


Figure 1 The diffusion of small, nonpolar molecules across the plasma membrane

Diffusion is faster when the concentration gradient is steeper – that is, when there is a greater difference in concentration between the intra- and extra-cellular environments. It will also speed up at higher temperatures.

Facilitated diffusion

Facilitated diffusion is the passive movement of molecules down their concentration gradient through a membrane protein. This occurs to large and/or polar molecules like glucose, potassium ions, and chloride. The charge and size of these molecules mean they cannot diffuse freely through the plasma membrane. Instead, they move through a **protein channel** or a **carrier protein**.

- Protein channels are pores or holes in the membrane that let a specific substance through. They open and close depending on whether the cell requires that substance or not.
- Carrier proteins bind to the substance that is being transported and undergo a conformational change to push the substance through to the other side of the membrane. They return to their original shape once the molecule has been transported.

Both channels and carrier proteins are specific to the molecule they allow through. This contributes to the selective permeability of the plasma membrane. Because facilitated diffusion can be faster than simple diffusion, some small and/or nonpolar molecules that can diffuse (like water) also have dedicated protein channels.

Osmosis

Osmosis is a type of diffusion. It occurs when water moves across a selectively permeable membrane from areas of low **solute** concentration to areas of high solute concentration. This is important as the semipermeable nature of the membrane means many solutes cannot cross it easily, but water can. So, if there is a high concentration of sugar molecules in the cytosol compared to the extracellular fluid, water (not sugar molecules) moves into the cell. This dilutes the sugar molecules until their concentration is equal both inside and outside the cell. The alternative is that the sugar molecules move through channels, but it can be easier to move the water.

To describe relative solute concentrations in adjacent compartments, biologists use the terms **hypertonic**, **isotonic**, and **hypotonic** (Figure 3). Hypertonic solutions have comparatively higher solute concentrations, so water moves into them from adjacent areas. Isotonic solutions have equal solute concentrations, so there is no net water movement. Hypotonic solutions have a comparatively low solute concentration, so water moves out of the region.

concentration gradient the difference in solute concentration between two adjacent areas

facilitated diffusion a type of passive transport where molecules move through a phospholipid bilayer with the aid of a membrane protein

protein channel a protein-based pore in a phospholipid bilayer that selectively enables transport of large or polar molecules

protein carrier a polypeptide that undergoes conformational change to transport molecules across a membrane

osmosis the passive transport of a solvent (typically water) through a semipermeable membrane from a hypotonic solution to a hypertonic solution

solute a substance dissolved in the solvent

solvent a liquid in which a solute is dissolved, forming a solution

hypertonic describes a solution with a higher solute concentration when compared to another

isotonic describes a solution with the same solute concentration when compared to another

hypotonic describes a solution with a lower solute concentration when compared to another

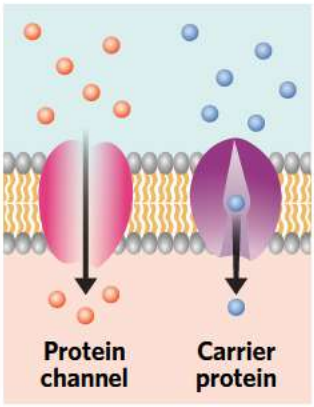


Figure 2 Facilitated diffusion using protein channels and carrier proteins

Analogy

Diffusion is something we can see (or smell) in everyday life. Think of a strong perfume (or an unwanted passing of gas). When someone sprays it, the perfume molecules are initially concentrated in one location. Over time, the molecules move to areas of low concentration, spreading throughout the room.

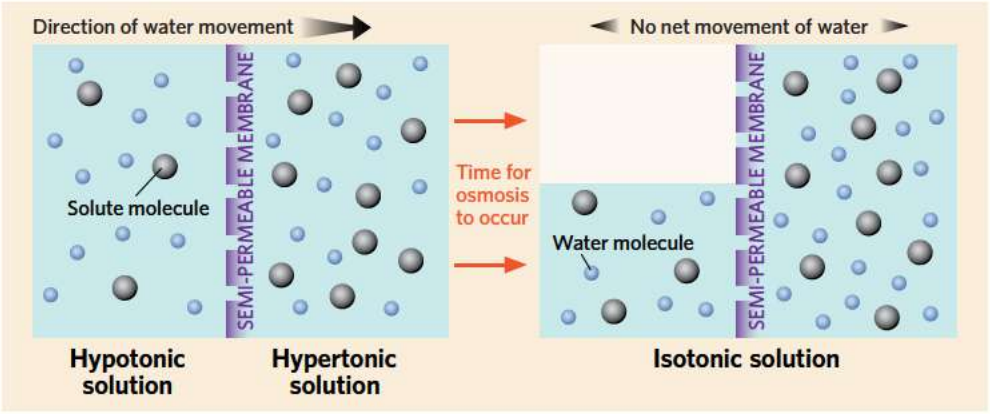


Figure 3 A model of osmosis from a hypotonic solution into a hypertonic solution, to create two isotonic solutions. Note that the volume of the hypotonic solution decreases as osmosis occurs.

lesson link There is a second type of energy-using transport called 'bulk transport' that you will explore in the next lesson (**3C**). It also requires energy to take place, but unlike membrane protein-mediated active transport, bulk transport moves molecules down or against their concentration gradient without the use of carrier proteins or protein pumps.

Case study

Tonicity

Tonicity can impact cell size. If a plant cell is hypertonic to extracellular fluid (Figure 4), water moves into a cell and it becomes turgid. The cell doesn't burst as it has a cell wall. When water moves out of a plant cell, the cell shrinks and becomes flaccid.

Regulating tonicity and osmosis are biologically very important. For example, plants change the turgidity of cells to open and close pores on their leaves called stomata. High turgor pressure in stems also prevents the plant from wilting. On the other hand, animal cells don't have cell walls. This means that they can increase in volume so much that they burst when placed in hypotonic solutions. This is one reason why, if you are placed on a drip in hospital, you are given a saline solution – not pure water.

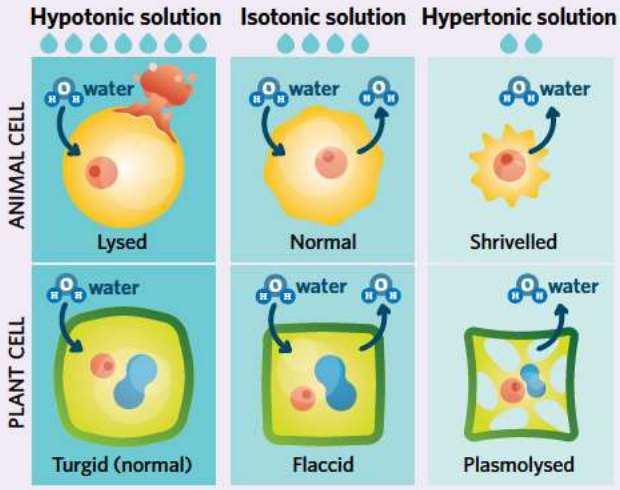


Image: VectorMine/Shutterstock.com

Figure 4 The effect of tonicity on animal and plant cells

Active transport 3.1.1.3

OVERVIEW

Active transport uses energy to move molecules across the plasma membrane against their concentration gradient. Molecules can be transported actively using either membrane proteins (this lesson) or bulk transport processes (next lesson, 3C).

THEORY DETAILS

Frequently, cells have lots of potassium ions – way more than the extracellular fluid. However, a cell may still require more. In this scenario, potassium ions must move against their concentration gradient to be taken into the cell. To achieve this, the cell must undertake **active transport**, which requires:

- energy, usually in the form of **ATP**
- membrane proteins, typically **protein pumps** but also carrier proteins.

The process of active transport occurs in the following three steps:

1. The target molecule that is specific to the protein pump binds to the protein.
2. Energy from ATP causes a conformational (shape) change to the protein pump.
3. This results in the target molecule being pushed through the protein and released to the other side of the membrane.

active transport the movement of molecules across a semipermeable membrane requiring an energy input

ATP adenosine triphosphate, a high energy molecule that, when broken down, provides energy for cellular processes

protein pump a polypeptide that transports molecules across a membrane against its concentration gradient with the aid of ATP

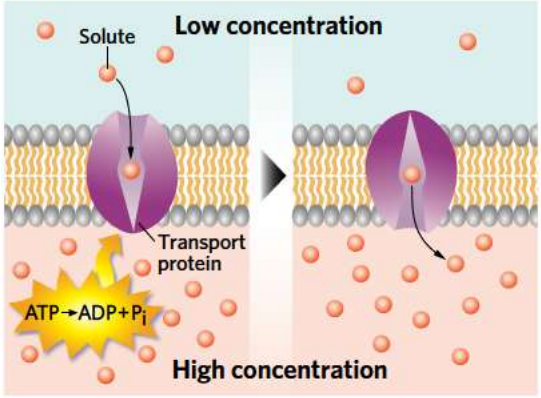


Figure 5 Active transport of molecules across a membrane against their concentration gradient

Case study

The Sodium–Potassium (Na^+/K^+) ion pump

The Na^+/K^+ protein pump maintains ideal concentrations of Na^+ and K^+ in the cell. It also plays a role in controlling the voltage of cell membranes, which is vital for passing on signals in neurons. The Na^+/K^+ pump works in four steps:

1. The cycle starts with the pump open to the cytoplasm, where it binds three Na^+.
2. ATP is hydrolysed into ADP + P_i, and the ADP is released. Energy from this reaction causes the pump to change shape and open to the extracellular space. In this new conformation, the pump does not have a high affinity for Na^+ so these ions are released.
3. Two K^+ are bound to the pump, and this triggers the release of the free-floating phosphate (left over from step 2).
4. The pump changes shape again, opening to the cytoplasm and releasing K^+. The cycle can start again.

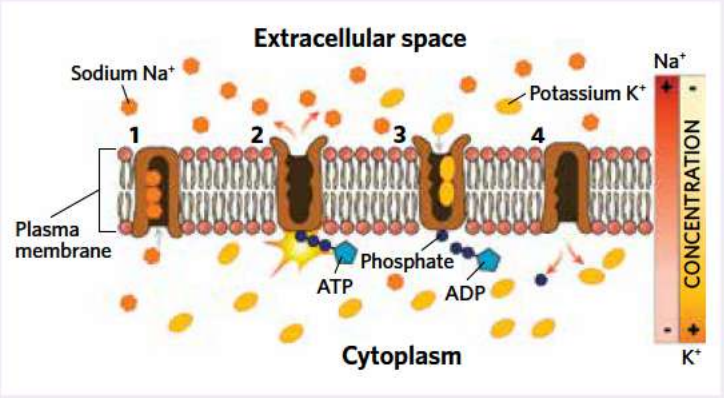


Figure 6 The mechanism of the Na^+/K^+ pump

Theory summary

Table 1 Summary of the different types of transport across the plasma membrane

	Requires energy?	Down or against concentration gradient?	Protein required?	Molecules involved
Osmosis	No	Down	No	H_2O
Diffusion	No	Down	No	Small, nonpolar molecules e.g. O_2, CO_2
Facilitated diffusion	No	Down	Channel or carrier protein	Large and/or polar molecules e.g. glucose, Na^+
Active transport	Yes	Against	Protein pump or carrier protein	Large or polar molecules

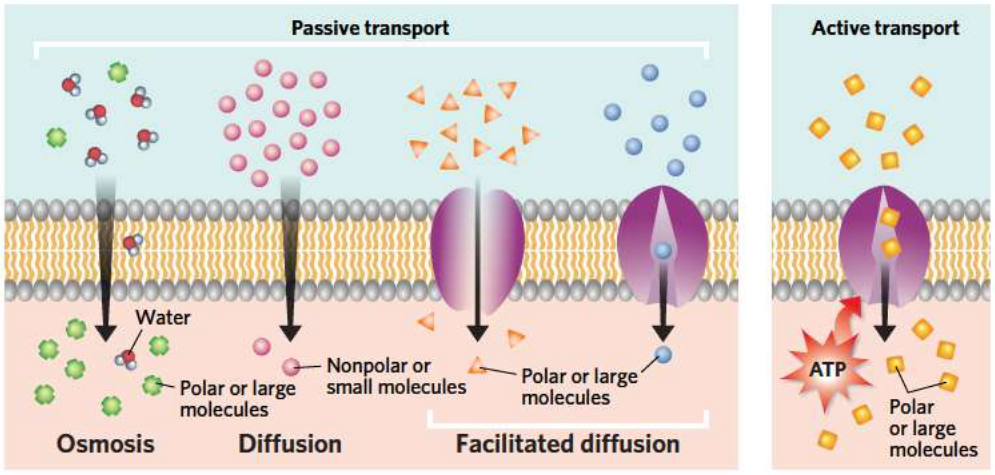


Figure 7 Diagrammatic summary of the types of transport across membranes

3B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ passive transport of water molecules across a phospholipid bilayer

b _____ membranes that only let specific molecules through

c _____ a type of passive transport that uses membrane proteins

d _____ transport across membranes that uses energy

e _____ a solution that has a lower solute concentration than another solution

f _____ the energy currency of the cell

g _____ a molecule that is dissolved in a solvent

Question 2

Which type of transport do the following diagrams represent?

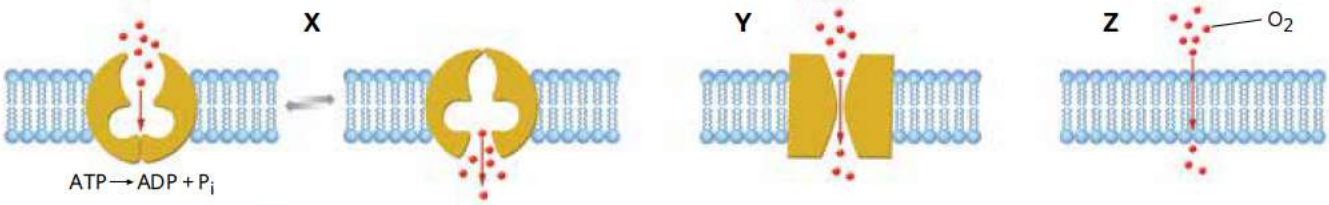


Image: Aldona Griskeviciene/Shutterstock.com

	X	Y	Z
A	Active transport	Facilitated diffusion	Osmosis
B	Active transport	Facilitated diffusion	Diffusion
C	Facilitated diffusion	Facilitated diffusion	Osmosis
D	Facilitated diffusion	Facilitated diffusion	Diffusion

Question 3

Fill in the blanks in the following sentences.

_____**I**_____ transport occurs when molecules move _____**II**_____ their concentration gradient _____**III**_____ the aid of ATP. Carrier proteins or _____**IV**_____ enable this process.

	I	II	III	IV
A	Active	down	with	protein pumps
B	Active	against	with	protein pumps
C	Passive	against	without	protein pumps
D	Passive	down	with	protein channels

Question 4

Red blood cells were placed in solutions M, N, and O. Which of the following options best describes the tonicity of each of the solutions?

	M	N	O
A	Isotonic	Hypertonic	Hypotonic
B	Hypotonic	Isotonic	Hypertonic
C	Isotonic	Hypotonic	Hypertonic
D	Hypotonic	Hypotonic	Hypertonic

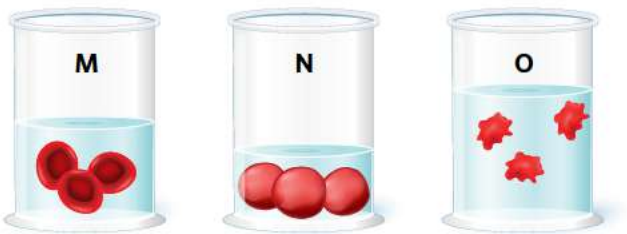
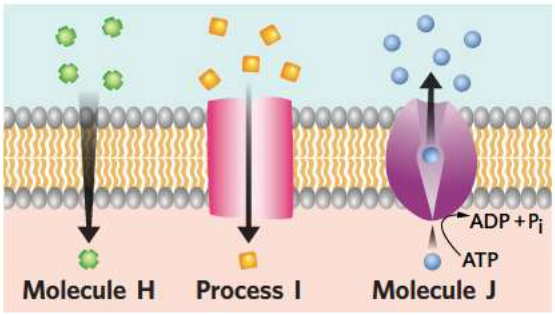


Image: Design a/Shutterstock.com

Question 5

Which of the following options correctly describes molecules H and J, and process I?

	H	I	J
A	Hydrophilic and small	Facilitated diffusion	Nonpolar
B	Water	Passive transport	Water
C	Hydrophobic	Active transport	Large and polar
D	Small and nonpolar	Facilitated diffusion	Ion



Exam-style questions

Within lesson

Question 6 (1 MARK)

Which of the following options best explains why certain individuals have trouble transporting glucose across the plasma membrane?

A These individuals do not have a fluid-mosaic plasma membrane.

B They are born with malfunctioning protein pumps in their plasma membranes.

C They are born with malfunctioning protein channels in their plasma membranes.

D These individuals rely on simple diffusion of glucose across the plasma membrane.

Adapted from VCAA 2017 Sample Exam Section A Q4

Question 7 (1 MARK)

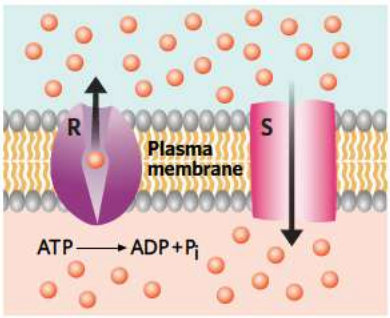
Consider the diagram of the plasma membrane. Which of the following statements is true about the diagram?

A R is an ion channel, S is an ion pump, and the diagram depicts ion movement across the plasma membrane.

B R is an ion pump, S is an ion channel, and the diagram depicts diffusion of ions across the plasma membrane.

C R is an ion pump, S is an ion channel, and the diagram depicts the movement of ions across the plasma membrane.

D R is involved in facilitated diffusion, S is an ion channel, and the diagram depicts the movement of polar molecules across the plasma membrane.



Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q6

Use the following information to answer Questions 8 and 9.

Rapid plant movements occur when plant structures such as leaves, flowers, or pollen move rapidly. For example, when the sensitive or 'tickle me' plant *(Mimosa pudica)* is touched by another organism, its leaves fold in upon themselves and its stems droop. This usually occurs in under one second. The leaves of *M. pudica* achieve this movement by changing turgor pressure. When 'extensor' cells have high turgor pressure, the leaves are open. When 'flexor' cells have high turgor pressure, the leaves are folded. High turgidity is achieved by pumping potassium and chloride ions into cells.

Image: sutham/Shutterstock.com

Question 8 (1 MARK)

Taking into consideration the opening and folding of the leaves, which one of the following statements is true?

A When the leaves are opening, water exits the extensor cells by osmosis.

B When the leaves are folding, water accumulates in flexor cells by active transport.

C When the leaves are folding, potassium and chloride ions are pumped into flexor cells by active transport.

D When the leaves are opening, potassium and chloride ions accumulate in flexor cells by facilitated diffusion.

Adapted from VCAA 2014 Section A Q11

Question 9 (1 MARK)

Pumping potassium and chloride ions into cells leads to turgidity because

A cells are filled with lots of potassium and chloride ions.

B water moves into areas of low solute concentration via osmosis.

C water moves into areas of high solute concentration via diffusion.

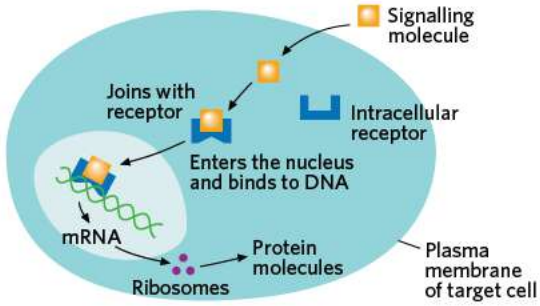
D water moves into areas of high solute concentration via osmosis.

Multiple lessons

Question 10 (12 MARKS)

Plasma membranes are selectively permeable boundaries found in every type of cell.

a Consider the diagram of a signalling molecule interacting within a target cell.



What evidence is there that the signalling molecule is hydrophobic? (1 MARK)

Adapted from VCAA 2018 Section A Q19

b Consider the diagram of the target cell's plasma membrane.

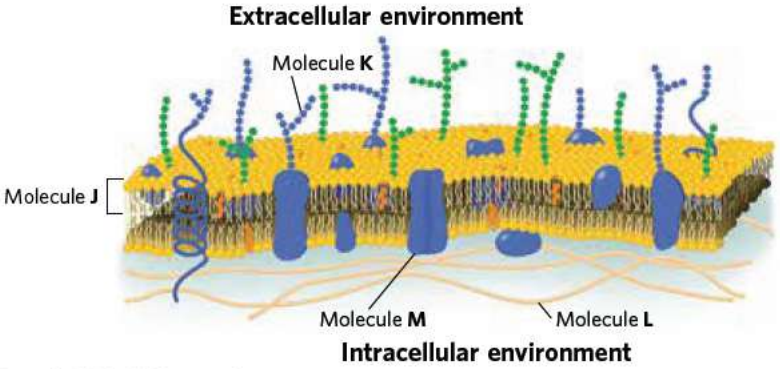


Image: Jamilia Marini/Shutterstock.com

i Draw an arrow of the path taken by the signalling molecules across the plasma membrane. (1 MARK)

ii Justify the pathway you have described. (2 MARKS)

iii Identify and outline the functions of Molecules J, K, and L. (3 MARKS)

iv Molecule M is a GLUT2 protein channel. Explain how GLUT2 enables facilitated diffusion of glucose. (2 MARKS)

Adapted from VCAA 2014 Exam 1 Section B Q3b

v Referring to structure and charge, explain why the phospholipid bilayer is an ideal boundary for the cell. (3 MARKS)

Adapted from VCAA 2017 Section B Q1a

Key science skills

Question 11 (10 MARKS)

Kinji read that you can observe the process of osmosis using a shell-less chicken egg.

Using a standard technique, she dissolved the eggshells of six eggs in acid. She then rinsed the eggs, measured their circumference, weighed them, and noted observations about their firmness.

She placed two eggs in a solution of pure corn syrup, another two eggs in a solution with 1.5 tablespoons of corn syrup and distilled water, and the final two eggs in pure distilled water. She left the eggs in their solutions for 24 hours.

At the end of the experiment, Kinji re-weighed the eggs, measured their circumference again, and noted observations about their firmness.

The diagram shows the set-up of Kinji's experiment.

Image: Designua/Shutterstock.com

a State the hypothesis Kinji was testing. (1 MARK)

b Identify three variables that would need to be controlled to ensure the experiment produced a valid result. (3 MARKS)

c State the independent variable and dependent variable in this experiment. (2 MARKS)

d What results would disprove the hypothesis of Kinji's experiment? (1 MARK)

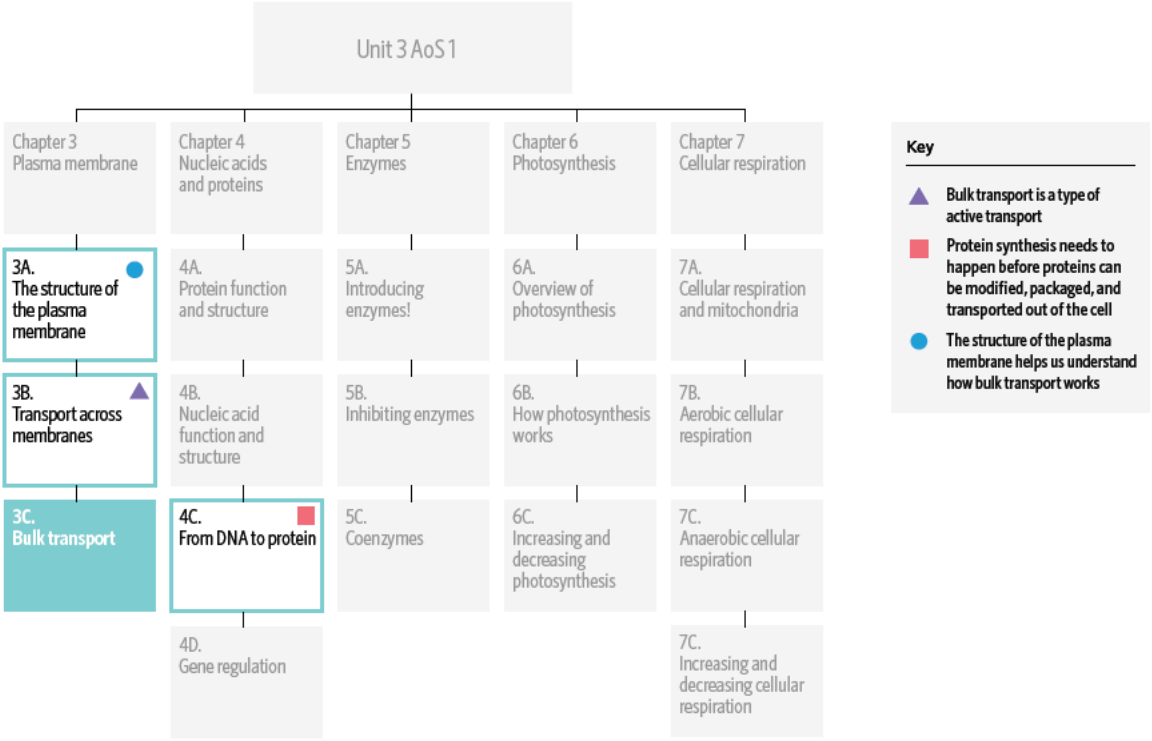
e Outline a further experiment Kinji could conduct that would determine the solute concentration inside the egg. (2 MARKS)

f Rick, a hard-nosed peer of Kinji's, said that even if Kinji completed the additional experiment and if all of those results supported the hypothesis, there may still be other plausible explanations for the results. Identify an explanation to which Rick could be referring, and suggest how this limitation could be overcome. (1 MARK)

Adapted from VCAA 2018 Section B Q11

3C BULK TRANSPORT

You know when you go to the supermarket for just one or two things and then suddenly have an armful? It's moments like these you need a trolley – or, in the case of a cell, a vesicle.



In this lesson you will learn that bulk transport is a type of active transport for moving large molecules or groups of molecules across the plasma membrane. It occurs in two ways: exocytosis and endocytosis.

Study design dot points

- the role of different organelles including ribosomes, endoplasmic reticulum, Golgi apparatus, and associated vesicles in the export of a protein product from the cell through exocytosis
- cellular engulfment of material by endocytosis

Key knowledge units

How protein packaging and exocytosis work	3.1.2.1
How endocytosis works	3.1.3.1

How protein packaging and exocytosis work 3.1.2.1

OVERVIEW

Proteins are made on ribosomes, then folded in the rough endoplasmic reticulum, modified and packaged for export by the Golgi body, then transported out of the cell by vesicles during exocytosis.

THEORY DETAILS

Bulk transport is a type of **active transport** that moves large molecules or groups of molecules – such as amino acids, **proteins**, signalling molecules, or pathogens – in or out of the cell. There are two types of bulk transport: exocytosis, which involves molecules exiting the cell, and endocytosis which involves molecules entering the cell.

Exocytosis

Exocytosis is the process by which the contents of a vesicle are released from a cell.

bulk transport the type of active transport that uses vesicles to move large molecules or groups of molecules into or out of the cell

active transport the movement of molecules across a semipermeable membrane requiring an energy input

protein a type of biomacromolecule made of amino acid chains folded into a 3D shape

exocytosis a type of bulk transport that moves large substances out of the cell

This is an important process because cells need to release waste products, hormones, neurotransmitters, antibodies, and other molecules that can't fit through a protein channel.

There are three steps in exocytosis:

1 A **vesicle** containing **secretory products** is transported to the plasma membrane.

2 The membranes of the vesicle and cell fuse.

3 The secretory products are released from the cell.

vesicle a small fluid-filled organelle enclosed in a phospholipid membrane that transports substances around the cell

secretory products the substances inside a vesicle that are being transported out of the cell

ribosome an organelle made of rRNA and protein that is the site of protein synthesis. Can be free or attached to RER

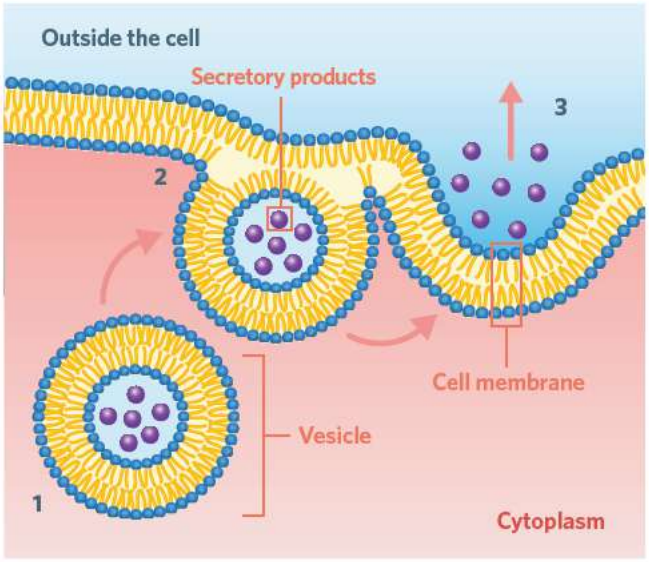


Image: Fancy Tapis/Shutterstock.com

Figure 1 The process of exocytosis

Exocytosis is possible because the plasma membrane is fluid, so it can fuse with the phospholipid bilayers of a vesicle. When a vesicle fuses with the plasma membrane, it adds phospholipids to the bilayer and makes the plasma membrane surface area bigger.

The pathway of proteins

Proteins such as enzymes, hormones, and antibodies are secreted from the cell via exocytosis. For VCE Biology, you need to be able to explain how a protein made at a **ribosome** can travel through various organelles to eventually be secreted via exocytosis (Figure 2 and Table 1)

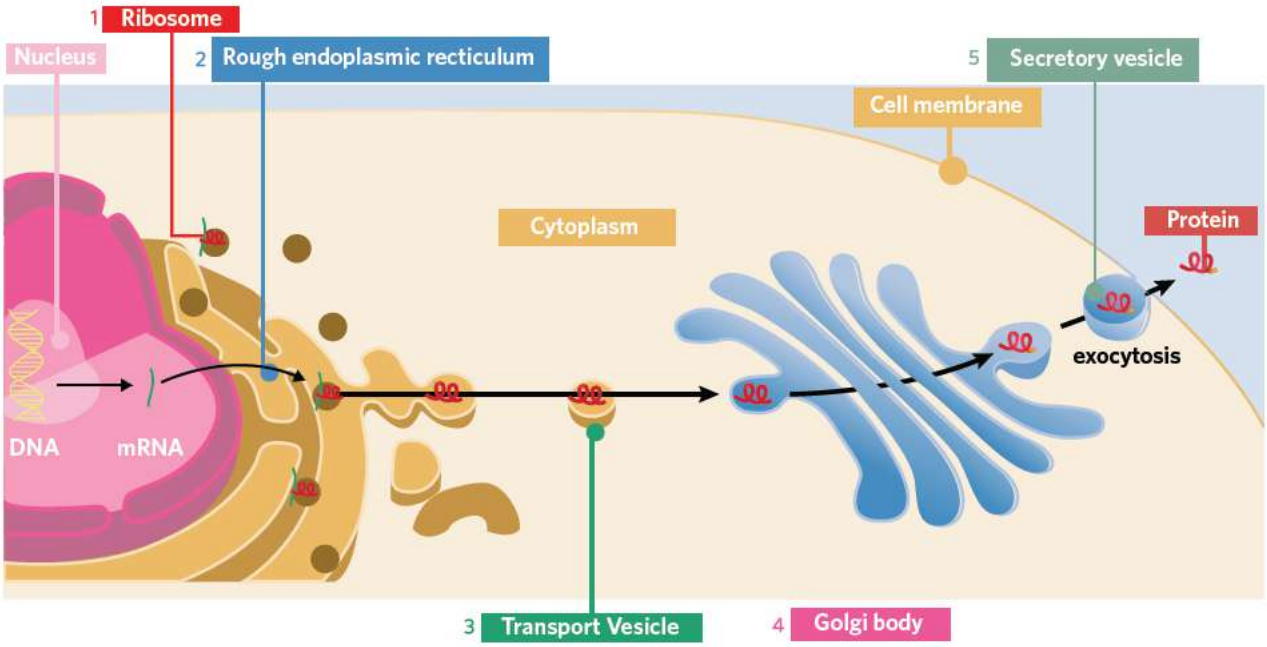


Figure 2 Diagram showing protein packaging for exocytosis and the organelles involved

Table 1 The function of key organelles involved in protein secretion

Step	Organelle	Function	Explanation
1	**Ribosome**	Synthesises proteins	The ribosome is the site of protein synthesis. Ribosomes assemble polypeptide chains from amino acids by translating mRNA.
2	**Rough endoplasmic reticulum (RER)**	Folds and transports proteins	If a protein is destined to be secreted, the ribosome is usually attached to the RER (rather than being free in the cytoplasm). The environment inside the **rough endoplasmic reticulum** allows for correct folding of the newly formed proteins before being passed through to the **Golgi body**.
3	**Transport Vesicle**	Transports proteins	A transport vesicle containing the protein buds off the RER and travels to the Golgi body. The vesicle fuses with the Golgi membrane and releases the protein into the lumen.
4	**Golgi body**	Modifies and packages proteins	Proteins can have chemical groups added or removed at the Golgi body, then they are packaged into vesicles for exocytosis.
5	**Secretory Vesicle**	Transports proteins	The secretory vesicle containing proteins for secretion pinches off the Golgi body, travels through the cytoplasm, and fuses with the plasma membrane (exocytosis). This releases the proteins into the extracellular space.

Other organelles are involved in protein packaging for exocytosis, but to a lesser extent. For example, **mitochondria** are the site of ATP synthesis so all the energy required to move the vesicles around and modify the proteins is generated there. The plasma membrane is also a key organelle involved in exocytosis, as vesicles fuse with it to allow release of the protein. Additionally, the nucleus stores DNA which contains the instructions for how to make a protein. These instructions are sent to ribosomes via mRNA.

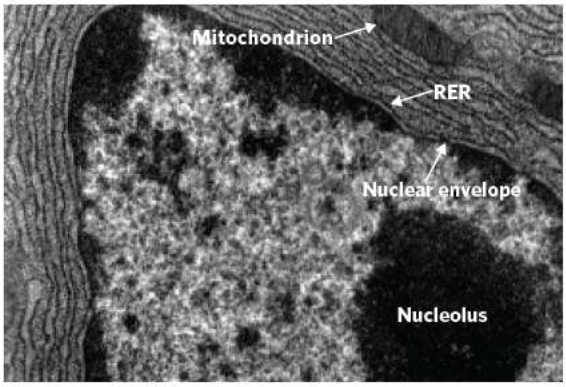


Figure 3 Electron micrograph showing RER, mitochondria, and the nucleus

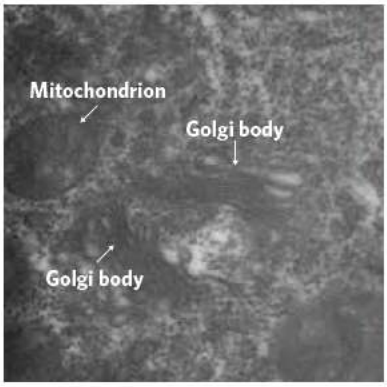


Figure 4 Electron micrograph showing Golgi bodies and mitochondrion

How endocytosis works 3.1.3.1

OVERVIEW

Endocytosis is the opposite of exocytosis. It is the bulk transport mechanism for substances being transported from the extracellular fluid into vesicles within the cell.

THEORY DETAILS

Endocytosis involves transporting large molecules or groups of molecules into the cell. The process is essential because many molecules that the cell needs to survive are too large to take in through protein channels in the plasma membrane. Once inside the cell, these substances can be used for metabolic processes or structural elements of the cell. Endocytosis can also be an effective defence mechanism. If a cell engulfs an invader or toxin, it can destroy it inside a **lysosome**.

lesson link Can't remember the structure of these organelles? Both RER and the Golgi body are flat, membranous sacs. Check ***Lesson 2A*** for details!

rough endoplasmic reticulum (RER) a membranous organelle shaped like a series of connected, flattened cylinders that folds and transports proteins

Golgi body an organelle made of flattened sacs of membrane involved in modifying, sorting, and packaging proteins

mitochondrion (pl. mitochondria) a double-membraned organelle that is the site of aerobic respiration

endocytosis a type of bulk transport that moves large substances into the cell

lysosome a vesicle containing digestive enzymes

There are three basic steps in endocytosis:

1 Fold: the plasma membrane folds inwards to form a cavity that fills with extracellular fluid and the target molecules.

2 Trap: the plasma membrane continues folding back on itself until the two ends of the membrane meet and fuse. This traps the target molecules inside the vesicle.

3 Bud: the vesicle (or endosome) pinches off from the membrane. It can then be transported to the appropriate cellular location or fused with a lysosome for digestion.

phagocytosis endocytosis of solid material or food particles

pinocytosis endocytosis of liquid or dissolved substances

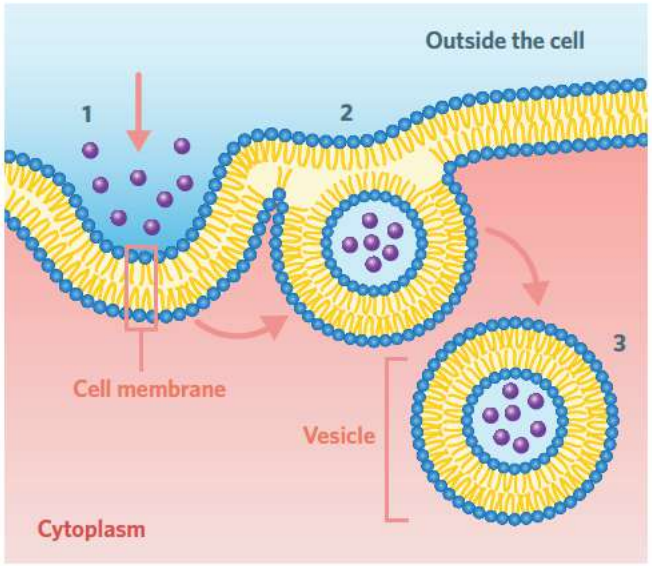


Image: Fancy Tapis/Shutterstock.com

Figure 5 The process of endocytosis

Note that endocytosis takes phospholipids away from the plasma membrane, so if large amounts of endocytosis occur the cell could shrink.

There are several types of endocytosis. In particular, you should know about **phagocytosis**. Phagocytosis ('cell eating') is the endocytosis of solid materials or food particles. This is what occurs when immune cells like macrophages engulf invading microorganisms. In contrast, **pinocytosis** ('cell drinking') is the process of engulfing molecules dissolved in extracellular fluid.

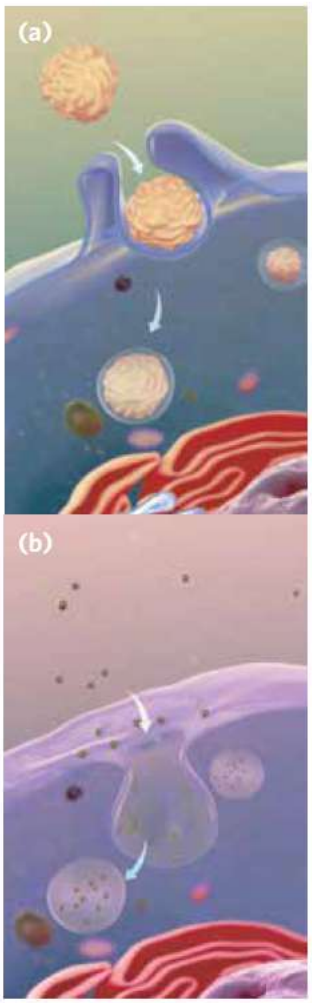


Figure 6 Two types of endocytosis: **(a)** phagocytosis; **(b)** pinocytosis

Theory summary

Exocytosis transports large molecules or groups of molecules out of cells using vesicles, while endocytosis transports them into cells. Collectively, these processes are termed bulk transport and are a form of active transport. You should also remember that proteins are a common substance for exocytosis. They are made at ribosomes, folded in the RER, then transported via transport vesicles to the Golgi body. Here, they may be modified before being packaged into a secretory vesicle. This secretory vesicle fuses with the plasma membrane, releasing the proteins into the extracellular fluid via exocytosis.

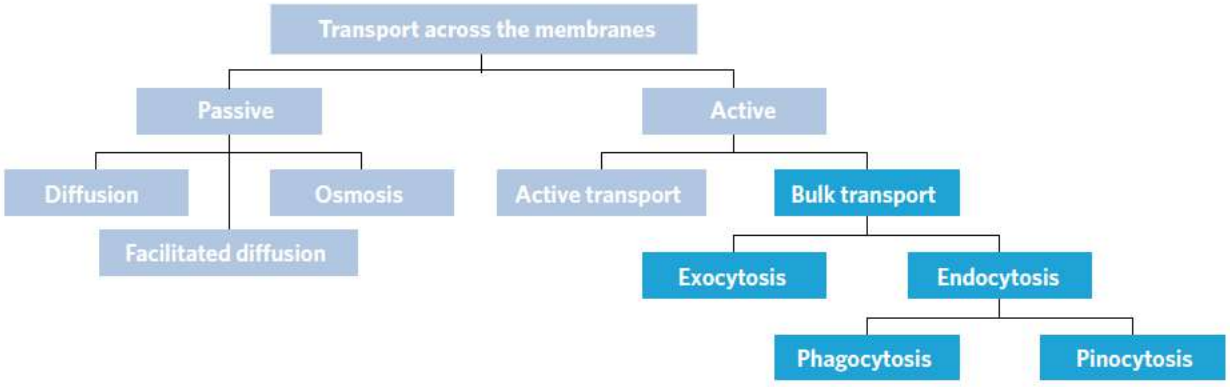


Figure 7 The types of transport across membranes

3C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ transport of large molecules out of a cell using vesicles

b _____ transport of large molecules or groups of molecules in or out of the cell

c _____ transport across the plasma membrane using energy

d _____ transport of large molecules into a cell using vesicles

e _____ a small, membrane-bound structure that transports proteins around the cell

f _____ an organelle that modifies and packages proteins

g _____ an organelle that folds and transports proteins

Question 2

Identify the correct labels for the following processes.

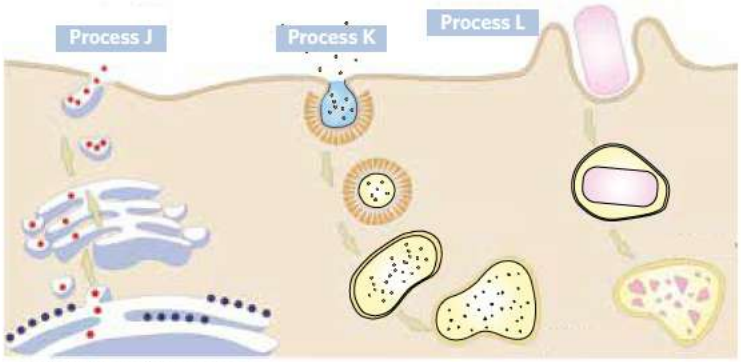


Image: Soleil Nordic/Shutterstock.com

	J	K	L
A	Endocytosis	Pinocytosis	Endocytosis
B	Exocytosis	Pinocytosis	Phagocytosis
C	Exocytosis	Phagocytosis	Pinocytosis
D	Protein secretory pathway	Pinocytosis	Endocytosis

Question 3

Identify the organelles in the image.

	D	E	F
A	vesicle	rough endoplasmic reticulum	proteins
B	endosome	Golgi apparatus	proteins
C	vesicle	Golgi body	rough endoplasmic reticulum
D	vesicle	Golgi complex	ribosomes

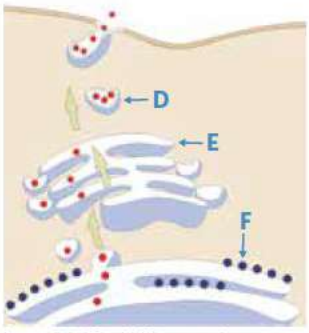


Image: Soleil Nordic/Shutterstock.com

Question 4

Which of the following options does not pair the organelle with its function?

	Organelle	Function
A	Lysosome	Contains digestive enzymes for breaking down toxins, pathogens, waste products, or malfunctioning molecules
B	Golgi body	Folds proteins
C	Vesicle	Transports proteins
D	Ribosome	Synthesises proteins

Question 5

Fill in the blanks in the following sentences.

_____**I**_____ involves transporting large molecules into the cell. _____**II**_____ is a type of endocytosis where solid substances like bacteria are engulfed, whereas solutes are engulfed in _____**III**_____. All these processes can _____**IV**_____ the total cell surface area.

	I	II	III	IV
A	Endocytosis	Phagocytosis	pinocytosis	decrease
B	Endocytosis	Pinocytosis	phagocytosis	decrease
C	Endocytosis	Phagocytosis	pinocytosis	increase
D	Exocytosis	Phagocytosis	pinocytosis	increase

Exam-style questions

Within lesson

Question 6 (1 MARK)

All specialised cells that secrete protein molecules

A have minimal ribosomes.

B contain numerous vacuoles.

C do not have a fluid-mosaic plasma membrane.

D have an extensive rough endoplasmic reticulum.

Question 7 (1 MARK)

Which one of the following statements is false?

A Protein export involves vesicular transport of proteins out of the cell.

B Protein export involves the fusion of vesicles with the plasma membrane.

C Protein export involves specialised vesicles transporting specific proteins.

D Protein export involves sorting and modification of proteins at the Golgi apparatus.

Question 8 (1 MARK)

Gastrin is a peptide hormone that is released from cells in the stomach, duodenum, and pancreas. It aids digestion by stimulating the secretion of gastric acid by cells that line the stomach.

One pathway for the production of gastrin is

A nucleus – ribosome – endoplasmic reticulum – vesicle – Golgi apparatus

B nucleus – ribosome – Golgi apparatus – vesicle – endoplasmic reticulum

C nucleus – vesicle – endoplasmic reticulum – Golgi apparatus – ribosome

D nucleus – Golgi apparatus – endoplasmic reticulum – vesicle

Use the following information to answer Questions 9 and 10.

The diagram pictured shows the structure of organelles in a cell.

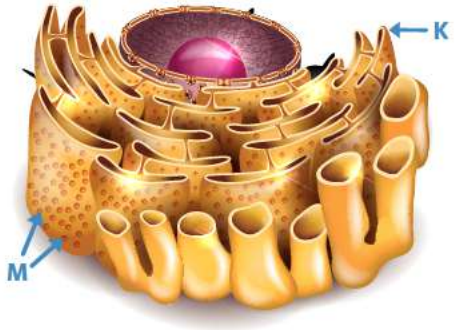


Image: Tefi/Shutterstock.com

Question 9 (1 MARK)

The organelle K

A folds and dispatches protein.

B is involved in the production of lipids.

C contains numerous vesicles for protein transport.

D synthesises most of the ATP molecules required for active transport.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q1

Question 10 (1 MARK)

The organelle M

A is only made of protein.

B contains many phospholipids.

C is the site of protein modification.

D can also exist in the cytosol, unattached to organelles.

Question 11 (1 MARK)

B lymphocytes are a type of immune cell that produce large amounts of antibodies. Antibodies are a type of protein that bind to and deactivate foreign substances like bacteria or toxins.

B lymphocytes

A undertake large amounts of endocytosis.

B have extensive networks of endoplasmic reticulum.

C must use facilitated diffusion to transport antibodies out of the cell.

D do not have a Golgi apparatus, as they are specialised to make one type of protein.

Adapted from VCAA 2015 Section B Q5c

Question 12 (4 MARKS)

In animal cells, tight junctions are multi-protein complexes that mediate cell-to-cell adhesion and regulate transport through the extracellular matrix. Proteins that form these complexes are made within the cell.

a Identify the cellular structure where the primary structure of these proteins are made. (1 MARK)

b Outline the pathway of exocytosis of this protein. (3 MARKS)

Adapted from VCAA 2016 Section A Q7

Multiple lessons

Question 13 (1 MARK)

Streptococcus pneumoniae is a bacterium that causes pneumonia. The disease causes the lungs' air sacs to become inflamed and filled with fluid. Which of the following process(es) correctly shows how *Streptococcus pneumoniae* enters through the plasma membrane?

A R
B S
C U
D T & U

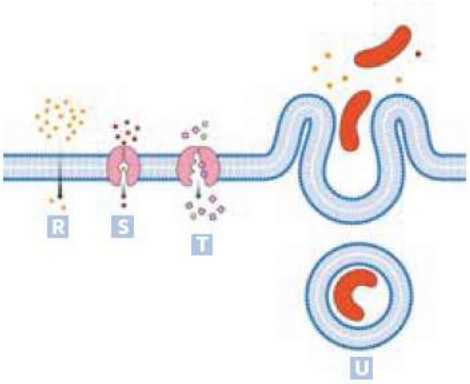


Image: Aldona Griskeviciene/Shutterstock.com

Question 14 (4 MARKS)

Novel nanomaterials called 'nanomedicines' are being developed to diagnose and treat disease. To work, nanomedicines must enter a cell and interact with particular sub-cellular molecules. Nanomedicines gain entry into target cells through endocytosis.

a Draw a labelled diagram to illustrate endocytosis of nanomedicines into target cells. (2 MARKS)

b Some scientists are concerned that after endocytosis, the nanomedicine may be destroyed by the cell. Explain how this might occur. (2 MARKS)

Adapted from VCAA 2018 Section B Q4a

Key science skills

Question 15 (10 MARKS)

Alzheimer's disease is a progressive brain disorder that causes problems with memory, thinking, and behaviour. It is characterised by a build-up of beta-amyloid around neurons. A group of scientists hypothesised that increased endocytosis by neurons of amyloid precursor protein (APP) may contribute to the accumulation of beta-amyloid.

The scientists cultured neurons from mice and aged them *in vitro*. The neurons undergo three developmental stages: they develop axons and dendrites after a week, reach peak maturation at 21 days, and exhibit aging at 28 days. The researchers compared 21-day-old neurons with 28-day-old ones for differences in APP endocytosis and beta-amyloid levels.

a Identify the
  i independent variable. (1 MARK)
  ii dependent variables. (1 MARK)

b What is meant by the term *'in vitro'*? (1 MARK)

c One researcher suggested that they measure the amount of endocytosis by measuring the size of the plasma membrane of the neurons. Evaluate how this suggestion could be both effective and ineffective. (2 MARKS)

d The scientists found that aged neurons had 50% more beta-amyloid, double the amount of APP endocytosis, and larger vesicles.
  i Do these results support or disprove the scientist's hypothesis? Justify your response. (2 MARKS)
  ii Explain why the size of vesicles may be significant. (1 MARK)
  iii Identify and explain one limitation of these results. (2 MARKS)

ACTIVITY

Movement of substances across a plasma membrane

This practical activity asks you to apply your knowledge and understanding of the structure of the plasma membrane and the movement of substances (namely sodium chloride and water) across it based on their size and polarity. The exercise also asks you to formulate a hypothesis, which is an important part of the scientific method. You will undertake an experiment to investigate the movement of water across a membrane in response to a solute concentration gradient. The content focus of the practical activity is diffusion and osmosis, and the structure and function of membranes.

Introduction

An unfertilised egg is a single, very large cell. It is surrounded by a cell membrane just as any other cell is. The shells of the eggs used in this experiment are removed using vinegar, which dissolves the shell but will not interfere with the function of the membrane in the experiment. (Natural sultanas can be used as an alternative to deshelled eggs in this investigation.)

Materials and apparatus

- 3 eggs
- 5% NaCl solution
- 10% NaCl solution
- Distilled water
- Spoon
- Electronic balance
- 3 beakers
- 3 jars
- Vinegar
- Paper towel

Aim

To investigate the movement of water across a membrane in response to a solute concentration gradient.

Preparation (may be conducted by the laboratory technician)

1. Pour 1 cup of vinegar into each of the three jars (alternatively, use a weak acid solution).
2. Add an egg to each jar. You will notice bubbles rising from the shell. These bubbles are carbon dioxide (CO_2), which is formed by the reaction between the calcium carbonate in the shell and the acid in the vinegar.
3. Leave the eggs in the vinegar for 24 hours. Don't leave them there for any longer as the pH of the vinegar will eventually alter the structure of some of the proteins in the plasma membrane.
4. Remove the eggs, examine them, and feel gently to make sure the shells are gone.

Procedure

1. Very carefully pick up a deshelled egg with a spoon, rinse it with distilled water, and allow it to drip-dry on a paper towel.
2. Carefully weigh the first egg using a balance. Record your results in the table provided or in a spreadsheet.
3. Repeat steps 1 and 2 for the two other eggs.
4. Place the first egg in a beaker containing 10% NaCl solution.
5. Place the second egg into a beaker with 5% NaCl solution.
6. Place the third egg in a beaker with distilled water. Make sure that there is the same volume of solution in each beaker and that the egg is completely submerged.
7. Leave the eggs in the solutions for 10 minutes. While waiting, answer question 1 (below). After the 10 minutes are up, remove the eggs, rinse carefully, and allow them to drip dry for a minute.
8. Weigh the eggs again and record the mass. (Be sure to keep track of which solution each egg was in).

Questions

1. While waiting for your results, write a hypothesis that relates to the aim.
2. Draw out the table in your logbook, and complete it by calculating the change in mass of each egg.

Solution	5 % NaCl	10 % NaCl	Distilled water
Initial mass			
Final mass			
Mass gain/loss			
Percent mass gain/loss			

3 Write a concluding paragraph that specifically addresses the extent to which you have met the aim of this practical investigation.

4 Explain any changes that you observed in the mass of the eggs, based on your understanding of osmosis.

5 Estimate the solute concentration of the egg's cytoplasm. Explain how you arrived at your estimation.

6 If the eggs were elongated (like a sausage) rather than ovate (the shape of an egg), would you expect your results to be different? Justify your answer.

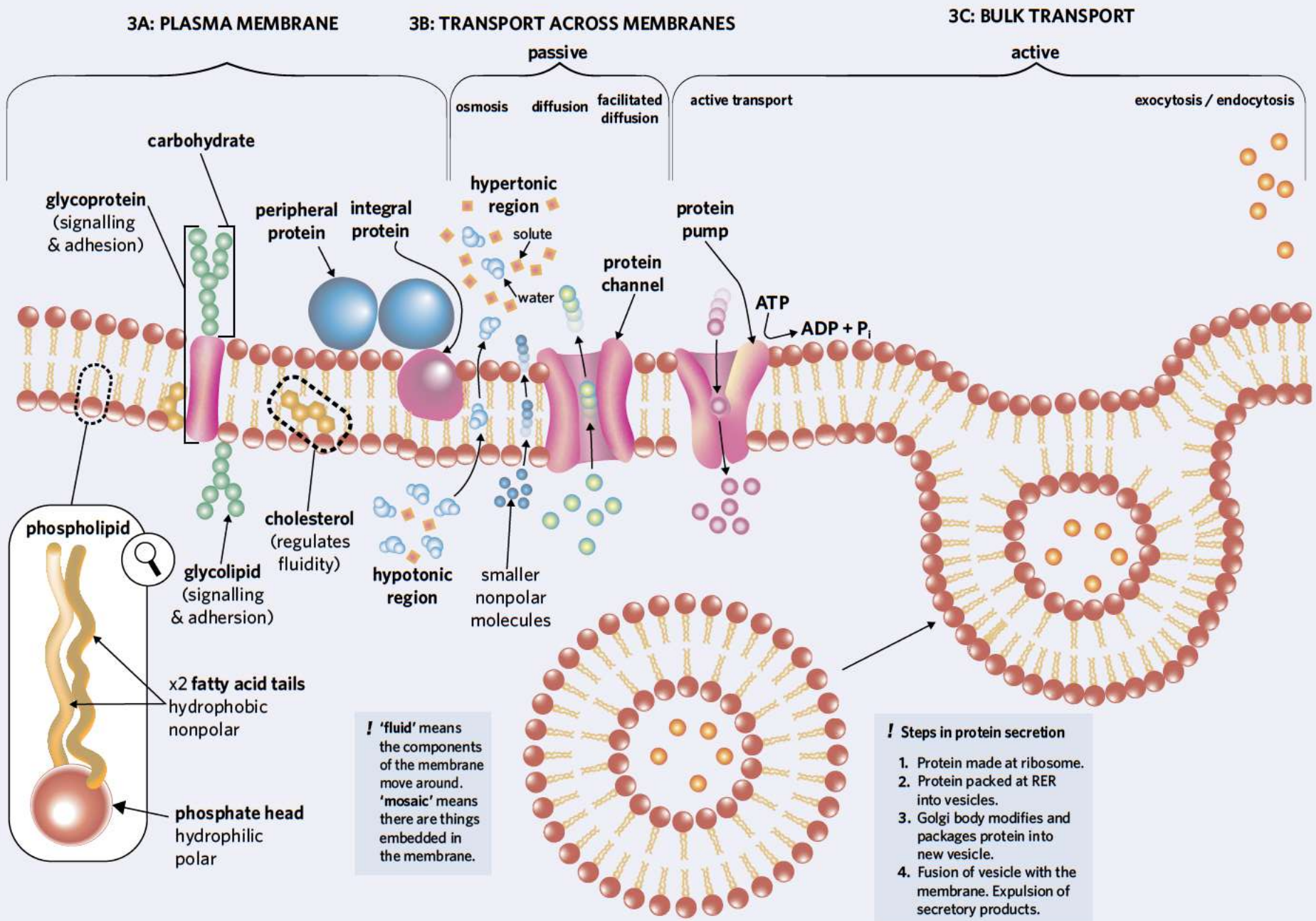
7 If an egg was left in distilled water overnight, what do you predict would happen? Why?

8 Suppose that an egg was placed for half an hour in 10% NaCl solution and then taken and placed in distilled water for half an hour.

- **a** What overall change do you predict for the egg (at the end of that hour)? Why?
- **b** Suggest how the rate of mass change of this egg might differ from the rate of mass change that was observed in the egg that you placed only in distilled water.

9 Critically evaluate the experiment that you have performed.

- **a** Discuss any weaknesses and strengths that you can see in the experimental design
- **b** Discuss any possible sources of error.
- **c** Discuss any limitations to the usefulness/relevance of the data. Try to account for any unexpected results.
- **d** Are there any aspects of the practical investigation that could be further investigated? If so, how might this be done?
- **e** Do you think that the results you obtained support your hypothesis? How strongly?

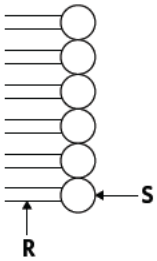

3A: PLASMA MEMBRANE
3B: TRANSPORT ACROSS MEMBRANES
3C: BULK TRANSPORT
passive
active
osmosis
diffusion
facilitated diffusion
active transport
exocytosis / endocytosis
carbohydrate
glycoprotein (signalling & adhesion)
peripheral protein
integral protein
hypertonic region
solute
water
protein channel
protein pump
ATP
ADP + Pi
phospholipid
glycolipid (signalling & adhersion)
cholesterol (regulates fluidity)
hypotonic region
smaller nonpolar molecules
x2 fatty acid tails
hydrophobic
nonpolar
phosphate head
hydrophilic
polar
! 'fluid' means the components of the membrane move around. 'mosaic' means there are things embedded in the membrane.
! Steps in protein secretion
1. Protein made at ribosome.
2. Protein packed at RER into vesicles.
3. Golgi body modifies and packages protein into new vesicle.
4. Fusion of vesicle with the membrane. Expulsion of secretory products.

CHAPTER REVIEW QUESTIONS

SECTION A (15 MARKS)

Question 1 (1 MARK)

Six molecules that form part of the plasma membrane of an animal cell are shown.



Which one of the following statements is false?

A The R portions of the molecules are not on the outer surface of the cell.
B The S portions of the molecules represent the hydrophilic phosphate heads.
C The molecules made of S and R do not remain in a fixed position within the membrane.
D The S and R portions of the molecules together allow for the easy transport of hydrophilic molecules.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q4

Question 2 (1 MARK)

Substances that cannot move by diffusion directly through the phospholipid bilayer of the plasma membrane include

A carbon dioxide molecules.
B oxygen molecules.
C water.
D H^+.

Adapted from VCAA 2018 Section A Q1

Question 3 (1 MARK)

Substances that move through channels in the phospholipid bilayer of the plasma membrane include

A chloride ions, down their concentration gradient.
B chloride ions, against their concentration gradient.
C all polar molecules, down their concentration gradient.
D oxygen molecules, against their concentration gradient.

Adapted from VCAA 2018 Section A Q1

Question 4 (1 MARK)

Molecules can move across the plasma membrane in various ways. Which of the following molecules are most likely to cross the plasma membrane by passing between the phospholipid molecules within the membrane?

A Polar molecules
B Transport proteins
C Hydrophobic molecules
D Molecules of ribonucleic acid

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q2

Use the following information to answer Questions 5–8.

Consider the diagram.

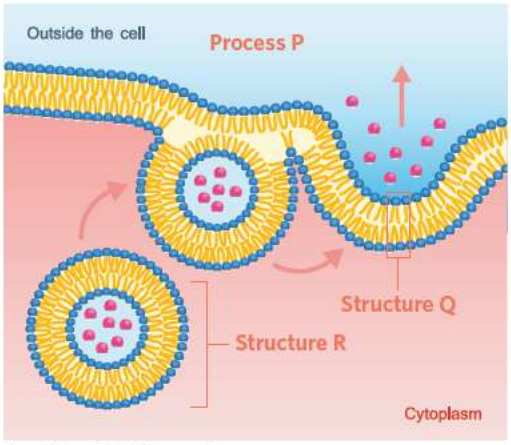


Image: Fancy Tapis/Shutterstock.com

Question 5 (1 MARK)

Process P is an example of

A phagocytosis.
B pinocytosis.
C exocytosis.
D endocytosis.

Question 6 (1 MARK)

Structure Q

A is hydrophobic.
B is the site of facilitated diffusion.
C can be embedded with proteins, glycoproteins, and cholesterol.
D packages and sorts protein molecules for export from the cell.

Question 7 (1 MARK)

Structure R could not

A carry modified protein molecules.
B contain a phospholipid bilayer.
C fuse with the plasma membrane.
D be transported through extracellular fluid by microtubules.

Question 8 (1 MARK)

Excluding the structures already pictured, the export of proteins by this cell would involve

A vesicles.
B lysosomes.
C chromosomes.
D the Golgi apparatus.

Adapted from VCAA 2014 Section A Q3

Question 9 (1 MARK)

Both fungi and plant cells have plasma membranes. Consider the structure of plasma membranes in plant cells.

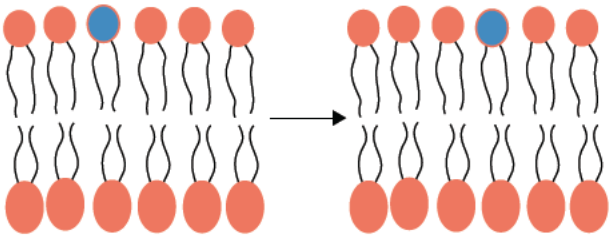
The plasma membranes of plant cells

A only use passive transport.
B are involved in endocytosis.
C have a cellulose structure similar to fungi cells.
D have a phospholipid bilayer that is very different from fungi.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q3

Question 10 (1 MARK)

Scientists observed a phospholipid (indicated in blue) in a plasma membrane over time and recorded what they observed in the diagram pictured.



The redistribution of phospholipids in the plasma membrane can be explained by

A the fluid mosaic model.
B movement due to osmosis.
C the presence of cholesterol in the plasma membrane.
D the active transport of phospholipids across the plasma membrane.

Adapted from VCAA 2016 Section A Q6

Use the following information to answer Questions 11 and 12.

In some plants, a modified leaf forms an insect trap. 'Motor cells' are located along the midrib of the modified leaf. In their resting state, these cells are turgid and contain potassium ions at a concentration higher than the surrounding fluid. When the trap is triggered, potassium ions stream out of the motor cells through ion channels and the motor cells lose their turgidity. The pressure in the surrounding cells then causes the modified leaf to bend and so the trap closes.

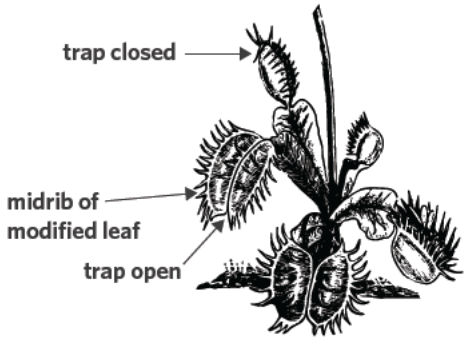


Image: Morphart Creation/Shutterstock.com

Question 11 (1 MARK)

Taking into consideration the opening and closing of the trap, turgidity

A increases in motor cells when the trap is closing.
B refers to the rigidity of the cell wall of motor cells.
C refers to the equalisation of potassium ion concentration in the motor cells and surrounding cells.
D increases in motor cells when they have a higher concentration of potassium ions than surrounding cells.

Adapted from VCAA 2014 Section A Q11

Question 12 (1 MARK)

Taking into consideration the opening and closing of the trap, which one of the following statements is false?

A When the trap is closing, water leaves the motor cells by osmosis.
B When the trap is opening, water increases the turgidity in motor cells.
C When the trap is opening, potassium ions enter the motor cells by bulk transport.
D When the trap is closing, potassium ions leave the motor cells through ion channels.

Adapted from VCAA 2014 Section A Q11

Question 13 (1 MARK)

Molecules can move across the plasma membrane in various ways.

Which of the following substances are most likely to cross the plasma membrane by passing through a protein channel?

A An enzyme
B Chloride ions
C Hydrophobic molecules
D Carbon dioxide molecules

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q2

Question 14 (1 MARK)

Corals are marine animals. Many species of coral have algae living in vesicles inside their cells. These algae require nutrients such as phosphorus to function. The concentration of phosphorus (present as phosphate ions) in sea water is generally less than two parts per million. However, in the cytoplasm of coral cells, the concentration of this nutrient may be as high as hundreds of parts per million. Based on this information, the transport of phosphate ions from sea water into coral cells is likely to be through

A endocytosis.
B active transport.
C protein channels.
D facilitated diffusion.

Adapted from VCAA 2003 Exam 1 Section B Q6f

Question 15 (1 MARK)

A small percentage of humans are born with malfunctioning protein pumps in their plasma membranes. Which one of the following molecules will be difficult to transport across plasma membranes with malfunctioning protein pumps?

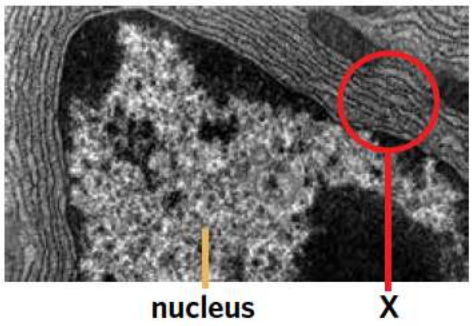
A Ions
B Water
C Lipid-based hormones
D Hydrophobic molecules

Adapted from VCAA 2017 Sample Exam Section A Q4

SECTION B (26 MARKS)

Question 16 (4 MARKS)

The cell shown in the figure is a lung cell. The secretory product of the cell is synthesised by an organelle, part of which is enclosed by the circle labelled X.



a Name this organelle. (1 MARK)
b Describe the transportation path taken by the secretory product from the organelle identified in part a until it leaves the cell. (3 MARKS)

Question 17 (6 MARKS)

The diagram represents a cross section of part of a cell membrane.

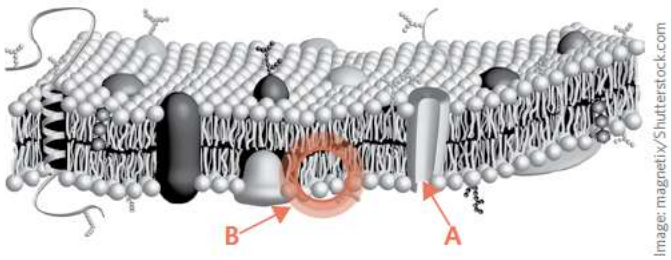


Image: magnetix/Shutterstock.com

a Name the structures labelled A and B. (2 MARKS)

b Identify two other structures found in the diagram and explain their function. (2 MARKS)

c The concentration of potassium ions, K^+, in human blood plasma is approximately 4 mM. In the cytoplasm of red blood cells the concentration of these ions is around 100 mM.
Explain how this difference in concentration is maintained. (2 MARKS)

Adapted from VCAA 2002 Exam 1 Section B Q11

Question 18 (6 MARKS)

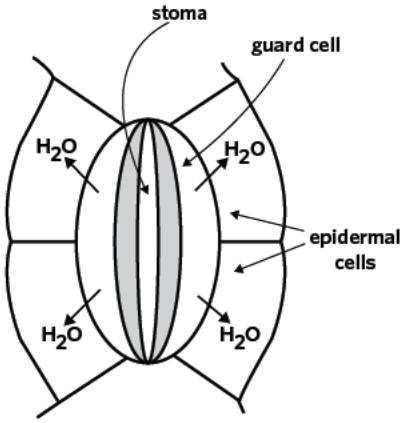
Plants require the passive movement of water for normal cellular function.

a When a plant cell is placed into distilled water, water enters the cell.

i What term is used to describe this movement of water into a cell? (1 MARK)

ii Animal cells placed in distilled water swell and burst. Describe what happens to plant cells in distilled water. (2 MARKS)

b The figure represents a stoma, a hole on the surface of a leaf. Stomata are made up of two guard cells, with surrounding epidermal cells.
The plant is in bright light. When water leaves the guard cells, the stoma opens and the plant can exchange gases with the environment.
The arrows on the diagram indicate the direction of the net movement of water from the guard cells into the epidermal cells.
Explain the change occurring inside the guard cells and epidermal cells that leads to the net movement of water. (3 MARKS)



Adapted from VCAA 2002 Exam 1 Section A Q2

Question 19 (10 MARKS)

Insulin is a protein that is synthesised in the beta cells of the pancreas. It is released from the cell via exocytosis, and enters the bloodstream to regulate glucose levels.

a Complete the table by naming three different organelles or structures directly associated with the transport and secretion of the synthesised insulin. State the role of each organelle or structure in this process. (3 MARKS)

Organelle/structure	Role

b When insulin binds to insulin receptors in the membranes of muscle and fat cells, it triggers a cascade of reactions that lead to an increase in the uptake of extracellular glucose by GLUT4 glucose transporters embedded in the plasma membrane. Glucose is an essential part of producing cellular energy, and once inside a muscle cell it is quickly converted into water, carbon dioxide, and ATP.

i Kiani and Mohsin were discussing the transport of glucose into muscle cells. Kiani said that it was a mode of active transport, but Mohsin thought it was passive transport. Identify who is correct, and justify your response. (2 MARKS)

ii To increase the amount of GLUT4 in the membranes of muscle and fat cells, vesicles with GLUT4 embedded in their membrane fuse with the plasma membrane. Using your knowledge of the plasma membrane structure, explain how this is possible. (3 MARKS)

iii Kiani had a test later in the year which questioned how glucose enters a cell. Completely forgetting the conversation with Mohsin, Kiani incorrectly suggested that glucose primarily enters the cell via pinocytosis. Outline the process of pinocytosis. (2 MARKS)

UNIT 3 AOS 1, CHAPTER 4

Nucleic acids and proteins 04

4A Protein function and structure

4B Nucleic acid function and structure

4C From DNA to protein

4D Gene regulation

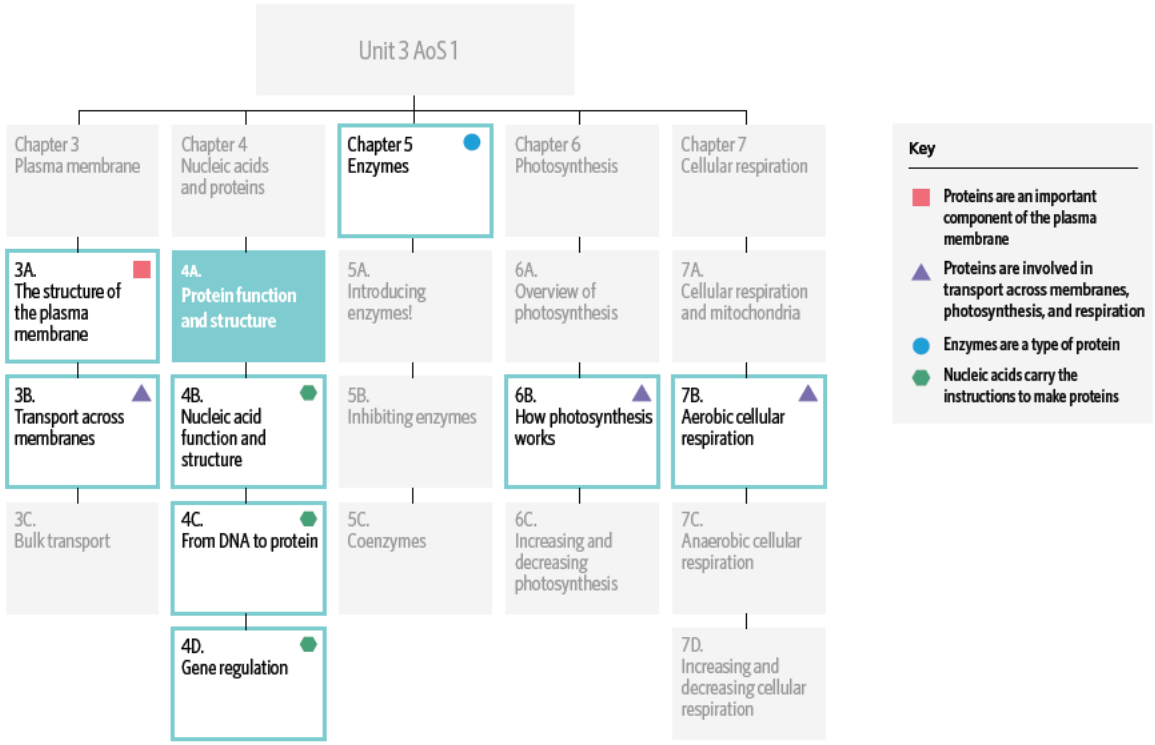
Key knowledge

- protein functional diversity and the nature of the proteome
- the synthesis of a polypeptide chain from amino acid monomers by condensation polymerisation
- the functional importance of the four hierarchical levels of protein structure
- nucleic acids as information molecules that encode instructions for the synthesis of proteins in cells
- the structure of DNA and the three forms of RNA including similarities and differences in their subunits, and their synthesis by condensation polymerisation
- the genetic code as a degenerate triplet code and the steps in gene expression including transcription, RNA processing in eukaryotic cells, and translation.
- the structure of genes in eukaryotic cells including stop and start instructions, promoter regions, exons and introns
- the functional distinction between structural genes and regulatory genes
- use of the lac operon as a simple prokaryotic model that illustrates the switching off and on of genes by proteins (transcriptional factors) expressed by regulatory genes

Image: Liya Graphics/Shutterstock.com

4A PROTEIN FUNCTION AND STRUCTURE

Sun's out, guns out! Muscle is chockas full of protein, but proteins have so many more functions than just contractile strength.



In this lesson you will learn what proteins do, how proteins are made, and what proteins look like at a molecular level.

Study design dot points

- Protein functional diversity and the nature of the proteome
- The synthesis of a polypeptide chain from amino acid monomers by condensation polymerisation
- The functional importance of the four hierarchical levels of protein structure

Key knowledge units

What proteins do	3.1.5.1
How to make a protein	3.1.7.1
Protein structure	3.1.6.1

What proteins do 3.1.5.1

OVERVIEW

Proteins have many functions in living things such as:

- providing structural support, such as in skin and hair
- helping transport molecules across membranes
- storing metal ions and amino acids
- receiving and sending signals
- defending against pathogens
- enabling muscle contraction
- catalysing reactions.

THEORY DETAILS

Proteins (or **polypeptides**) are one of four types of biomacromolecule found in living things (the others are carbohydrates, nucleic acids, and lipids). Proteins are made of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sometimes also sulphur (S) and other elements. The **proteome** refers to the entire set of proteins expressed by an organism at a given time - from the keratin found in hair, to the haemoglobin in red blood cells, to the amylase in saliva. Proteomics is the study of the proteome, including the structure, function, and interaction of proteins.

Proteins fulfil many roles in living things, so scientists say that they demonstrate 'functional diversity'. Some of these functions are outlined in Table 1.

Table 1 Functions of proteins

Function	Explanation	Examples
Enzymes	Organic catalysts that speed up chemical reactions	• Catalase: breaks down toxic hydrogen peroxide into water and oxygen • Amylase: a digestive **enzyme** that breaks down starch into maltose • ATPase: makes ATP in cellular respiration
Transport	Typically embedded in membranes, **transport proteins** control the movement of substances around an organism	• Chloride channels • Sodium-potassium pumps • Glucose channels
Structural	Support cell and tissue shape	• Collagen: found in connective tissues such as tendon, dermis, and ligaments • Keratin: tough protein found in skin, hair, and nails • Elastin: found in elastic connective tissues such as within skin • Actin: part of the cytoskeleton in eukaryotic cells
Receptors	Receive signals from the environment to which a cell can respond	• G-protein coupled receptors • Acetylcholine receptors • Hormone receptors
Hormones	Many (but not all) hormones are proteins. Hormones are chemical messengers used to communicate and induce changes in cells	• Insulin: regulates blood sugar levels • Vasopressin: regulates the amount of water in blood • Growth hormone: stimulates growth and regeneration of cells
Defence	Form part of the immune system by recognising and destroying pathogens	• **Antibodies** (immunoglobulins) • Complement proteins
Motor/ contractile	**Motor proteins** contract, causing muscles to contract. They also help with cilia and flagella movement, and the movement of internal cell contents around the cytoplasm	• Myosin and actin: work together to enable muscle contraction • Kinesin: moves along microtubules, enabling mitosis and vesicular transport
Storage	Proteins, often found in blood, plant seeds, egg whites, and milk, that act as reserves for metal ions and **amino acids**	• Ferritin: which stores iron • Prolamin gliadin: found in wheat

protein a type of biomacromolecule made of amino acid chains folded into a 3D shape

peptide a short chain of amino acids

polypeptide a long chain of amino acids. Proteins can be made of one or many polypeptides

proteome all the proteins that are expressed by a cell or organism

enzyme an organic molecule, typically a protein, that catalyses (speeds up) specific reactions

transport protein a protein that moves substances across membranes or around organisms

structural protein a type of protein that confers strength and shape to cells

receptor protein a protein within or on the surface of a cell that binds with signalling molecules, leading to a change in cellular activity

peptide hormone a protein signalling molecule that regulates physiology or behaviour

antibody a protein produced by plasma cells during the adaptive immune response that is specific to an antigen and combats pathogens in a variety of ways. Also known as **immunoglobulin**

motor protein a protein that converts chemical energy into mechanical work

storage protein a protein that is a reserve of amino acids and metal ions

amino acid the monomer of proteins

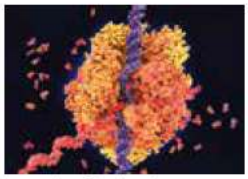


Image: Juan Gaertner/ Shutterstock.com

Figure 1 The enzyme RNA polymerase (orange) catalysing the formation of mRNA (red) from a DNA template (purple)

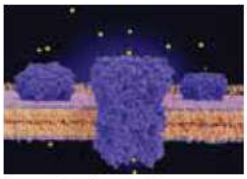


Image: Juan Gaertner/ Shutterstock.com

Figure 2 Chloride channels (purple) regulate the transport of chloride ions (yellow) across the plasma membrane, affecting muscle excitation.

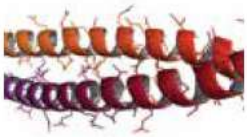


Image: molekuul_be/ Shutterstock.com

Figure 3 The fibrous, elongated structure of keratin. Keratin is the main protein in skin, hair, and nails.

Image: Juan Gaertner/ Shutterstock.com

Figure 4 The insulin receptor protein (blue) embedded in a plasma membrane. It is bound to the hormone insulin (orange), which is a signalling protein.

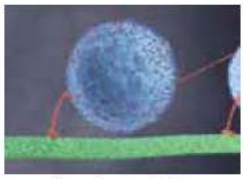


Image: Sebastian Kaulitzki/ Shutterstock.com

Figure 5 The motor protein kinesin (red) transporting a vesicle along a microtubule (green) inside a cell

How to make a protein 3.1.7.1

OVERVIEW

Amino acids are the building blocks of proteins. They are joined together via a condensation reaction where water is a byproduct. A chain of amino acids (a polypeptide) then folds to form an active protein.

THEORY DETAILS

Amino acids are the building blocks of proteins. They bond together into a long chain to form a polypeptide, in the same way that individual pearls are strung together to make a pearl necklace. Chemically speaking, we describe amino acids as the **monomer** of proteins (Figure 6). Likewise, proteins are the **polymer** of amino acids. To understand how proteins form, you first need to understand the structure of amino acids.

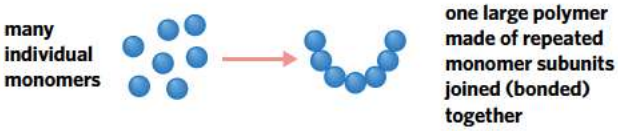


Figure 6 Formation of polymers from monomers

An amino acid consists of a central carbon that is bonded to four things: a hydrogen, a **carboxyl group** (COOH), an **amino group** (NH_2), and an **R-group** (Figure 7). There are 20 different types of R-groups, which is what makes amino acids different from each other. This means that there are 20 different types of amino acids.

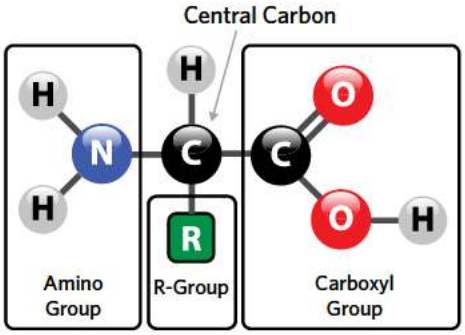


Image: gstraubi/Shutterstock.com

Figure 7 The basic structure of an amino acid. Carboxyl is acidic, so amino group + acidic group = amino acid.

To form a protein, many amino acids join via a **condensation reaction**. The process is outlined in Figure 8

monomer a molecule that forms the smallest basic unit of a polymer

polymer a large molecule that is made up of small, repeated monomer subunits

carboxyl group the functional group on amino acid molecules that contains a hydroxyl (-OH) and an oxygen double-bonded to a carbon atom

amino group the functional group on amino acid molecules that is made up of one nitrogen and two hydrogens (NH_2). Also known as an **amine group**

R-group the variable part of the amino acid molecule. It can be one of twenty variations and determines the identity of the amino acid

condensation reaction a reaction where two small molecules join to form one larger molecule, producing water as a by-product in the process

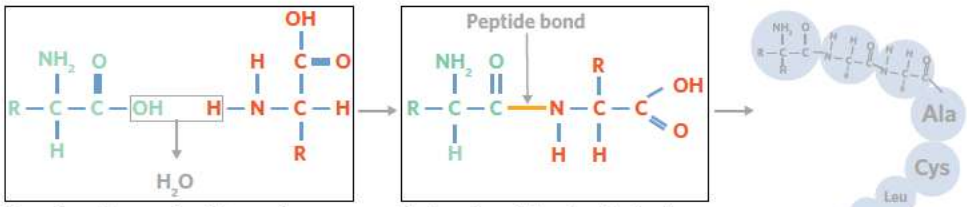


Figure 8 A condensation reaction leading to the formation of a polypeptide chain

Tip You don't need to memorise the 20 amino acids and their R-groups, but you will come across them again when you learn about translation in 4C and in Unit 4. They can be as simple as glycine, which has a single hydrogen molecule as its R-group. Or, they can be more complex, like tryptophan which has two carbon rings.

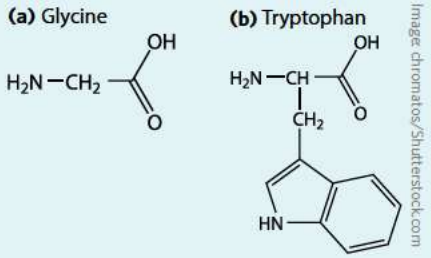


Figure 9 **(a)** the structure of glycine and **(b)** the structure of tryptophan

Protein structure 3.1.6.1

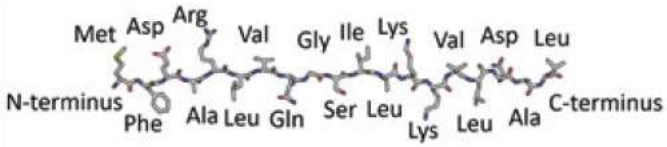
OVERVIEW

There are four levels of protein structure: the order of amino acids (primary); arrangement into alpha-helices, beta-pleated sheets, or random coils (secondary); the 3D shape of the protein (tertiary); and the binding of multiple polypeptide subunits (chains) together (quaternary).

THEORY DETAILS

In order for a protein to function correctly, it must have the right shape. The four levels of protein structure describe how a polypeptide chain folds to form this shape, starting from the **primary structure** and becoming increasingly more complex to form **tertiary** or **quaternary structures.**

Primary



The primary structure of proteins is the order (sequence) of amino acids in the polypeptide chain. **Peptide bonds** hold amino acids in the correct order, with the ends of the polypeptide chain being called the N-terminus (where the amino group is exposed) and the C-terminus (where the carboxyl group is exposed).

Secondary

The **secondary structure** of proteins is the folding and coiling of a section within a polypeptide chain, which builds on the primary structure. This folding and coiling is determined by hydrogen bonds between different amino acids. Therefore, the protein does not stay as a linear chain, but forms regular structures such as **alpha (α) helices** or **beta-pleated (β) sheets. Random coils** are irregular parts of secondary structure that join α-helices and β-pleated sheets.

Figure 10 The primary and secondary levels of protein structure

primary structure the first level of protein structure, which is the order of amino acids in the chain

secondary structure the level of protein structure where the amino acid chain forms either alpha helices, beta-pleated sheets, or random coils

tertiary structure the 3D shape of the polypeptide chain

quaternary structure the level of protein structure where multiple polypeptide chains bond together, or prosthetic groups are added to form a fully functional protein

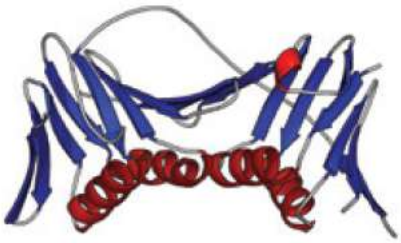
peptide bond the chemical bond linking two amino acid monomer subunits

alpha helix a coiled secondary structure of proteins

beta-pleated sheet a folded secondary structure of proteins

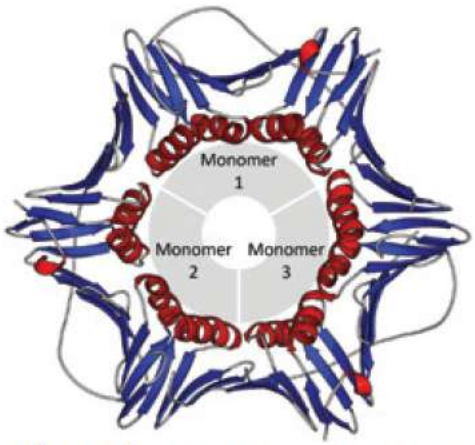
random coil a secondary structure of proteins that is neither alpha helix nor beta-pleated sheet

Tertiary



The tertiary structure is the overall 3D shape of the protein, which builds on the secondary structure. It is determined by the arrangement of the components of secondary structure, which bend and twist into the lowest energy, or most stable state. The tertiary structure is stabilised by hydrogen bonds between R-groups and stronger disulphide bridges between cysteine amino acids. Generally, when in an aqueous environment, hydrophobic R-groups are buried in the interior of the protein while hydrophilic R-groups are on the outside. Most proteins are functional at the tertiary structure.

Quaternary



Not all proteins have a quaternary structure. It occurs when a protein is made of two or more polypeptide chains joined together, or has a **prosthetic group** attached. For example, haemoglobin (Figure 12) is made of four polypeptide subunits. Each of these subunits also contains an iron atom embedded in a haem prosthetic group.

Figure 11 The tertiary and quaternary levels of protein structure

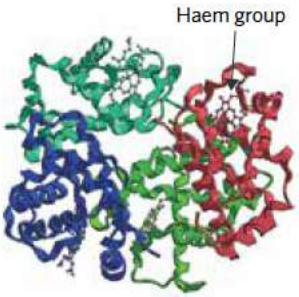


Image: Raimundo79/Shutterstock.com

Figure 12 The molecular structure of haemoglobin, showing the four polypeptide subunits in different colours and one of the haem groups

prosthetic group a non-protein group bound to a protein. For example, a vitamin or ion

Theory summary

Proteins demonstrate functional diversity, and have roles in signalling and reception, transport, muscle contraction, storage, immunity, and structure. Amino acids are the monomers of proteins, and they join together via condensation reactions. The primary level of protein structure is the order of amino acids, the secondary level of protein structure is alpha helices and beta-pleated sheets, the tertiary level is described by the 3D shape of the protein, and when there are two or more polypeptides in a protein it is said to have a quaternary structure.

4A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a type of protein that is involved in defence against pathogens

b _____ a biomacromolecule that contains carbon, hydrogen, nitrogen, oxygen, and sometimes sulphur and other elements

c _____ the monomer of peptides

d _____ water is produced during this process

e _____ the level of protein structure where alpha helices and beta-pleated sheets form

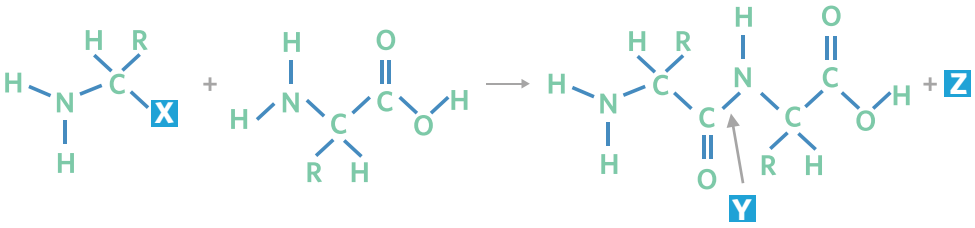
f _____ a type of protein that is a chemical messenger

g _____ the level of protein structure defined by the order of amino acids

h _____ all of the proteins expressed by a cell, tissue, or organism

Question 2

Which of the following options correctly completes the condensation reaction?



	X	Y	Z
A	Carboxyl group	Polypeptide bond	Water
B	Amino group	Ester bond	Energy
C	Carboxyl group	Peptide bond	Water
D	Carboxyl group	Condensation bond	Energy

Question 3

Proteins demonstrate functional diversity. Which of the following options describes only correct protein functions?

A Cell structure, storage of genetic information, movement, transport across membranes, transport of oxygen around the body, regulates fluidity of cell membrane

B Movement, enzymes, transport, storage of glucose, structure of cells and tissues, hormones

C Movement, strength, catalysis, contraction, relaxation, storage, transport of nitrogen in blood

D Cell signalling, hormones, receptors, storage of amino acids, transport around the cell

Question 4

Match the following descriptions with the correct level of protein structure.

I The order of amino acids in a polypeptide.

II Additional prosthetic groups attached.

III The 3D shape of the protein.

IV Alpha helices.

V More than one polypeptide chain in the protein.

VI Beta-pleated sheet

	Primary	Secondary	Tertiary	Quaternary
A	I, II	IV, VI	III	V
B	I	IV, VI	III	II, V
C	I	IV, VI	V	II, III
D	I, VI	II, IV	III	V

Exam-style questions

Within lesson

Question 5 (1 MARK)

The proteome is

A all the proteins in a cell, tissue, or organism.

B the complete set of chromosomes found inside a gamete.

C the set of genes that code for all the proteins in an organism.

D the entire set of proteins expressed by a population at a given time.

Adapted from VCAA 2018 Section A Q2

Question 6 (1 MARK)

Consider the structure and functional importance of proteins. Which one of the following statements about proteins is false?

A The tertiary structure of a protein can be stabilised by disulfide bridges.

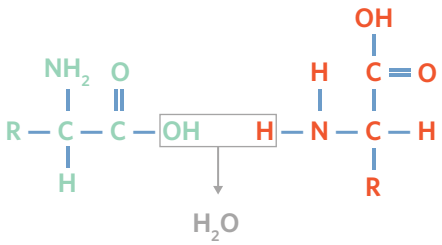
B Two proteins with different amino acid sequences will have different functions.

C A change in the secondary structure of a protein will not affect the biological function of the protein.

D Proteins with a quaternary structure are not more active than proteins without a quaternary structure.

Adapted from VCAA 2017 Section A Q1

Use the following diagram to answer Questions 7–9.



Question 7 (1 MARK)

The diagram represents monomers of an organic molecule being joined together. The monomers are

A amino acids.

B nucleic acids.

C monopeptides.

D monosaccharides.

Question 8 (1 MARK)

The joining of these adjacent monomers

A creates a fatty acid.

B creates a hydrogen bond.

C is an energy-using reaction.

D occurs on the plasma membrane.

Question 9 (1 MARK)

The 'R' symbol on the monomer represents

A the chemical element rubidium.

B one of 25 possible amino acids.

C a variable group specific to the amino acid.

D the continuation of the carbon-hydrogen-nitrogen chain.

Adapted from VCAA 2018 Section A Q3

Question 10 (6 MARKS)

The diagrams represent four levels of structure with respect to the folding and assembly of a protein. The diagrams are not to scale.

W

Image: ibreakstock/Shutterstock.com

X

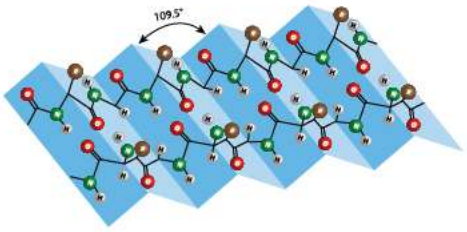


Image: magnetix/Shutterstock.com

Y

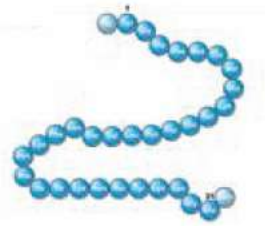


Image: chromatos/Shutterstock.com

Z

Image: Raimundo79/Shutterstock.com

a Complete the table to indicate which diagram represents each structural level of a protein. (2 MARKS)

Structural level of protein	Diagram (W, X, Y, or Z)
Primary	
Secondary	
Tertiary	
Quaternary	

b Name the molecular subunit of a protein. (1 MARK)

Adapted from VCAA 2015 Section B Q1aii

c Describe the chemical reaction that takes place to join together the subunits of proteins. (3 MARKS)

Adapted from VCAA 2017 Section B Q1biii

Question 11 (5 MARKS)

Oxytocin is a peptide hormone that has an important role in social bonding, childbirth, lactation, and sperm movement. It is produced in the hypothalamus and released by the posterior pituitary gland.

a Name the bond that joins the monomers of oxytocin. (1 MARK)

b Draw and label the general structure of the oxytocin monomer on a piece of paper. (2 MARKS)

c Peptide hormones can also display a secondary, tertiary, and quaternary structure. Explain what is meant by 'tertiary' and 'quaternary' structure. (2 MARKS)

Adapted from VCAA 2017 Section B Q1

Multiple lessons

Question 12 (1 MARK)

All specialised cells that secrete protein molecules uniquely

A have extensive endoplasmic reticulum.

B have a flexible plasma membrane.

C have large vacuoles for storage.

D contain numerous chloroplasts.

Adapted from VCAA 2015 Section A Q5

Question 13 (1 MARK)

Consider the diagram of the plasma membrane. Identify which of the following molecule/s are made up of many amino acids.

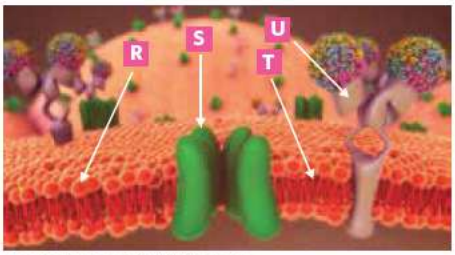


Image: sciencepics/Shutterstock.com

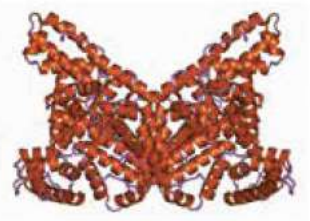
A S
B R
C R & T
D S & U

Adapted from VCAA 2017 Section B Q1bi

Key science skills

Question 14 (9 MARKS)

The following figure depicts a globular protein called albumin.



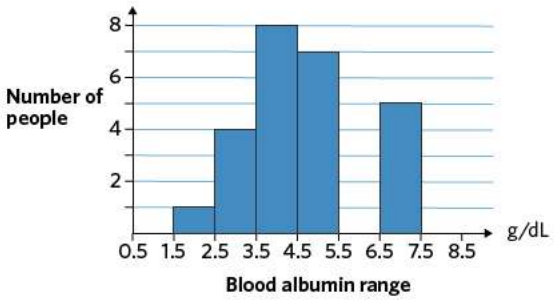
Albumin has many hydrophilic R-groups on the outside of the molecule, and hydrophobic R-groups facing the interior of the molecule. The molecule is likely to be highly insoluble in lipids.

a Outline why such a conclusion can be made about the lipid solubility of this molecule. (2 MARKS)

b Albumin normally constitutes 50% of human plasma protein. It is important for regulating blood pressure. Identify two other functional roles of proteins in living things. (1 MARK)

c Low albumin may be caused by liver disease, malnutrition, and burns. High albumin is usually caused by dehydration. Albumin in the urine can be indicative of kidney disease.

A doctor working for Médecins Sans Frontières at a refugee camp was concerned about the blood albumin levels of her patients. She took blood samples from each of her patients to run a test for blood albumin, and documented these results.



The normal range of albumin is 3.5 to 5.5 grams per decilitre (g/dL).

i How many of her patients have abnormal albumin levels? (1 MARK)

ii During the test, someone labelled some of the blood samples incorrectly, so the doctor was unsure which of her patients had the lowest blood albumin level. Identify the type of error that has occurred. (1 MARK)

iii The doctor calculated that she could ensure 80% of her patients have normal albumin levels if they were rehydrated appropriately. Is the doctor correct? Justify your response. (2 MARKS)

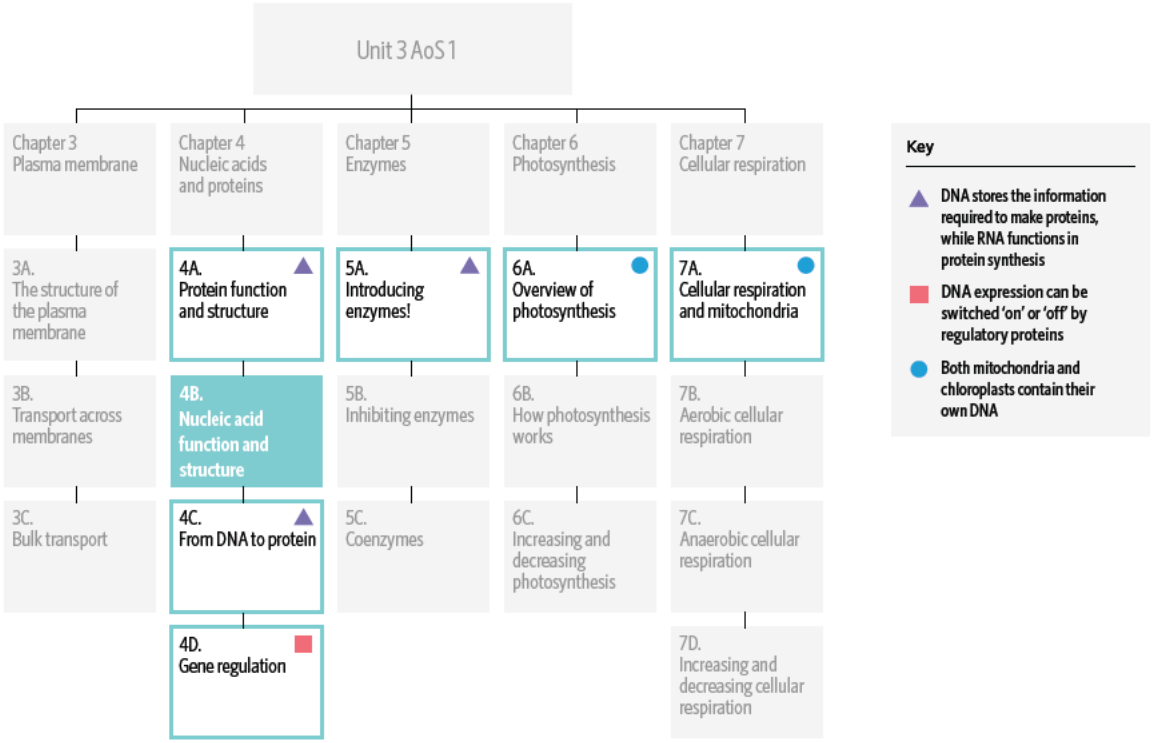
iv In Melbourne, another doctor measured blood albumin levels in one patient from several blood samples taken during the same visit.

Sample	Blood albumin level (g/dL)
1	5.75
2	3.21
3	4.12
4	4.25

Are these results precise? Justify your response. (2 MARKS)

4B NUCLEIC ACID FUNCTION AND STRUCTURE

Ever heard of the saying 'nature versus nurture'? Today we are going to learn all about 'nature', the genetic component of who we are.



Found in every living thing on Earth, nucleic acids are essential organic polymers that store genetic information and help produce the proteins required for survival. Nucleic acids can be classified into two types: DNA or RNA. **In this lesson** you will learn about nucleotides, how they join together to form nucleic acids, and the structural differences between DNA and RNA.

Study design dot points

- nucleic acids as information molecules that encode instructions for the synthesis of proteins in cells
- the structure of DNA and the three forms of RNA including similarities and differences in their subunits, and their synthesis by condensation polymerisation

Key knowledge units

What DNA looks like	3.1.4.1
What RNA looks like	3.1.8.1
How to make a nucleic acid	3.1.8.2

What DNA looks like 3.1.4.1

OVERVIEW

Deoxyribonucleic acid (DNA) is one of the two types of nucleic acids found in living things. A single strand of DNA is made of covalently-linked nucleotides, and two strands of DNA bind together by complementary base pairing. These complementary strands run in opposite directions and twist around each other to form a double helix structure.

THEORY DETAILS

When you zoom in on a eukaryotic cell you can see the nucleus. Inside the nucleus, your **DNA** is packaged into 46 **chromosomes** that contain tens of thousands of genes.

DNA (deoxyribonucleic acid) a double-stranded nucleic acid chain made up of nucleotides. DNA carries the instructions for proteins which are required for cell and organism survival

chromosome the structure made of protein and nucleic acids that carries genetic information

Every **gene** contains the information required to make a protein. The complete set of DNA in an organism is referred to as the **genome**. DNA (and the traits it codes for) is heritable and is passed from parents to their child.

Because it determines the structure of a protein, and proteins play a key role in the structure and function of cells and tissues, DNA is essential for life. If there are differences in DNA between individuals and species, there are usually differences in proteins.

Nucleic acids are formed entirely out of chains of **nucleotide** monomers. Each nucleotide has the same basic structure (Figure 1a). In DNA, nucleotides are made up of:

- a phosphate group
- a five-carbon deoxyribose sugar
- and a nitrogen-containing base. In DNA, the base can be:
  - adenine (A)
  - thymine (T)
  - guanine (G) or
  - cytosine (C).

The five carbons in the sugar are labelled 1' ('one prime') to 5' ('five prime') (Figure 1b). The phosphate group of each nucleotide is attached to the 5' carbon in the sugar molecule on the same nucleotide. The nitrogen-containing base, attached to the 1' carbon, determines the overall type of nucleotide (A, T, G, or C).

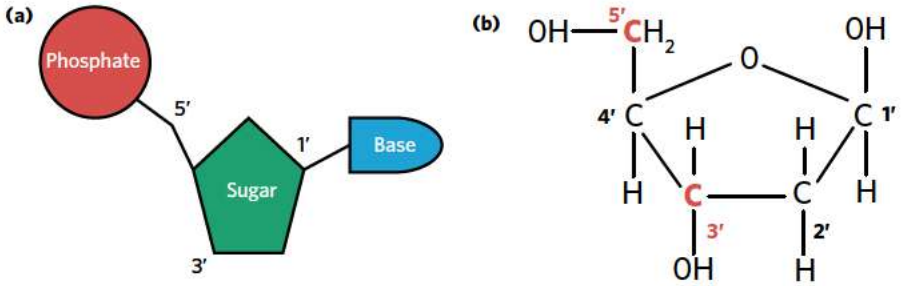


Image: Bacsica/Shutterstock.com

Figure 1 The basic structure of **(a)** a nucleotide and **(b)** a deoxyribose molecule

When many nucleotides bond together, they form a polynucleotide chain. The bonds joining nucleotides are strong covalent bonds (called **phosphodiester bonds** in nucleic acids) between the sugar group of one nucleotide and the phosphate group of another. The linkage of sugars and phosphate groups forms the **'sugar-phosphate backbone'** of nucleic acids.

DNA is made of two polynucleotide chains. These two strands are **antiparallel** to each other, meaning that one strand will run in a 3' to 5' direction and the other will run in a 5' to 3' direction (Figure 2a). The two chains join together by **complementary base pairing**, which dictates the pairs of nucleotides that can form hydrogen bonds. In DNA, the base pairing rules are:

- adenine will always form a pair with thymine (A-T) and
- guanine will always form a pair with cytosine (G-C).

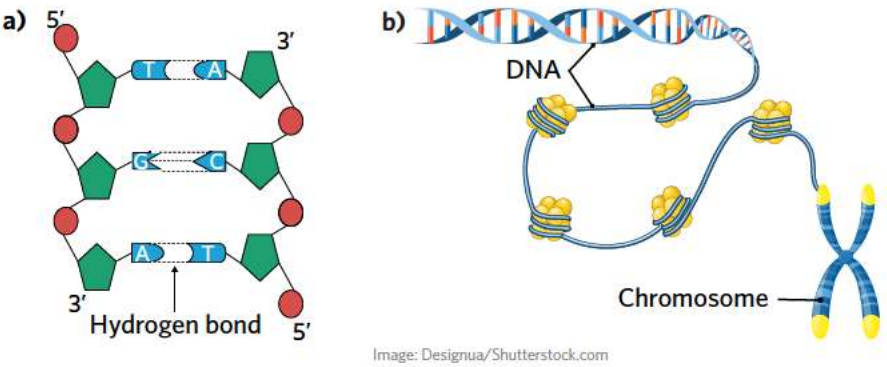


Image: Designua/Shutterstock.com

Figure 2 The **(a)** complementary base pairing of DNA and **(b)** helix structure and tight packaging of DNA

gene a section of DNA that carries the code to make a protein

genome the complete set of DNA within an organism

nucleic acid the class of macromolecules that includes DNA and RNA. All nucleic acids are polymers made out of nucleotide monomers

nucleotide the monomer unit of nucleic acids. Made up of a nitrogen-containing base, a sugar molecule (ribose in RNA and deoxyribose in DNA), and a phosphate group

phosphodiester bond the chemical bond linking a five-carbon sugar to a phosphate group

sugar-phosphate backbone the strong covalently linked chain of five-carbon sugar molecules and phosphate groups in a nucleic acid chain

antiparallel a characteristic of DNA strands, describing how each strand runs in an opposite direction to the other. One strand runs in a 3'→5' direction and the other runs in a 5'→3' direction

complementary base pairing describes which nucleotides can form hydrogen bonds with each other; C pairs with G, A pairs with T (or U in RNA)

Tip Be aware that DNA is found in places besides the nucleus. For instance, mitochondria and chloroplasts have their own DNA. Prokaryotes don't have nuclei, so their circular chromosome is just in the nuclear region of the cytoplasm.

lesson link Humans have 46 chromosomes which are arranged into 23 pairs. Flies have 4 chromosomes, and some ferns have over 1200! Chromosome structure, function, and malfunctions will be covered in ***11A***.

Analogy

The DNA helix is like a 'twisted ladder'. The hydrogen bonds between bases are much weaker than the covalent bonds between sugars and phosphates, so the 'rungs' of the ladder will break before the two side rails break.

By understanding complementary base pairing, we can predict the nucleotide sequence on a strand of DNA if we know the nucleotide sequence of the opposite (complementary) strand (Table 1). Using the same rules, we also know that in a double-stranded molecule of DNA there will always be equal numbers of the nucleotides A and T, and equal numbers of G and C.

Table 1 The nucleotide sequence of paired DNA strands according to the rules of complementary base pairing

DNA strand	3′ A C T G G A C A 5′
complementary DNA strand	5′ T G A C C T G T 3′

Given the sheer length of DNA (the human nuclear genome is approximately three billion base pairs long), DNA needs to be compressed and stored effectively. In all DNA, the two strands will twist around each other, forming a **double helix** (Figure 3). In **nuclear DNA**, this helix structure coils around proteins known as histones, which then condense further to form tightly packed chromosomes (Figure 2b).

What RNA looks like 3.1.8.1

OVERVIEW

RNA is the other type of nucleic acid found in living things. RNA molecules are single strands of nucleotides that come in a variety of forms and are found in many different parts of the cell. RNA primarily assists with protein synthesis.

THEORY DETAILS

RNA has a similar structure to DNA, aside from a few key differences. For instance, RNA nucleotides contain a ribose five-carbon sugar, which has one more oxygen than a deoxyribose molecule. The nitrogenous base thymine cannot be found in RNA. Instead, thymine is replaced by uracil.

RNA is single stranded and is usually much shorter than DNA. This single-stranded structure allows RNA to fold into many different forms due to complementary base pairing. In RNA:

- adenine pairs with uracil (A-U) and
- guanine pairs with cytosine (G-C).

Despite folding by complementary base pairing, as RNA is single-stranded you will not find equal numbers of complementary nucleotides.

The variable folding of RNA allows it to perform a variety of functions throughout the cell. Three of the most important types of RNA in cells are outlined in Table 2.

double helix double-stranded DNA in the nucleus of eukaryotic cells forms a double helix structure, where each DNA strand wraps around a central axis

nuclear DNA DNA that is located in the nucleus of a cell

RNA (ribonucleic acid) a single stranded nucleic acid chain made up of nucleotides. Includes mRNA, rRNA, and tRNA

messenger RNA (mRNA) RNA molecules that are produced during transcription and carry genetic information from the DNA to the ribosomes

transfer RNA (tRNA) RNA that recognises individual codons on the mRNA strand and adds the corresponding amino acid to the polypeptide chain during protein synthesis

anticodon the sequence of three nucleotides on a tRNA molecule that recognises a specific sequence of three nucleotides (codon) on an mRNA strand

ribosomal RNA (rRNA) RNA that is a key structural component of ribosomes, which assemble proteins

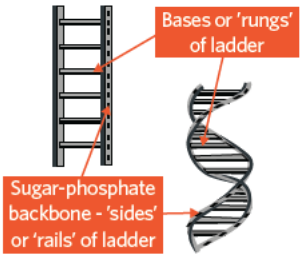


Figure 3 DNA structure is similar to that of a 'twisted ladder'

Table 2 The three types of RNA and their corresponding function and structure

RNA type	Function	Structure	Diagram
messenger RNA (mRNA)	Carries genetic information from the DNA to the ribosomes for protein synthesis	mRNA is a single, linear strand of RNA	 Image: udaix/Shutterstock.com
transfer RNA (tRNA)	Delivers individual amino acids to the ribosome after recognising specific nucleotide sequences	tRNA is formed from a single strand of RNA folded into three hairpin loops to form a 'cloverleaf' structure. A sequence of three bases called the anticodon is located on the middle hairpin	 Image: Emre Terim/Shutterstock.com
ribosomal RNA (rRNA)	The main structural component of ribosomes in the cell	rRNA folds into a large and a small subunit to make up a ribosome	

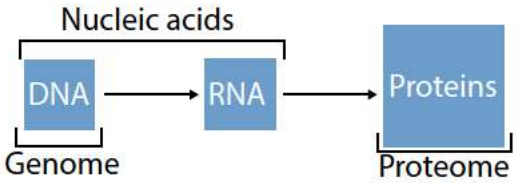


Figure 4 DNA encodes the sequence of nucleotides in RNA and amino acids in proteins.

lesson link The three major forms of RNA will be covered in detail in ***4C*** when discussing the process of protein synthesis.

How to make a nucleic acid 3.1.8.2

OVERVIEW

You already know that the building blocks of DNA and RNA are nucleotides. But how do nucleotides join together to form these biomacromolecules? The answer: condensation reactions.

lesson link In ***4A*** you learnt that the condensation reaction in protein synthesis involves joining an amine and carboxyl group between two amino acids. Here, the condensation reaction joins a phosphate group with a five-carbon sugar. The similarity? Both reactions release a water molecule.

THEORY DETAILS

When nucleotides polymerise they undergo a condensation reaction. This reaction occurs when a phosphodiester bond forms between the phosphate group from one nucleotide and the sugar molecule on another nucleotide, and releases a water molecule in the process. This can happen over and over again, creating a long polynucleotide chain. The exposed phosphate group is referred to as the 5' end and the exposed 3' carbon is referred to as the 3' end (Figure 5).

Tip DNA tends to be double stranded (dsDNA) and RNA tends to be single stranded (ssRNA). However, like most things in biology, there are always exceptions to the rule. Some bacterial viruses (such as those in the Microviridae family) contain single-stranded DNA (ssDNA) and other viruses, including rotaviruses, contain double-stranded RNA (dsRNA). If possible, you should rely on the set of nucleotides in a strand to differentiate the two, as DNA will contain T whilst RNA will contain U. To be doubly sure, you can also look at the five-carbon sugar found within each nucleotide, DNA will always contain one less oxygen molecule than RNA, thus giving the prefix deoxy- ('one less oxygen').

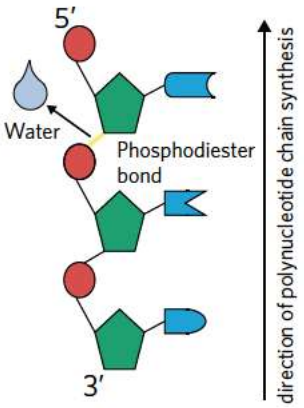


Figure 5 Nucleotides polymerise by a condensation reaction to form a chain.

Theory summary

In this lesson you have learned that nucleic acids carry genetic information and help synthesise proteins. You have also learned about the basic structure of a nucleotide, how nucleotides polymerise by a condensation reaction to form a nucleic acid, and the important structural and functional differences between DNA and RNA (summarised in Table 3).

Table 3 Similarities and differences between DNA and RNA

	DNA	RNA
Similarities	• nucleotides follow the same basic structure (phosphate group, five-carbon sugar molecule, nitrogen-containing base) • contain the nucleotides adenine, guanine, and cytosine • contain a sugar-phosphate backbone • nucleotides form chains along the sugar-phosphate backbone by a condensation reaction • follow the complementary base pairing rule: C pairs with G, A pairs with T (or U)	
Differences	• nucleotides contain a deoxyribose sugar • contains the base thymine (T) • double-stranded • equal numbers of the nucleotides adenine-thymine and guanine-cytosine • double helix • inherited/long-term storage	• nucleotides contain a ribose sugar • contains the base uracil (U) • single-stranded • different numbers of the nucleotides adenine-uracil and guanine-cytosine • many different structures • temporary molecules

4B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a biomacromolecule made up of nucleotide monomers

b _____ a nucleic acid that contains the base uracil

c _____ a type of RNA that forms part of ribosomal structure

d _____ a characteristic of DNA which describes the opposite directions of complementary strands

e _____ a nucleic acid which contains a deoxyribose molecule

f _____ the full name of tRNA

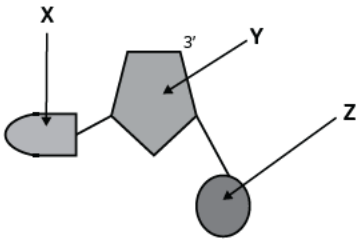
g _____ a term used to describe the strong linkage of sugar molecules and phosphate groups in nucleic acids

h _____ the single monomer unit of nucleic acids

Question 2

Which of the following correctly identifies the three key components of a nucleic acid monomer?

	X	Y	Z
A	nucleotide	five-carbon sugar	phosphate group
B	nitrogen-containing base	six-carbon sugar	phosphate head
C	nucleotide	deoxyribose molecule	phosphate group
D	nitrogen-containing base	five-carbon sugar	phosphate group



Question 3

A diagram of a nucleic acid molecule is shown.

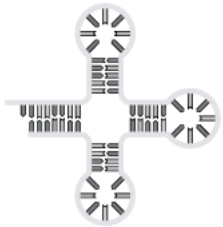


Image: Emre Terim/Shutterstock.com

To which of the following groups of nucleic acid does this molecule belong?

A tRNA

B rRNA

C mRNA

D mtDNA

Question 4

Which of the following is not a correct difference between DNA and RNA?

	DNA generally contains	RNA generally contains
A	deoxyribose molecules.	ribose molecules.
B	the nucleotide thymine.	the nucleotide uracil.
C	a single strand.	a double strand.
D	identical numbers of complementary nucleotides.	different numbers of complementary nucleotides.

Question 5

Fill in the blanks in the following sentence.

When forming nucleic acids by a condensation reaction, successive nucleotides form a _____I_____ bond, which _____II_____.

	I	II
A	peptide	releases water
B	phosphodiester	consumes water
C	phosphodiester	releases water
D	peptide	consumes water

Exam-style questions

Within lesson

Question 6 (1 MARK)

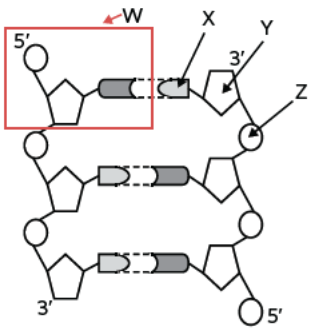
A particular DNA double helix is 100 nucleotide bases long and contains 40 cytosine bases. The number of adenine bases in this DNA double helix would be

A 10.
B 20.
C 40.
D 60.

Adapted from VCAA 2012 Exam 1 Section A Q5

Use the following information to answer Questions 7 and 8.

The diagram represents part of a nucleic acid macromolecule.



Question 7 (1 MARK)

A nucleic acid is made up of nucleotides which are linked by a sugar-phosphate backbone. According to the diagram, structure(s)

A Y and Z must make up the sugar-phosphate backbone.
B W is a nitrogen-containing base.
C Y is a ribose sugar molecule.
D X is a phosphate group.

Adapted from VCAA 2015 Section A Q3

Question 8 (1 MARK)

If the boxed structure W is the nucleotide thymine, then

A sub-unit X must be the base uracil.
B sub-unit X must be the base adenine.
C sub-unit Y must be the base cytosine.
D sub-unit X must be the nucleotide adenine.

Question 9 (1 MARK)

Which of the following correctly describes a difference between DNA and RNA?

	DNA contains	RNA contains
A	the same number of guanine and thymine nitrogen bases.	a different number of guanine and thymine nitrogen bases.
B	a ribose sugar.	a deoxyribose sugar.
C	the nitrogen base uracil.	the nitrogen base thymine.
D	hydrogen bonding between complementary strands.	no hydrogen bonding between strands.

Adapted from VCAA 2017 Sample Exam Section A Q2

Question 10 (1 MARK)

A gene involved in the function of the male reproductive system has been sequenced. A small section of this gene is shown in the diagram.

The sequence of nucleotides on the complementary sequence of DNA would be

A GCACUCCGGU.
B CGTGAGGCCA.
C GCACTCCGGT.
D TCCAGAATTG.

Question 11 (1 MARK)

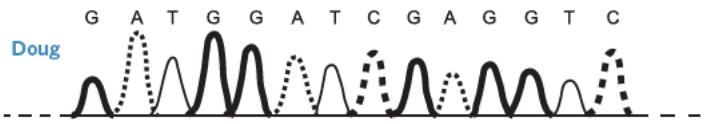
A particular mRNA strand is 50 nucleotide bases long and contains 10 adenine bases. The number of thymine bases in this mRNA strand would be

A 0.
B 10.
C 40.
D 50.

Adapted from VCAA 2012 Exam 1 Section A Q5

Question 12 (1 MARK)

A fragment of DNA on chromosome 7 from a person, Doug, is sequenced. The nucleotide sequence is shown.



For the sequence of nucleotides shown, the total number of cytosine bases on the complementary strand would be

A 0.
B 2.
C 6.
D 8.

Adapted from VCAA 2012 Exam 2 Section A Q15

Multiple lessons

Question 13 (1 MARK)

Genes

A are made up of the five nucleotide bases: adenine, thymine, cytosine, guanine, and uracil.

B contain the genetic information required to make proteins.

C can only be found in the nuclear DNA of a eukaryotic cell.

D are made up of amino acid monomers.

Use the following information to answer Questions 14—16

The diagrams represent the four major groups of biomacromolecules.

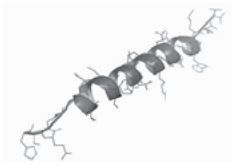
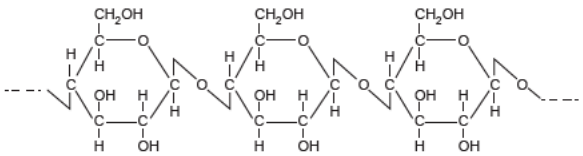


Image: StudioMolekuul/Shutterstock.com

Group A

Group B



Group C

Group D

Question 14 (1 MARK)

Each monomer of a macromolecule from Group A is made up of a

A carboxyl group, an R group, and an amine group.

B carboxylic acid, an R group, and an amine acid group.

C ribose sugar, a phosphate group, and a nitrogen-containing base.

D deoxyribose sugar, a phosphate group, and a nitrogen-containing base.

Adapted from VCAA 2016 Section A Q3

Question 15 (1 MARK)

A feature that can be seen in the diagram of the macromolecule in Group B is

A its deoxyribose subunits.

B the double-helical structure of DNA.

C the complementary base pairing of C-G and A-U.

D the antiparallel arrangement of two complementary strands of amino acids.

Adapted from VCAA 2015 Section A Q4

Question 16 (1 MARK)

A single monomer of the class of macromolecule represented by Group C could be found in

A the backbone structure of the macromolecule in Group B.

B the phosphate heads of the macromolecule in Group D.

C the hydrophobic tails of the macromolecule in Group D.

D the primary structure of the macromolecule in Group A.

Question 17 (1 MARK)

When two monomers of DNA are joined together via a chemical reaction, water is formed. This reaction is best known as

A a condensation reaction.

B an exergonic reaction.

C a catabolic reaction.

D hydrolysis.

Adapted from VCAA 2014 Section A Q2

Question 18 (1 MARK)

Nitrogen is an essential component of many of the molecules needed for growth and reproduction. Some bacteria live in the root systems of certain plant species, taking the nitrogen from our atmosphere and producing nitrogen-containing compounds (such as ammonia). These compounds can then be taken up by the plants and used to produce molecules that are essential for life. Soils lacking in these bacteria and nitrogen-containing fertilisers may become nitrogen deficient. Plants growing in these soils may be unable to produce sufficient levels of

A carbohydrates.
B nucleic acids.
C fatty acids.
D cellulose.

Adapted from VCAA 2012 Exam 1 Section A Q6

Question 19 (4 MARKS)

Researchers studying macromolecules found two tightly packed polymers in the nucleus of an animal cell. A short section of these macromolecules are shown in the diagram.

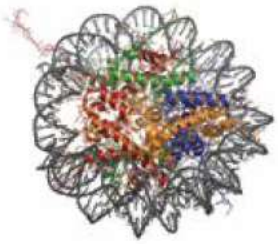


Image: molekuul_be/Shutterstock.com

a Name the two types of macromolecules shown in the diagram. (2 MARKS)

Adapted from VCAA 2014 Section B Q9a

b Each of the two macromolecules shown in the diagram are made up of repeating units called monomers. Identify the monomers of the two types of macromolecules shown in the diagram. (2 MARKS)

Key science skills

Question 20 (8 MARKS)

Two scientists were busy sequencing two samples of DNA.

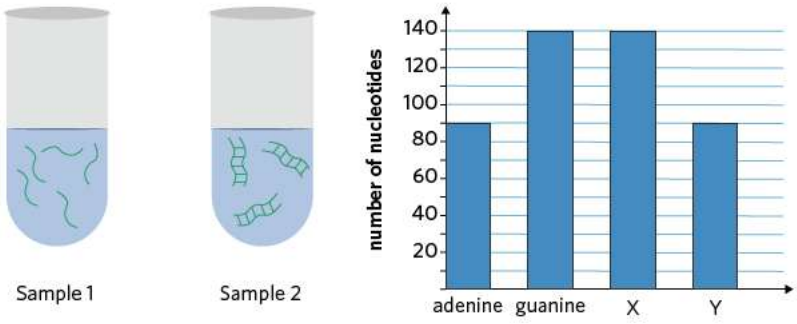
a All polymers are made up of repeating sequences of monomers. Scientists can determine the sequence of monomers in a sample by sequencing the sample.

i What information is obtained from protein sequencing? (1 MARK)

ii What information is obtained from gene sequencing? (1 MARK)

Adapted from VCAA 2017 Northern Hemisphere Exam 1 Section B Q7a

b Sample 1 only contained single stranded sequences of DNA while sample 2 contained double stranded sequences of DNA. After sequencing one of the samples, they plotted the number of individual nucleotides on a graph.



i Identify the nucleotides represented by the bars labelled X and Y on the graph. (1 MARK)

ii Scientist A argued that the graph shows data from sample 1, while Scientist B argued that it is more likely that the graph shows data from sample 2. Which scientist is correct? Explain your reasoning. (2 MARKS)

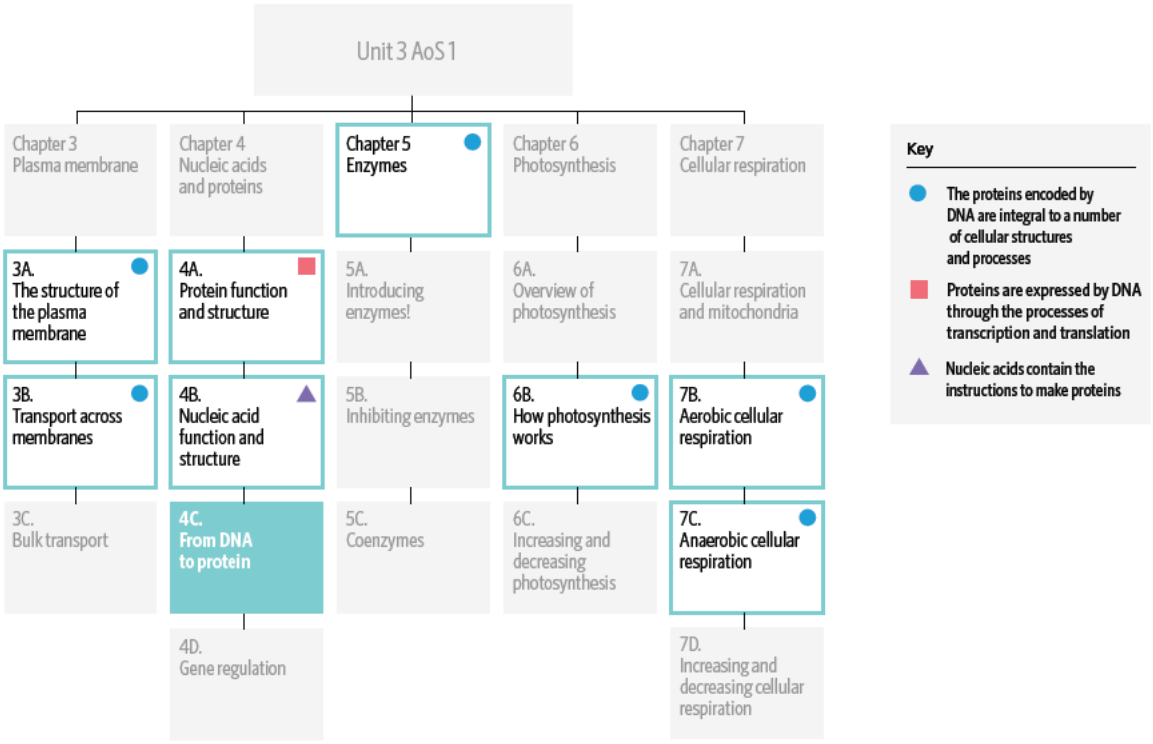
iii What is the length of the DNA strand in the sequenced sample? (1 MARK)

iv Draw a labelled diagram of a single monomer of the macromolecule found in sample 2. (2 MARKS)

Adapted from VCAA 2014 Section B Q9a

4C FROM DNA TO PROTEIN

Our DNA is the instructions to assemble the flat packs that are proteins. Luckily, cells are better at following instructions than we are.



In this lesson you will learn how the genetic code enables nucleic acids to encode the information required for protein synthesis. During transcription, DNA is used as a template to create mRNA. This mRNA molecule is processed before being exported from the nucleus to the ribosomes for translation. During translation, individual codons on the mRNA molecule are read and corresponding amino acids are added to a polypeptide chain, and a protein is formed.

Study design dot points

- the genetic code as a degenerate triplet code and the steps in gene expression including transcription, RNA processing in eukaryotic cells, and translation
- the structure of genes in eukaryotic cells including stop and start instructions, promoter regions, exons and introns

Key knowledge units

The genetic code	3.1.9.1
Transcription	3.1.9.2 & 3.1.11.1
RNA processing	3.1.9.3
Translation	3.1.9.4

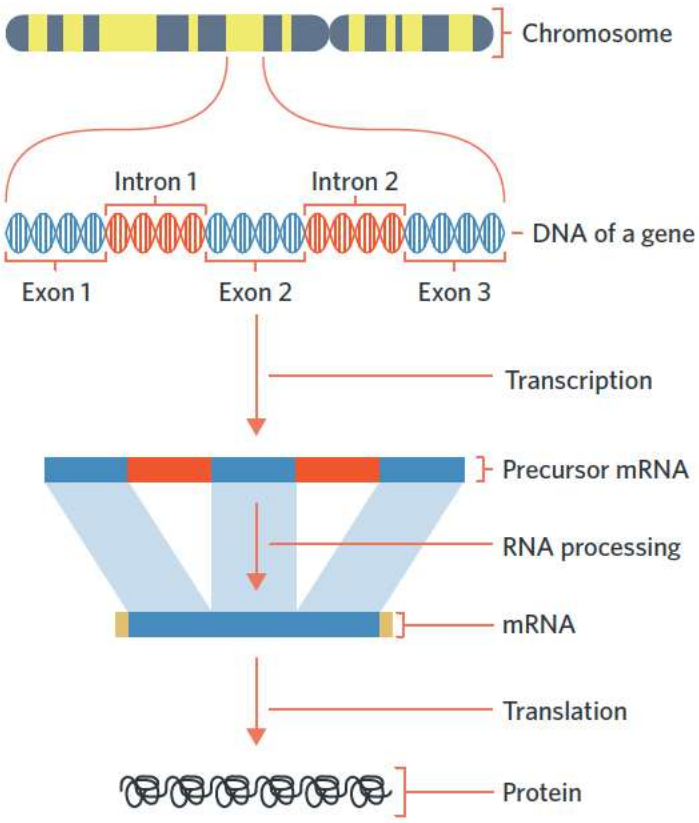


Figure 1 An overview of gene expression leading to protein production

The genetic code 3.1.9.1

OVERVIEW

Protein production is essential to all life on Earth. Genes within our DNA carry the information for the synthesis of proteins. This is possible because of the genetic code, which is of a non-overlapping triplet nature, universal, and degenerate.

THEORY DETAILS

A cell produces proteins by reading and interpreting the information within the **genes** of its **DNA**. Protein synthesis occurs in several steps: 1) **transcription**, 2) **RNA** processing, and 3) **translation**. In steps 1 and 2, the nucleotide sequence in a gene is copied into an RNA form. In step 3, the RNA is used as a guide to order the **amino acid** monomers in a protein. In this section, you will learn why information in nucleic acids determines the order of amino acids in a protein. In the following sections, you will apply this knowledge by learning the three steps in protein synthesis.

The steps in protein synthesis are possible because genes follow the **genetic code**, a set of rules that define how the information in nucleotides (from both DNA and RNA) is translated into functional molecules (e.g. proteins).

The information in DNA and RNA is stored as three-sequence sections of nucleotides. In DNA, this grouping of three nucleotides is called a **triplet**. When a DNA triplet is transcribed into an **mRNA** molecule, the triplet is called a **codon** (Figure 2).

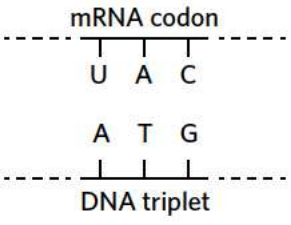


Figure 2 Example of a triplet in the DNA and complementary codon in mRNA

gene a section of DNA that carries the code to make a protein

DNA (deoxyribonucleic acid) a double-stranded nucleic acid chain made up of nucleotides. DNA carries the instructions for proteins which are required for cell and organism survival

transcription the process whereby a sequence of DNA is used to produce a complementary sequence of mRNA

RNA (ribonucleic acid) a single stranded nucleic acid chain made up of nucleotides. Includes mRNA, rRNA, and tRNA

translation the process whereby an mRNA sequence is used to produce a corresponding amino acid sequence to build a polypeptide

amino acid the monomer of proteins

genetic code the set of rules by which information is encoded in genetic material

triplet a sequence of three nucleotides in DNA coding for one amino acid

messenger RNA (mRNA) RNA molecules that are produced during transcription and carry genetic information from the DNA to the ribosomes

codon the sequence of three nucleotides in mRNA coding for one amino acid

Codons and triplets are incredibly important as one triplet or codon codes for one amino acid in the final polypeptide chain. There are also specific triplets and codons that instruct the cell to start and stop protein synthesis. Therefore, these rules determine which nucleotides are read and translated into a polypeptide sequence.

Second Base									
First Base	U		C		A		G		Third Base
U	UUU	phe	UCU	ser	UAU	tyr	UGU	cys	U
	UUC		UCC		UAC		UGC		C
	UUA	leu	UCA		UAA	STOP CODON	UGA	STOP CODON	A
	UUG		UCG		UAG		UGG	trp	G
C	CUU	leu	CCU	pro	CAU	his	CGU	arg	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	gln	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	ile	ACU	thr	AAU	asn	AGU	ser	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	lys	AGA	arg	A
	AUG	met (START CODON)	ACG		AAG		AGG		G
G	GUU	val	GCU	ala	GAU	asp	GGU	gly	U
	GUC		GCC		GAC		GGC		C
	GUA		GCA		GAA	glu	GGA		A
	GUG		GCG		GAG		GGG		G

Figure 3 The codon table shows which RNA codons encode each amino acid.

Tip VCAA does not require you to memorise this codon table, or remember all the different amino acids. However, they frequently supply the table on exams and ask students to extract information from it (e.g. see the 2018 exam, Section A Q20). The amino acid table can also be displayed for DNA triplets, all you need to look for is T instead of U.

The order of codons indicates the order of amino acids in a polypeptide chain. For example, if the mRNA sequence was:

GUA - UAU - CAG

Then we can use the codon table (Figure 3) to know that the amino acid sequence would be:

valine (val) - tyrosine (tyr) - glutamine (gln)

As adjacent codons do not overlap, the code is said to be **non-overlapping** (Figure 4).

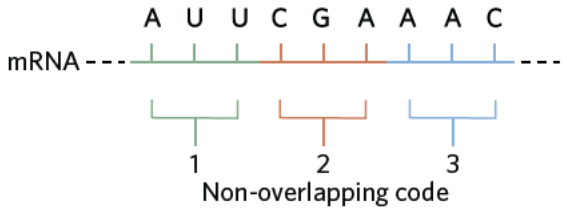


Figure 4 Codons display the non-overlapping nature of the genetic code.

You will notice that more than one codon can code for the same amino acid. Because of this, the genetic code is said to be **degenerate** or redundant. Notice that AUG is the **start codon** (coding for methionine). It signals the initiation of translation. The codons UAA, UAG, and UGA are **stop codons** that do not code for an amino acid, but signal the termination of translation. The genetic code is **universal**, meaning that the rules are the same for all organisms on Earth.

non-overlapping a property of the genetic code which means that nucleic acids are read in successive sets of three nucleotides and each nucleotide is part of only one codon

degenerate a property of the genetic code which means that a single amino acid can be coded for by more than one codon

start codon the sequence of three nucleotides in mRNA that signals the start of translation

stop codon the sequence of three nucleotides in mRNA that signals the end of translation

universal a property of the genetic code which means that the same nucleic acid sequence codes for the same amino acids in all living things

lesson link The universality of the genetic code is integral to processes that manipulate DNA (***16A***) and genetically modify organisms (***15D*** and ***16B***). For example, the UAC codon will always code for the amino acid tyrosine (tyr) regardless of whether it is in a human or a bacterium.

Tip The genetic code is degenerate because there are more codon types than amino acid types. To be clear, there are four nucleotides in RNA (A, C, G, and U), and three nucleotides in a codon, so there are 64 possible codons ($4^3 = 64$). However, three of these are 'STOP' codons which signal to stop translation (UAA, UAG, and UGA). This means that there are 61 codons that code for only 20 amino acids. This means that leucine, for example, is coded for by six amino acids.

Transcription 3.1.9.2 & 3.1.11.1

OVERVIEW

Transcription is the first step in gene expression, and involves the creation of a pre-mRNA molecule from genetic information found in DNA. DNA is large and cannot leave the nucleus, so transcription is important as it creates a molecule (mRNA) that is able to transport the code for a protein around the cell.

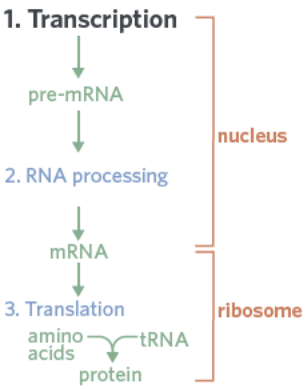


Figure 5 Transcription is the first step in protein synthesis.

THEORY DETAILS

Transcription is the first stage of **gene expression**. It involves the creation of an RNA-based molecule, called **pre-mRNA**, that can copy and transport the information carried within DNA. The pre-mRNA is produced by an enzyme called **RNA polymerase**. As it involves copying DNA, the transcription stage occurs in the nucleus of a cell.

Structure of a gene

Eukaryotic genes have several key structural features in common that allow for transcription to occur (Figure 5). Each gene contains:

- a **promoter** region - the upstream (5' end) binding site of RNA polymerase, the enzyme responsible for transcription. By allowing RNA polymerase to bind to certain genes, promoter regions determine which genes are transcribed, where transcription begins, and the direction of transcription. In eukaryotes, the promoter region is often the sequence of bases 'TATAAA', commonly known as the **TATA box**.
- a **termination sequence** - the sequence in DNA that signals for the end of transcription, also known as the terminator region.

Figure 6 Eukaryotic genes contain a promoter region and termination sequence.

Transcription process

The transcription of a gene can be summarised in three steps:

- initiation
- elongation
- termination.

1 Initiation – To begin transcription, specific proteins called **transcription factors** bind to the promoter region to activate transcription. With the help of transcription factors, RNA polymerase binds to the promoter region. This signals for the weak hydrogen bonds between the two DNA strands to break. This results in the bases of each strand being exposed, and the DNA helix is unwound and unzipped. RNA polymerase is then able to start transcribing.

2 Elongation – RNA polymerase moves along the **template strand**, reading the nucleotide sequence and bringing in free complementary RNA nucleotides (Figure 7). This produces a new single-stranded RNA molecule, known as precursor mRNA (pre-mRNA). The pre-mRNA molecule is synthesised in the 5' to 3' direction, so new RNA nucleotides are added to the exposed 3' end. This pre-mRNA strand is complementary in nucleotide sequence to the DNA template strand. The strand of DNA that is not read by RNA polymerase is called the **coding strand**. As it is also complementary to the template strand, the coding strand is identical to the pre-mRNA strand (except the pre-mRNA includes U not T).

gene expression the process of reading the information stored within a gene to create a functional product, typically a protein

precursor messenger RNA (pre-mRNA) the immediate product of transcription of a DNA sequence. Requires modifications before it can undergo translation

RNA polymerase the enzyme responsible for copying a DNA sequence and constructing an mRNA sequence during transcription

promoter the sequence of DNA to which RNA polymerase binds

TATA box a type of promoter region to which RNA polymerase binds

termination sequence a sequence of DNA that signals the end of transcription

transcription factor proteins that bind to the promoter region and control the function of RNA polymerase

template strand the strand of DNA transcribed by RNA polymerase to produce a complementary mRNA strand

coding strand the strand of DNA not transcribed by RNA polymerase, contains an identical sequence to the mRNA strand produced (except thymine is replaced with uracil in mRNA)

lesson link RNA polymerase is a type of protein called an enzyme, which will be covered in ***5A***.

3 Termination – Transcription ends when the RNA polymerase reaches the termination sequence of a gene, signalling the end of transcription. The RNA polymerase then detaches, releasing the pre-mRNA molecule, and the DNA molecule winds up again into a double helix. The pre-mRNA molecule will be processed, becoming a messenger RNA (mRNA) molecule, and carry the message for protein synthesis from DNA in the nucleus to **ribosomes** in the cytosol.

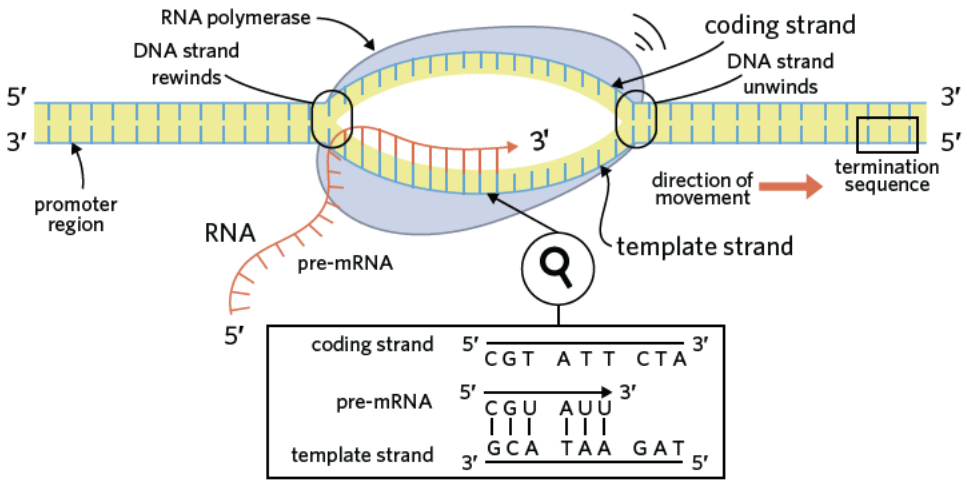


Figure 7 DNA is transcribed by RNA polymerase into a pre-mRNA molecule.

Tip VCAA do not assess transcription in terms of Initiation-Elongation-Termination; it is just a framework for remembering the process. However, the steps in transcription are frequently assessed. In the 2016 (Section B Q6b) and 2013 (Section B Q6ai) exams, the points required for a full mark answer on the steps of transcription were:

- DNA unwinds/unzips
- RNA polymerase catalyses transcription
- Nucleotides are joined by RNA polymerase
- Transcription of the DNA template strand into pre-mRNA
- pre-mRNA is complementary to the DNA template strand
- In the pre-mRNA, A pairs with U, not with Thymine (T).

ribosome an organelle made of rRNA and protein that is the site of protein synthesis. Can be free or attached to RER

5′ methyl cap (five-prime cap) a molecule added to the 5′ end of pre-mRNA during RNA processing

poly-A tail a stretch of adenine nucleotides added to the 3′ end of pre-mRNA during RNA processing

splicing process during gene expression where introns are cut out of a pre-mRNA molecule, and exons are joined together

introns sequences of DNA that do not code for proteins. They are spliced out during RNA processing

RNA processing 3.1.9.3

OVERVIEW

The processing of RNA is the second step in gene expression, and involves modifying the pre-mRNA molecule into an mRNA molecule that can be used in translation.

THEORY DETAILS

Following transcription, the pre-mRNA molecule is not yet ready to help build a polypeptide sequence. The molecule must undergo processing before being sent to the ribosomes of a cell. This processing is known as RNA processing, or post-transcriptional modification, as it can be categorised as part of the transcription stage. It also occurs in the nucleus. The processing modifications include:

- the addition of a **5′ methyl cap** and a **poly-A tail**
- **splicing** (removal) of **introns** (mRNA maturation).

Tip You will frequently hear the process of turning DNA into a protein as only transcription and translation. This is because RNA processing (or post-transcriptional modifications) can be classified as part of the transcription stage (e.g. see the 2013 exam, Section B Q6).

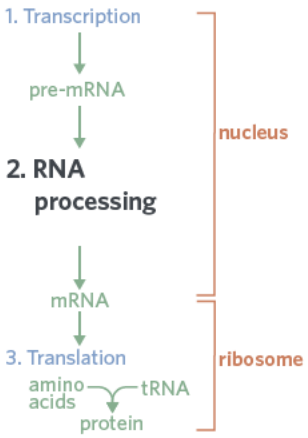


Figure 8 RNA processing/post transcriptional modification is the second step in protein synthesis.

Addition of 5′ methyl cap and poly-A tail

The pre-mRNA is processed by the addition of a methyl molecule at the 5' end during transcription, called a 5' cap. Additionally, a chain of adenine nucleotides is added to the 3' end of the pre-mRNA, which is known as the poly-A tail.

The 5' cap and poly-A tail stabilise the mRNA, preventing it from degrading and allowing it to bind it to the ribosome during translation.

Splicing

Another feature consistent in eukaryotic genes is the presence of intron and **exon** regions. Exons are the regions of DNA that code for amino acids and are expressed, and introns are regions that do not code for amino acids.

All pre-mRNA must have the introns removed before beginning the translation stage (Figure 9). To do this, a complex molecule called a **spliceosome** removes the introns from the pre-mRNA and joins the exon regions to form an mRNA molecule containing only protein coding regions.

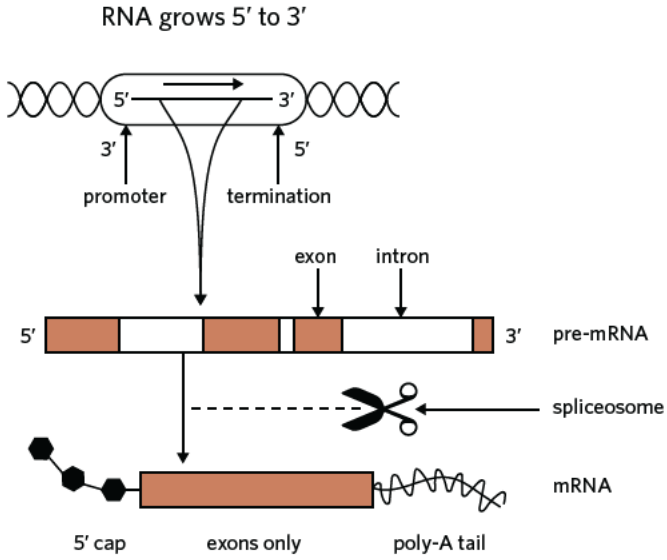


Figure 9 Transcribed pre-mRNA must undergo splicing and processing before it can be translated.

Sometimes exons are removed during the splicing process. This means that a pre-mRNA strand could produce many different mRNA molecules, depending on which exons are spliced out. The differences in splicing, and therefore differences in formation of mRNA, is known as **alternative splicing**. This means that one gene has the capacity to create different mRNA strands and code for different proteins (Figure 10).

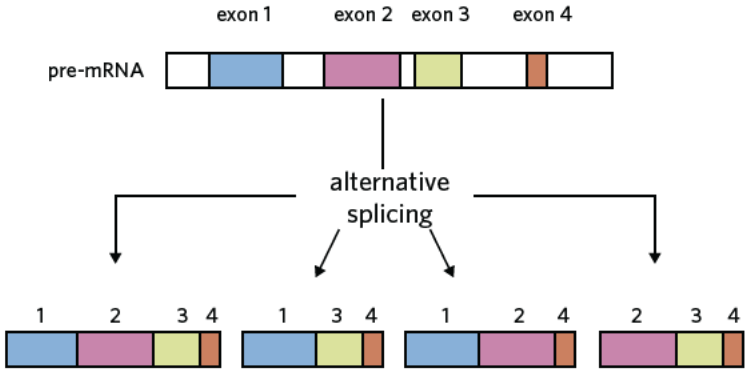


Figure 10 Alternative splicing can create different strands of mRNA from the same gene.

exons sequences of DNA that code for proteins. They make up the mRNA molecule

spliceosome the enzyme that removes introns from the pre-mRNA molecule during RNA processing

alternative splicing process during gene expression where different exons may be spliced, resulting in a single gene producing multiple mRNA strands

Tip An easy way to remember the difference between introns and exons is that **ex**ons **ex**it the nucleus for translation whereas **in**trons stay **in**side the nucleus.

Translation 3.1.9.4

OVERVIEW

Translation is the final step in gene expression, and involves reading and converting the information in the mRNA molecule into a polypeptide sequence.

THEORY DETAILS

After a pre-mRNA molecule is produced from a DNA template strand and undergoes post-transcriptional modification it is ready for translation. In this stage, the information of mRNA codons is translated into a sequence of amino acids (a polypeptide chain).

To undergo translation, mRNA exits the nucleus through a nuclear pore, and travels to a ribosome in the cytoplasm or on the rough endoplasmic reticulum (Figure 12).

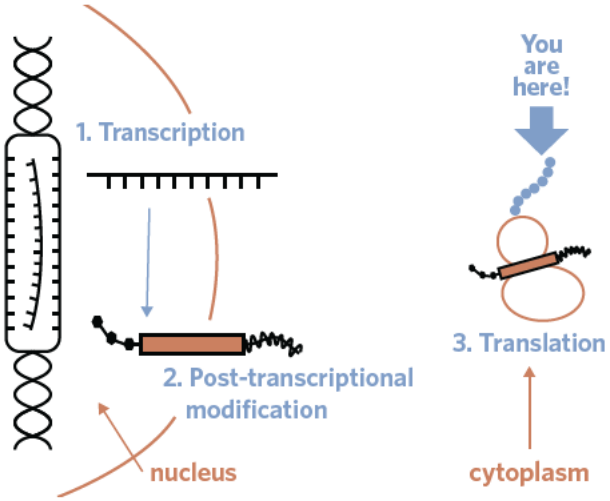


Figure 12 Unlike transcription and post-transcriptional modifications, translation occurs outside of the nucleus at the ribosome.

There are a number of key players in translation including: mRNA, **rRNA** making up the ribosome, **transfer RNA** (tRNA), and amino acids. During translation, the mRNA binds to the ribosome. The tRNA delivers specific amino acids to the ribosome, which are added on to the end of the polypeptide chain. The amino acid is determined by the codon on the mRNA, which is complementary to the **anticodon** on the tRNA (Figure 13). The detailed steps of translation are described below.

The translation of mRNA into a polypeptide can be summarised in three steps:

- initiation
- elongation
- termination.

1 Initiation – The small **ribosomal subunit** attaches to the 5' end of the mRNA strand, and reads it until it reaches a start codon (AUG). Then, a tRNA molecule with the complementary anticodon (UAC) binds to the ribosome and delivers the amino acid methionine (the codon AUG, and therefore anticodon UAC, codes for 'met'). The large ribosomal subunit then also binds to the mRNA, and translation can begin.

2 Elongation – After the first amino acid is attached, the mRNA is fed through the ribosome so the next codon can be matched to a new complementary tRNA. The new tRNA delivers the other specific amino acid, which binds to methionine with a **peptide bond** via a condensation polymerisation reaction. The first tRNA molecule then leaves and is free to pick up another amino acid, and the next mRNA codon is exposed for more tRNA-delivered amino acids to add to the growing amino acid chain.

3 Termination – The reading of mRNA, delivery of amino acids by tRNA, and linking of amino acids in a polypeptide chain continues until the ribosome reaches a stop codon on the mRNA. The stop codon signals the end of translation as there are no corresponding tRNA molecules. The polypeptide chain is then released by the ribosome, into the cytosol or endoplasmic reticulum.

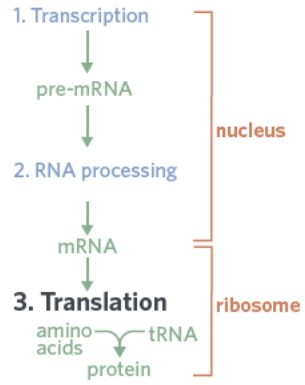


Figure 11 Translation is the third step in protein synthesis.

Analogy

You can think of transcription as photocopying recipes from a cookbook. Then translation is a chef (ribosome) using the recipe (mRNA) to produce a dish (protein). The chef's assistant (tRNA) fetches the ingredients (amino acids) needed to make the perfect dish.

ribosomal RNA (rRNA) RNA that is a key structural component of ribosomes, which assemble proteins

transfer RNA (tRNA) RNA that recognises individual codons on the mRNA strand and adds the corresponding amino acid to the polypeptide chain during protein synthesis

anticodon the sequence of three nucleotides on a tRNA molecule that recognises a specific sequence of three nucleotides (codon) on an mRNA strand

ribosome subunit a structure that forms part of a ribosome. Each ribosome is comprised of a small and a large subunit

peptide bond the chemical bond linking two amino acid monomer subunits

lesson link The tRNA molecules pick up free-floating amino acids in the cytosol, in a reaction catalysed by special proteins called enzymes (***5A***).

Tip Triplet = DNA
Codon = mRNA
Anticodon = tRNA

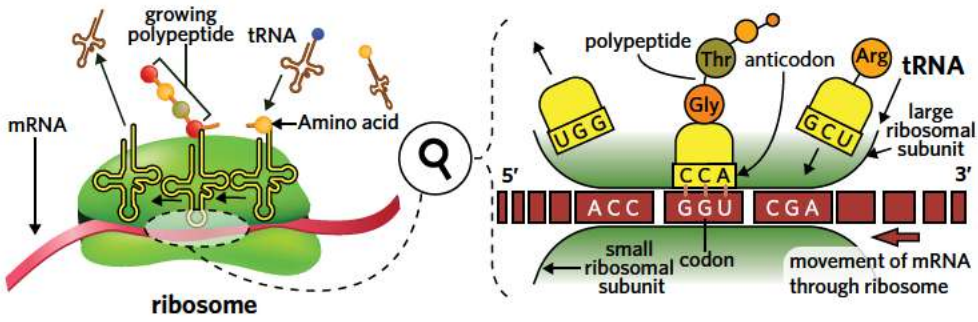


Image: Designua/Shutterstock.com

Figure 13 The translation of mRNA at the ribosome

Tip VCAA do not assess translation in the Initiation-Elongation-Termination steps; it is just a framework for remembering the process. However, the steps in the process are frequently assessed. In the 2018 (Section B Q1a) and 2014 (Section B Q7a) exams, the points required for a full mark answer on the steps of translation were:

- Ribosome binds to and reads the mRNA
- tRNA anticodons are complementary to mRNA codons
- tRNA brings specific amino acids
- The amino acids are joined in a polypeptide chain by condensation polymerisation.

Following translation, the mRNA can be reused to produce more polypeptides. At the endoplasmic reticulum and Golgi apparatus, the polypeptide chain is folded and modified into a fully functional protein (see lesson 3C). The protein can then either remain in the cell for use, or can undergo exocytosis to be used outside the cell.

Theory summary

The information required to produce proteins is stored within genes in the form of DNA triplets. Transcription involves copying this information onto a pre-mRNA molecule that undergoes post-transcriptional modifications (e.g. intron splicing) to become an mRNA molecule. The codons in mRNA indicate the order of amino acids to be assembled at the ribosome during translation. The translation process is aided by tRNA molecules, and the final product is a polypeptide chain.

The process of protein synthesis works because the genetic code gives instructions about what triplet/codon codes for what amino acid. The genetic code is degenerate, universal, and non-overlapping.

Table 1 Summary of the three steps in protein synthesis and the genetic code

	The genetic code	Transcription	RNA processing	Translation
Key points	• Triplet nature • Universal • Degenerate • Non-overlapping	• RNA polymerase binds to promoter region • DNA unwinds • RNA polymerase reads template strand • Complementary nucleotides brought in pre-mRNA strand produced, complementary to the template strand • Transcription ends when termination sequence is reached	• Introns removed and exons joined • Addition of a methyl cap to 5′ end • Addition of a poly-A tail to 3′ end	• Ribosome reads mRNA • tRNA anticodons complementary to mRNA codons • tRNA deliver amino acids • Amino acids joined by condensation reaction to form a polypeptide • Translation ends when STOP codon reached
Location	-	Nucleus	Nucleus	Ribosomes
Facilitated by	-	• RNA polymerase • Promoter region	• Spliceosome	• Ribosome subunits • tRNA molecules
Product	-	pre-mRNA from DNA template strand	mRNA from pre-mRNA	Polypeptide from mRNA

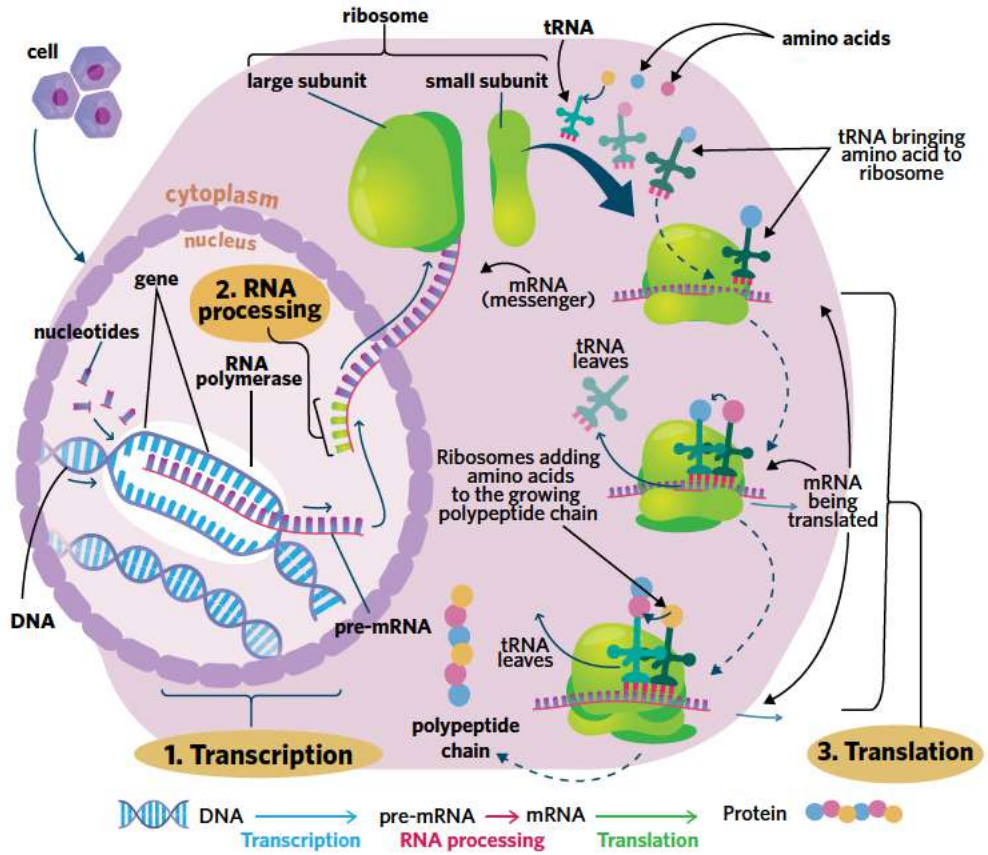


Image: VectorMine/Shutterstock.com

Figure 14 Summary of translation and the preceding steps in protein synthesis within a cell

4C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a segment of DNA that codes for the production of a polypeptide
b _____ the strand of DNA that is read and copied during transcription
c _____ a group of three nucleotides in mRNA that codes for one amino acid
d _____ a set of rules about reading DNA that is said to be degenerate and universal
e _____ the nitrogenous base found in RNA but not DNA
f _____ an addition to the 5′ end of pre-mRNA during post-transcriptional modifications
g _____ the specialised enzyme that binds to the promoter region during transcription
h _____ the strand of DNA that is not read and copied during transcription
i _____ the process of using mRNA to produce a polypeptide
j _____ an RNA strand that carries the information from genes before splicing
k _____ RNA molecules that transport amino acids to ribosomes
l _____ three nucleotides in mRNA that signal for the end of translation
m _____ a group of three nucleotides in DNA that codes for one amino acid
n _____ the process of converting the information within genes to mRNA
o _____ the site of translation
p _____ a sequence of nucleotides that signals for RNA polymerase to stop its action
q _____ an addition to the 3′ end of pre-mRNA during post-transcriptional modification
r _____ the segment of a gene that codes for a polypeptide

s _____ the segment of a gene that does not code for a polypeptide

t _____ the type of bond formed between amino acids

u _____ the site of transcription and RNA processing

Question 2

Which of the following are all true of the transcription process?

A	RNA polymerase facilitates the process	DNA is permanently unwound	Ends at a STOP codon
B	RNA polymerase facilitates the process	DNA is unwound and rewound	Ends at a termination sequence
C	RNA polymerase facilitates the process	DNA is permanently unwound	Ends at a termination sequence
D	tRNA molecules facilitate the process	DNA is unwound and rewound	Ends at a STOP codon

Question 3

Fill in the blanks in the following sentences.

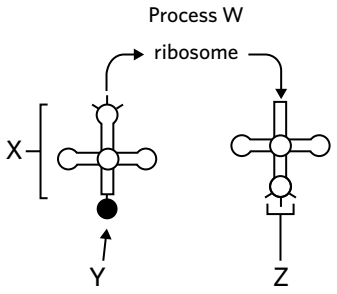
Translation occurs at the _____**I**_____, where the ribosome binds to the _____**II**_____ strand and reads it. The process is facilitated by tRNA molecules and their tri-nucleotide sequences known as _____**III**_____. Amino acids delivered by tRNA molecules are linked into a polypeptide chain until a _____**IV**_____ is reached and translation ends.

	I	**II**	**III**	**IV**
A	nucleus	tRNA	anticodons	STOP codon
B	ribosome	mRNA	codons	STOP anticodon
C	ribosome	mRNA	anticodons	STOP codon
D	ribosome	mRNA	codons	STOP anticodon

Question 4

Which of the following correctly identifies W-Z?

	Process W	**X**	**Y**	**Z**
A	transcription	tRNA	protein	codon
B	translation	tRNA	amino acid	anticodon
C	translation	tRNA	protein	anticodon
D	transcription	mRNA	amino acid	codon



Question 5

Which of the following correctly identifies features of the genetic code?

A degenerate, of a triplet nature, universal, ambiguous, non-overlapping

B of a triplet nature, unpredictable, degenerate, universal

C non-overlapping, degenerate, of a triplet nature, random

D universal, non-overlapping, of a triplet nature, degenerate

Question 6

Fill in the blanks in the following sentences.

To create a protein from genetic information, a cell must undergo a series of steps. The first is transcription, where the _____**I**_____ is read and transcribed into pre-mRNA. This pre-mRNA must be processed before translation by splicing introns and the addition of a 5′ cap and a _____**II**_____. The mRNA can now be translated. This is possible due its sequences of three nucleotides in the mRNA known as _____**III**_____. At the ribosome, mRNA is used to create a _____**IV**_____.

	I	II	III	IV
A	coding strand	poly-A tail	anticodons	polypeptide chain
B	template strand	poly-A tail	anticodons	amino acid
C	coding strand	tRNA	codons	amino acid
D	template strand	poly-A tail	codons	polypeptide chain

Exam-style questions

Within lesson

Question 7 (1 MARK)

In populations of fruit flies, there are individuals that are resistant to the effects of insecticides. In normal insecticide-susceptible fruit flies, a specific section of mRNA has the sequence CAU, whereas, in the insecticide-resistant fruit flies, the sequence is CAA. Considering the mRNA sequence of insecticide-susceptible fruit flies, the corresponding sequence of nucleotides on these individuals' DNA is

A GUA.
B CAU.
C GTT.
D GTA.

Adapted from VCAA 2014 Section A Q22

Question 8 (1 MARK)

A molecule of messenger RNA could include the nucleotide sequence

A CTGTATUTA
B AGTGUACTT
C GTACGTAGG
D CUACGAGUU

Adapted from VCAA 2011 Exam 1 Section A Q4

Question 9 (1 MARK)

The following is a sequence of amino acids located within a polypeptide: **Asn-Phe-Ala-Asp-Tyr**

1st position (5′ end)	2nd position				3rd position (3′ end)
	U	**C**	**A**	**G**	
U	Phe	Ser	Tyr	Cys	**U**
	Phe	Ser	Tyr	Cys	**C**
	Leu	Ser	STOP	STOP	**A**
	Leu	Ser	STOP	Trp	**G**
C	Leu	Pro	His	Arg	**U**
	Leu	Pro	His	Arg	**C**
	Leu	Pro	Gln	Arg	**A**
	Leu	Pro	Gln	Arg	**G**
A	Ile	Thr	Asn	Ser	**U**
	Ile	Thr	Asn	Ser	**C**
	Ile	Thr	Lys	Arg	**A**
	Met	Thr	Lys	Arg	**G**
G	Val	Ala	Asp	Gly	**U**
	Val	Ala	Asp	Gly	**C**
	Val	Ala	Glu	Gly	**A**
	Val	Ala	Glu	Gly	**G**

Using the table provided, the DNA template sequence that could code for this amino acid sequence is

A TTA / AAG / CGC / CTA / ATG

B TTG / AAA / GGC / CTA / ACC

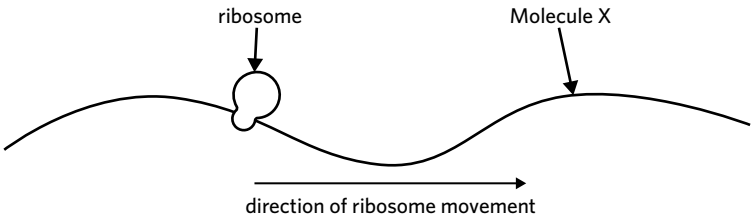
C UUA / AAA / CGC / CUG / AUG

D UUG / AAG / GGC / CUA / ACC

Adapted from VCAA 2015 Section A Q23

Use the following information to answer Questions 10 and 11.

Ricin is a naturally occurring, powerful poison that affects eukaryotic organisms. Studies have concluded that ricin stops the movement of a ribosome along a specific molecule labelled Molecule X.



Question 10 (1 MARK)

Which monomer is Molecule X made of?

A fatty acids

B nucleotides

C amino acids

D carbohydrates

Question 11 (1 MARK)

At the stage shown in the diagram, Molecule X contains

A exons only.

B introns only.

C both exons and introns.

D neither exons or introns.

Multiple lessons

Question 12 (1 MARK)

The genome of the Northern white-cheeked gibbon, *Nomascus leucogenys*, has been sequenced and compared to other primate species.

The *N. leucogenys* genome would

A include the base uracil.

B include only the non-coding DNA sequences.

C be identical to the genome of the buffed-cheeked gibbon, *Nomascus annamensis.*

D contain the same nitrogenous base types to the genome of the black-crested gibbon, *Nomascus concolor.*

Adapted from VCAA 2015 Section A Q24

Question 13 (5 MARKS)

Consider the template strand of a hypothetical gene shown. The exons are in bold type.

3′ **TAC ACC GCT** TAT TTT **CAT** CTT **TCT** GCA TAG **GAT ATC** 5′

NOTE:

- The DNA triplet TAC indicates START and codes for the amino acid methionine that remains in the polypeptide
- The DNA triplets ATC, ATT and ACT code for a STOP instruction.

a How many amino acids would be present in the polypeptide expressed by this gene? (1 MARK)

b The template strand is used to produce mRNA.

i What is the pre-mRNA strand that would be produced from this DNA sequence? (1 MARK)

ii What is the corresponding mRNA sequence following RNA processing? (1 MARK)

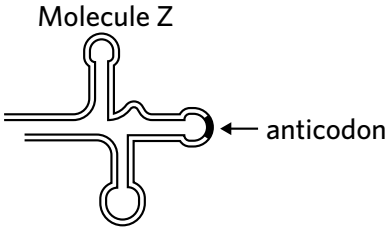
iii Using the table provided, what is the amino acid sequence produced when the mRNA molecule is translated? (2 MARKS)

1st position (5′ end)	2nd position				3rd position (3′ end)
	U	C	A	G	
U	Phe	Ser	Tyr	Cys	**U**
	Phe	Ser	Tyr	Cys	**C**
	Leu	Ser	STOP	STOP	**A**
	Leu	Ser	STOP	Trp	**G**
C	Leu	Pro	His	Arg	**U**
	Leu	Pro	His	Arg	**C**
	Leu	Pro	Gln	Arg	**A**
	Leu	Pro	Gln	Arg	**G**
A	Ile	Thr	Asn	Ser	**U**
	Ile	Thr	Asn	Ser	**C**
	Ile	Thr	Lys	Arg	**A**
	Met	Thr	Lys	Arg	**G**
G	Val	Ala	Asp	Gly	**U**
	Val	Ala	Asp	Gly	**C**
	Val	Ala	Glu	Gly	**A**
	Val	Ala	Glu	Gly	**G**

Question 14 (6 MARKS)

The hormone insulin is a relatively small protein. Researchers studying the production of insulin in the cells of the pancreas noted that one of the early steps in this process was the formation of a polypeptide called preproinsulin.

Researchers noted that the formation of this polypeptide required repeated use of different types of the Molecule Z shown.



a Molecule Z is heavily involved in a specific process.

i Which process is Molecule Z involved in? (1 MARK)

ii Identify the role of anticodons in this process. (2 MARKS)

b Proteins have four levels of structure.

i What level of structure is preproinsulin if it has not configured into an alpha helix or beta-pleated sheet structure? (1 MARK)

ii Insulin is made of two peptide chains, referred to as the A chain and B chain. Outline how preproinsulin is converted to insulin. (2 MARKS)

Adapted from VCAA 2016 Section B Q6

Question 15 (8 MARKS)

Scientists studying the nucleus of the fruit fly *Drosophila melanogaster* observed distinct types of nucleic acid chains. One type of nucleic acid chain was able to pass through the nuclear membrane and move to a ribosome. After the nucleic acid chain attaches to the ribosome, a polymer is produced.

a What type of molecule is this nucleic acid chain? (1 MARK)

b Describe the steps that occur within a cell that result in the production of this nucleic acid chain. (3 MARKS)

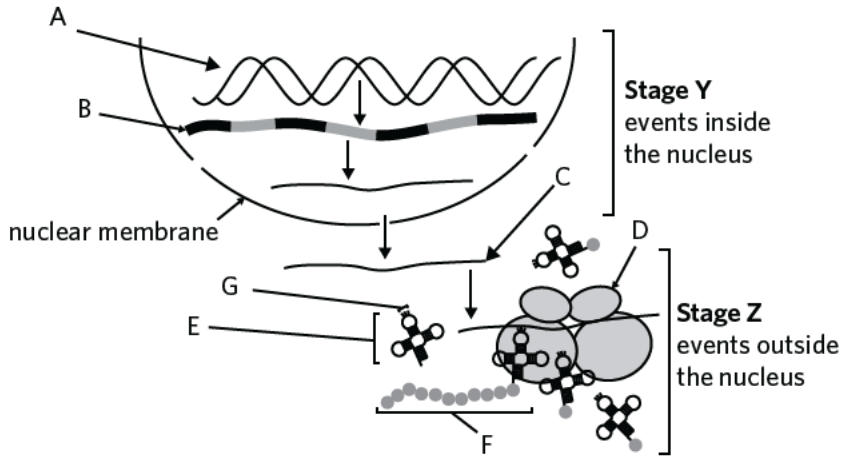
c What type of molecule is the polymer produced? (1 MARK)

d Describe the steps that occur at the ribosome that convert this nucleic acid chain into the polymer. (3 MARKS)

Adapted from VCAA 2014 Section B Q7

Question 16 (9 MARKS)

The following diagram outlines various events that occur in cells when DNA is activated.



Complete the table by identifying the structures or processes in the diagram.

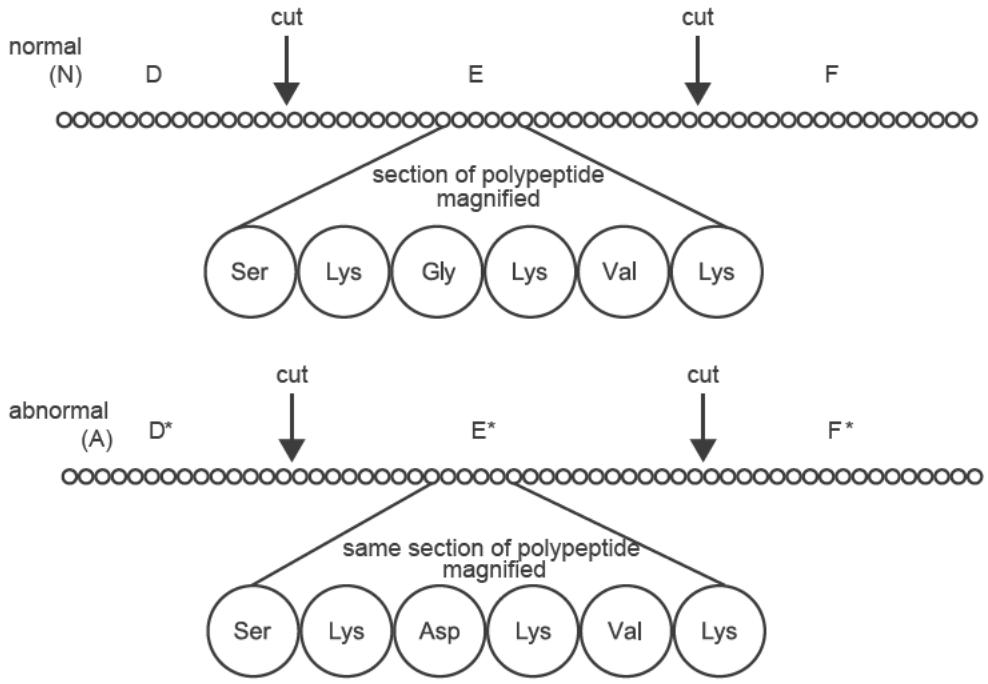
A	
B	
C	
D	
E	
F	
G	
Stage Y	
Stage Z	

Adapted from VCAA 2013 Section B Q6

Key science skills

Question 17 (7 MARKS)

Scientists have investigated how the nucleus accumulates the essential proteins that it needs to function. They found a possible reason while studying a certain normal polypeptide sequence, and an abnormal version. The abnormal polypeptide produced was not able to cross the nuclear membrane in the same way the normal form did. The polypeptides in the normal (N) and abnormal (A) sequence are shown. A sequence of six amino acids from the middle is magnified.



An experiment was carried out where both chains were cut into three smaller chains - D, E, and F (D*, E* and F*) - as shown. Each polypeptide was put into a cell and then its accumulation in the nucleus was measured. The table shows the results of the experiment.

Polypeptide	Accumulates in nucleus
N	yes
A	no
D	no
E	yes
F	no
D*	no
E*	no
F*	no

a Name the dependent and independent variables of this experiment. (2 MARKS)

b Which polypeptides were easily able to cross the nuclear envelope? Justify your answer. (2 MARKS)

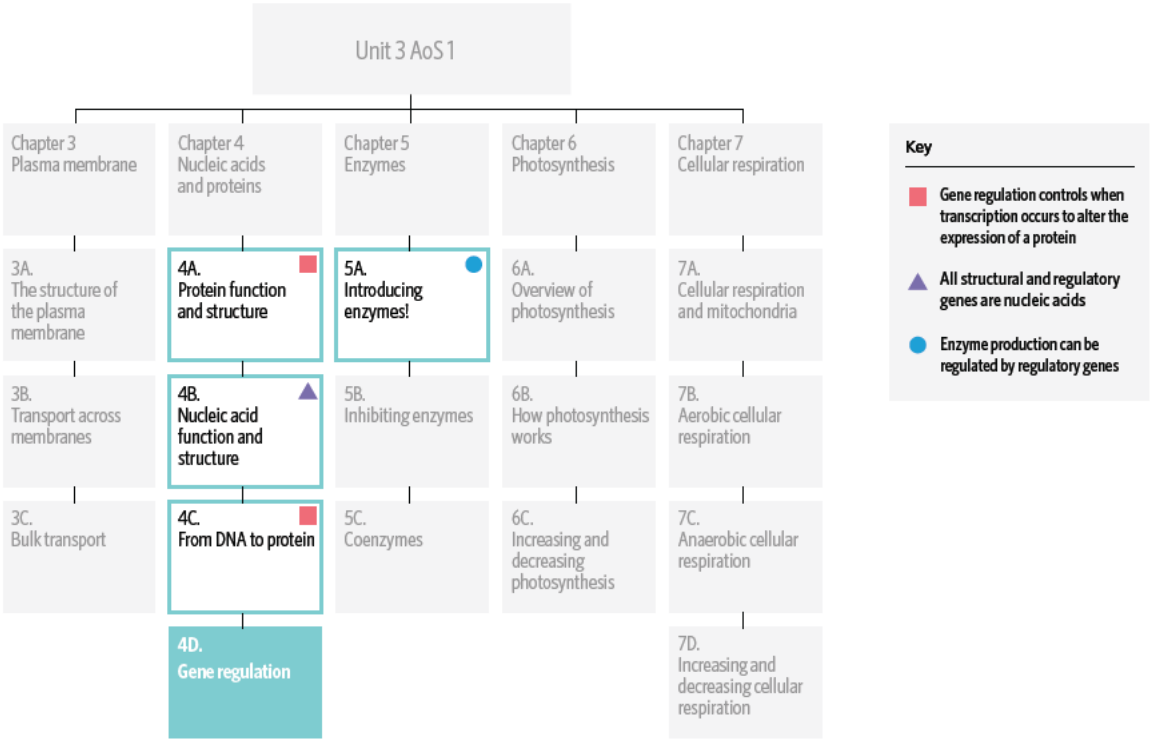
c Polypeptide E accumulated in the nucleus whereas polypeptide E* did not. Suggest a reason why polypeptide E* did not accumulate in the nucleus like E. (1 MARK)

d How could the scientists increase the precision of their experiment? (2 MARKS)

Adapted from VCAA 2014 Section B Q2

4D GENE REGULATION

Jeans vs genes: one costs a lot of money, one costs a lot of energy, but both can make you look very good.



In this lesson you will learn how regulatory genes either initiate or prevent transcription. You will look specifically at the switching on and off of the *lac* operon in *E. coli* bacteria as a simple model to learn about gene regulation.

Study design dot points

- the functional distinction between structural genes and regulatory genes
- use of the *lac* operon as a simple prokaryotic model that illustrates the switching off and on of genes by proteins (transcriptional factors) expressed by regulatory genes

Key knowledge units

Structural vs regulatory genes	3.1.10.1
How the *lac* operon works	3.1.12.1

Structural vs regulatory genes 3.1.10.1

OVERVIEW

Regulatory genes code for proteins that influence the expression of structural genes. This prevents the over or under expression of a particular protein and allows the cell to adapt to its needs.

THEORY DETAILS

Think about how much energy we use in a single day. It takes a lot to make our heart beat, maintain our body temperature, suck air into our lungs, and even to think! Not to mention the energy costs of walking, running, jumping, or even picking up your phone. Because we burn a lot of energy, we need to be smart about how it gets used.

Protein production is a complex process that requires a high energy investment. The enzymes that double check that proteins have been correctly produced also require energy. This means that organisms need to prevent any unnecessary production of proteins. Proteins that control transcription are called regulatory proteins, and the genes that encode for their production are **regulatory genes.**

regulatory gene a segment of DNA responsible for producing proteins that control the expression of other gene(s)

Regulatory genes are responsible for the production of protein molecules that can:

- turn gene expression on or off
- increase or decrease expression of a gene by promoting or hindering transcription
- control the types of post-transcriptional modifications that occur, including the way gene splicing occurs.

Structural genes do not make proteins that are involved in the regulation of other genes. They encode for proteins that have a role in the structure or function of an organism. For example, enzymes, keratin, haemoglobin, channel proteins, and insulin are all structural or functional proteins. Structural genes are often found downstream (towards the 3' end of a piece of DNA) of the regulatory gene that controls them.

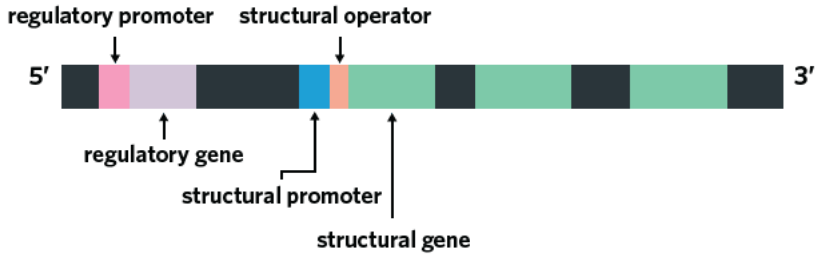


Figure 1 Basic structure of an operon with three structural genes

In 4C, you learned about the basic structure of a gene including the: **promoter** region, start and stop codons, introns and exons, and the influence each of these have on protein production (Figure 1). Often, multiple genes are arranged together in groups so that their expression can be controlled by a single 'on-off switch'. These switches are known as **operator** sequences. Operators are always located downstream of the gene's promoter region. So, if the operator is blocked with a **repressor protein**, RNA polymerase cannot move downstream from the promoter and the genes of the **operon** cannot be transcribed ('switched off'). If the repressor protein is not bound to the operator, transcription can continue as usual ('switched on'). Because repressor proteins regulate gene expression, the sequence that codes for them is considered a regulatory gene. The proteins encoded by an operon typically all play a role in the same cellular pathway.

structural gene a segment of DNA that doesn't code for regulatory proteins, but codes for proteins that will be used functionally or structurally throughout a cell or organism

promoter the sequence of DNA to which RNA polymerase binds

operator a short region of DNA that interacts with regulatory proteins to alter the transcription of an operon

repressor protein a protein coded for by a regulatory gene that prevents gene expression by binding to an operon

operon a cluster of linked genes that all share one promoter region and are transcribed at the same time

***lac* operon** an operon in *E. coli* that contains a regulatory gene, promoter, operator, and three structural genes useful for digestion of lactose as an energy source

gene regulation the control of gene expression, typically achieved by switching transcription on or off

How the *lac* operon works 3.1.12.1

OVERVIEW

The *lac* operon of *E. coli* contains genes that digest lactose, so it can be used as an alternative energy source. The *lac* operon contains a regulatory gene, promoter region, operator region, and the structural genes: *lacZ*, *lacY*, and *lacA*. Its expression is regulated by a repressor protein and the concentration of environmental lactose.

Analogy

Think of our genes as retail employees. Our structural genes are the team members that get to do all the manual labour, like stocking shelves or cleaning up on aisle six. Our regulatory genes are the managers that decide who is working when and what they will be doing.

THEORY DETAILS

The switching on-and-off of the ***lac* operon** in *Escherichia coli (E. coli)* bacteria provides a simple representation of the importance of **gene regulation**. The *lac* operon consists of a regulatory gene, a promoter region, an operator region, and the three structural genes *lacZ*, *lacY*, and *lacA*. Transcription of the *lac* operon is regulated by the upstream regulatory gene (Figure 2).

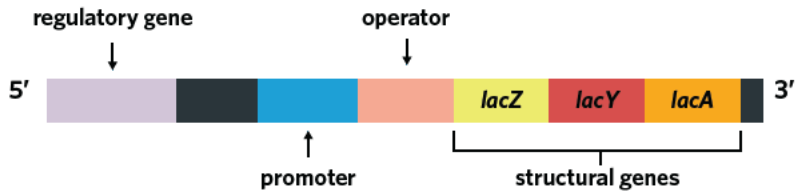


Figure 2 The *lac* operon of *E. coli*

E. coli use glucose as an energy source. Lactose is made of glucose and galactose, so by splitting the lactose molecules, glucose can be produced and fed into the cellular respiration pathway. This means the enzymes required to breakdown and metabolise lactose are only required when glucose is limited. These enzymes are encoded by the three structural genes found in the *lac* operon.

It is selectively advantageous to only express proteins when they are required. When glucose is plentiful, *E. coli* will preferentially metabolise glucose and the *lac* operon is repressed to prevent unnecessary protein synthesis.

The regulatory gene for the *lac* operon (*lacI*) is constantly expressed to produce a repressor protein that binds to the operator region of the *lac* operon. In this way, the repressor prevents transcription of the structural genes by blocking RNA polymerase (Figure 3).

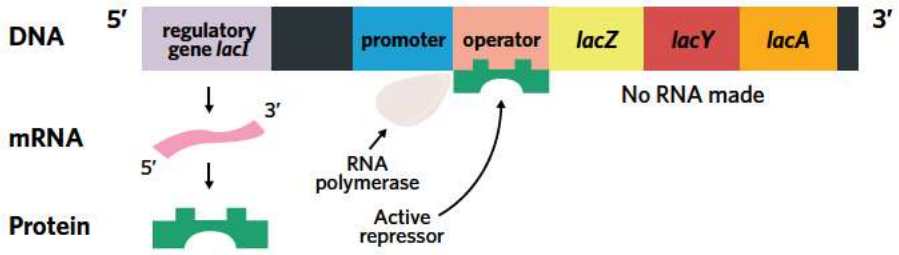


Figure 3 When lactose levels are low, the repressor protein binds to the operator and prevents transcription.

When lactose levels are high, some lactose is converted into **allolactose** (which involves a slight change in chemical structure). Allolactose binds to and changes the shape of the repressor protein, causing the repressor protein to disconnect from the DNA strand. This means that RNA polymerase can begin transcription of the *lac* operon, and the three structural proteins encoded by the structural genes *lacZ*, *lacY*, and *lacA* are produced. The ultimate result is that these structural proteins break down lactose into glucose and galactose, and glucose can be used in cellular respiration. When the lactose is eventually used up allolactose releases the repressor, which will once again inhibit transcription of the structural genes.

allolactose an inducer molecule that binds to the *lac* repressor to release it from the operator region

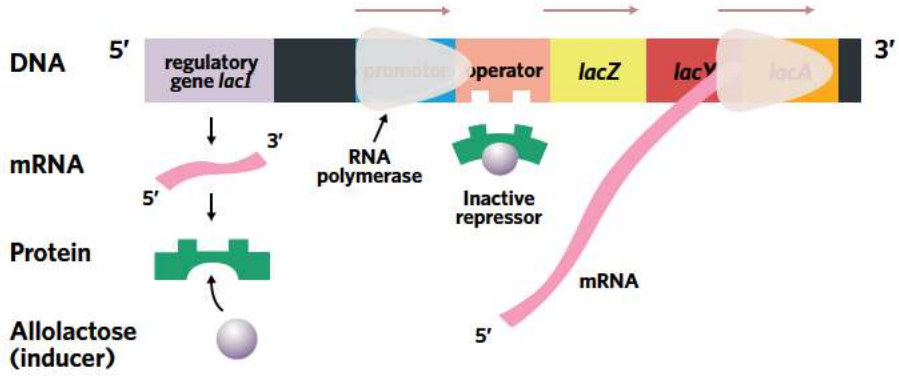


Figure 4 When lactose is present in large amounts, allolactose binds to the repressor protein and RNA polymerase can transcribe the *lac* operon in *E. coli*.

Theory summary

Genes can be classified into two types, structural and regulatory genes. Structural genes encode proteins that will be used functionally or structurally throughout a cell or organism whilst regulatory genes produce proteins that influence the expression of other genes. The regulation of genes is necessary to prevent the overproduction or underproduction of proteins. The *lac* operon in *E. coli* provides a simple model to study gene regulation. It involves a repressor protein binding to the operator region of the operon when there are low levels of lactose present in the cell, preventing transcription. When lactose levels are high, the repressor protein cannot bind to the operator and transcription of the *lac* operon can take place.

Table 1 Summary of the action of the *lac* operon in different concentrations of lactose

Lactose levels	Regulatory sequence	Repressor	*lacZ*, *lacY*, and *lacA*
High	Transcribed	Releases from operator	Transcribed
Low	Transcribed	Binds to operator	Not transcribed

4D QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a gene that encodes a protein that affects the expression of another gene

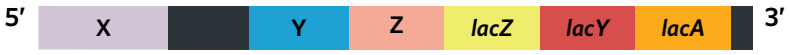
b _____ a protein that can prevent transcription

c _____ found in *E. coli*, this section of DNA is transcribed when glucose concentrations are low and lactose concentrations are high

d _____ a gene that codes for a protein that makes up the physical structure or function of an organism that does not regulate the expression of another gene

Question 2

Which of the following options correctly describes regions X, Y, and Z of the *lac* operon in *E. coli* bacteria?



	X	Y	Z
A	promoter	regulatory gene	operator
B	structural gene	promoter	operon
C	regulatory gene	promoter	operator
D	regulatory gene	promoter	structural gene

Question 3

Which of the following correctly describes the relationship between lactose and glucose concentration in *E. coli* and the action of the repressor protein?

	lactose concentration	glucose concentration	repressor protein
A	high	low	bound to DNA
B	low	low	bound to DNA
C	low	high	unbound to DNA
D	high	low	unbound to DNA

Question 4

Which of the following is false?

A Regulatory genes do not contain a promoter region.

B Regulatory genes can encode proteins which regulate the expression of structural genes.

C In high concentrations of lactose, the repressor unbinds from the *lac* operon.

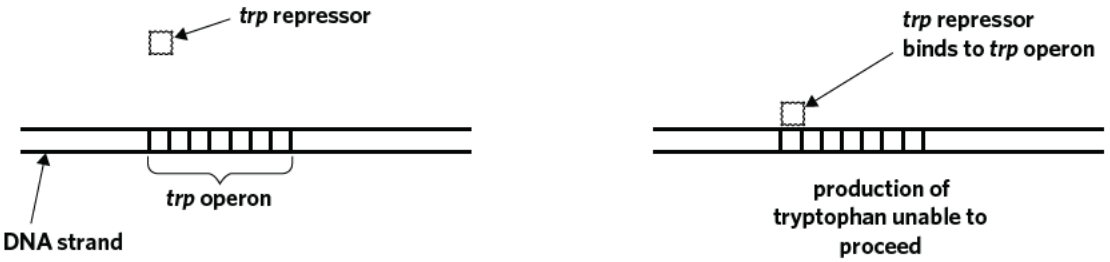
D Gene regulation helps an organism to conserve energy.

Exam-style questions

Within lesson

Use the following information to answer Questions 5 and 6.

Tryptophan is an amino acid that is produced by many bacteria. Genes that code for enzymes that produce tryptophan are found on bacterial DNA and together are called the *trp* operon. In the process of gene regulation, a repressor protein (*trp* repressor) binds to the *trp* operon. When such binding occurs, the process of tryptophan production stops. This is illustrated in the diagram.



Question 5 (1 MARK)

Using your knowledge of the *lac* operon, the *trp* repressor will bind to

A the promoter region.

B the operator region.

C pre-mRNA.

D tRNA.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q27

Question 6 (1 MARK)

Which of the following statements is correct concerning the *trp* operon?

A The *trp* repressor molecule is encoded by a structural gene.

B The *trp* operon is most active when trp concentration is high.

C Low concentrations of tryptophan increase the likelihood of *trp* repressor releasing from the DNA.

D High concentrations of RNA polymerase increase the likelihood of *trp* repressor releasing from the DNA.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q28

Multiple lessons

Question 7 (1 MARK)

Which of the following is a correct statement regarding the structure of a gene in a eukaryotic cell?

A Only prokaryotes exhibit gene regulation.

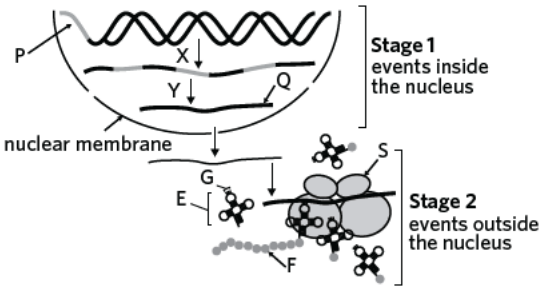
B An intron is transcribed but not translated.

C Structural genes encode for repressor proteins.

D A regulatory gene is always found downstream of a gene.

Question 8 (6 MARKS)

The following diagram outlines various events that occur in cells when DNA is activated.



a Name and outline the purpose of Stage 1 and Stage 2. (2 MARKS)

b Outline events that occur during action Y. (2 MARKS)

c Note that structure P consists of two different kinds of genes. Name and describe the role of each of the two types of genes. (2 MARKS)

Question 9 (10 MARKS)

The *lac* operon was originally identified in *Escherichia coli*. The *lacZ* gene codes for the production of the enzyme β-galactosidase, which catalyses the breakdown of lactose into glucose and galactose. The diagram shows the order of the genes found in the *lac* operon. The dots represent the DNA nucleotides between the genes.

a Name a structural gene found in the *lac* operon. (1 MARK)

b Outline the role of the repressor molecule in the *lac* operon. Be sure to include where it binds and how it is released. (2 MARKS)

c Describe the role of the promoter region in the *lac* operon. (1 MARK)

d In the presence of lactose, the β-galactoside protein can be produced. Briefly outline the biochemical processes that must occur to produce the protein. (4 MARKS)

e Suggest why the regulation of the *lac* operon is important for the survival of *E. coli*. (2 MARKS)

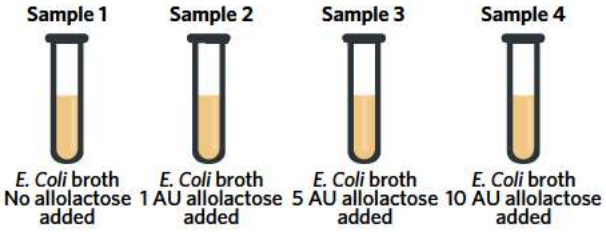
Adapted from VCAA 2017 Section A Q2

Key science skills

Question 10 (8 MARKS)

Sinead and Gillian designed an experiment to test the effect of allolactose concentration on the production of the enzyme β-galactoside transacetylase, which is encoded by the *lacA* gene and found in the *lac* operon.

The experimental design is shown in the diagram.



a Outline what an experimental control is and explain its purpose. Identify which sample acts as an experimental control in this experiment. (3 MARKS)

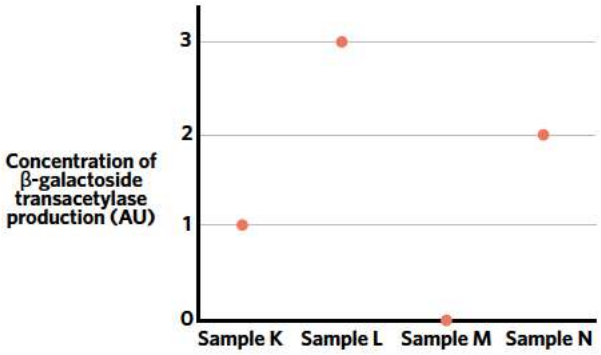
b Outline a safety consideration that should be applied to this experiment. (1 MARK)

c State the hypothesis that Sinead and Gillian were testing. (1 MARK)

d Sinead and Gillian forgot to label each test tube in their experiment.

i Identify the type of error that has occurred. (1 MARK)

ii They collected their results and graphed them. State which test tube you'd expect to match each sample shown in the graph. Using your knowledge of the *lac* operon, briefly explain your response. (2 MARKS)



ACTIVITY

Extracting DNA

Introduction

To get DNA out of anything that has DNA (e.g. broccoli, bacon, a blood cell), follow the basic procedure below. We will use an onion.

Purpose

The aim of this experiment is to visualise DNA, and to make inferences about the structure of DNA and other cell components.

Requirements

- large test tube
- liquid dishwashing detergent
- meat tenderiser (powder)
- small strainer
- alcohol (ethanol or rubbing alcohol)
- onion (or any other vegetable material, bananas, strawberries, and kiwi fruit also work well)
- blender (or mortar and pestle)
- water
- stirring rod
- clock

Procedure

1. The sample of onion tissue needs to be broken up to separate the cells from each other. To do this is, add the onion and a little bit of water to a blender and blend it until it is a 'soup'. Alternatively, use a mortar and pestle.
2. Once you have broken up the tissue into a soup, you will need to strain it. You need about one-third of a test tube full of 'soup'. Straining the soup ensures that you get onion cells and water in the test tube but not fibre (which is not needed and will make it harder to mix the cells with detergent and enzymes).
3. Add one-sixth as much detergent as you have 'soup'. Use the stirring rod to gently mix the detergent with the cells in the soup. Allow this mixture to sit for about 7 minutes.
4. Add a pinch of meat tenderiser, which contains protease enzymes. Stir very gently.
5. Gently pour alcohol down the side of the test tube until the test tube is about three-quarters full. It is important to pour the alcohol very gently down the side of the test tube so that it does not mix with the 'soup' but instead forms a layer on top of it.
6. Allow the mixture to sit for a while and you should be able to see the DNA from the onion floating up into the alcohol layer. Illuminating it from behind with a lamp makes it even more visible.

Questions

1. What does the DNA in your test tube look like? Describe it and draw a sketch of it.
2. Is it possible to get the DNA out of the test tube? Try it!
3. Dishwashing detergent is used to wash dishes because it emulsifies fats, allowing them to be washed away from your dishes. Based on your understanding of cellular structure and composition, explain the role of the detergent in this practical activity.
4. Meat tenderiser contains protease enzymes (which you will become familiar with in 5A). It is used in cooking because it digests the fibrous proteins (actin and myosin) in muscle cells and thereby makes the meat softer. Based on your understanding of cellular structure and composition, try to explain the role of the protease enzymes (meat tenderiser) in this practical activity.
5. In this practical activity, the purity of the DNA is unimportant (we are not using it for forensic science or genetic testing). In applications in which the purity of the DNA is important, it is not appropriate to use detergent or meat tenderiser. Suggest another way to get the DNA out of the cells without using detergent or protease enzymes.
6. Explain why the DNA moves up into the alcohol layer.
7. Predict where the proteins and membranes of the onion cells are in the test tube by the end of the practical activity.

CHAPTER SUMMARY

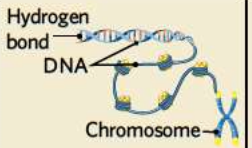
Rotate page

NUCLEIC ACIDS

Function

- **DNA** stores genetic information
- **mRNA** transports the genetic information in DNA
- **tRNA** transports amino acids to the ribosome for translation
- **rRNA** is a structural component of ribosomes

Structure

	DNA	RNA
Similarities	• nucleotides follow the same basic structure (phosphate group, five-carbon sugar molecule, nitrogen-containing base) • contain the nucleotides adenine, guanine, and cytosine • contain a sugar-phosphate backbone • nucleotides form chains along the sugar-phosphate backbone by a condensation reaction • follow the complementary base pairing rule: G-C, A-T/U	
Differences	• nucleotides contain a deoxyribose sugar • contains the base thymine (T) • double-stranded • equal numbers of the nucleotides adenine-thymine and guanine-cytosine • double helix • inherited/long-term storage	• nucleotides contain a ribose sugar • contains the base uracil (U) • single-stranded • different numbers of the nucleotides adenine-uracil and guanine-cytosine • many different structures • temporary molecules
Diagram	 Image: Designua/Shutterstock.com	 Image: Emre Terim/Shutterstock.com Image: udaix/Shutterstock.com

Condensation reaction

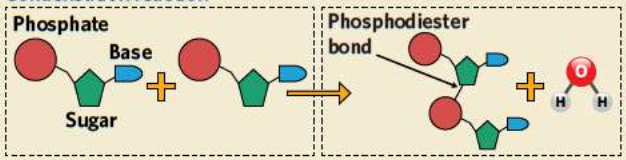
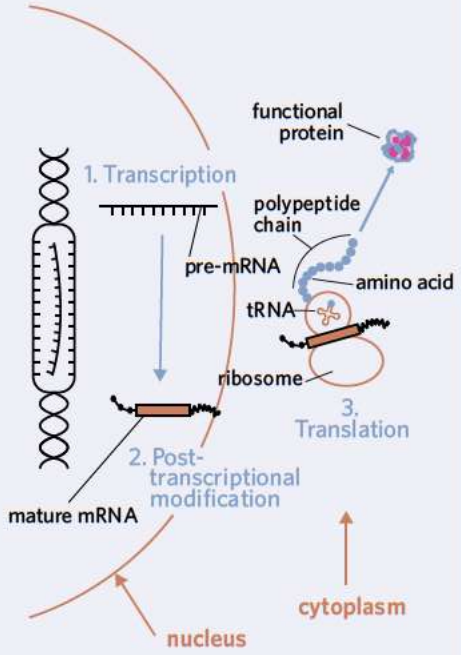


Image: gstraubi/Shutterstock.com

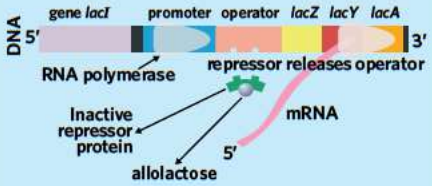
Biomacromolecules

Nucleic acids | Lipids | Carbohydrates | Proteins



An example of gene regulation

When **allolactose is present**, it binds to the **repressor**, which releases the operator so **transcription** of **structural genes** can occur.



PROTEINS

Function

Diverse set of functions, including:

- Structure (e.g. collagen)
- Enzyme (e.g. amylase)
- Motor (e.g. actin)
- Transport (e.g. membrane proteins)
- Receptors (e.g. insulin receptors)
- Signalling molecules/hormones (e.g. insulin)
- Storage (e.g. ferritin).

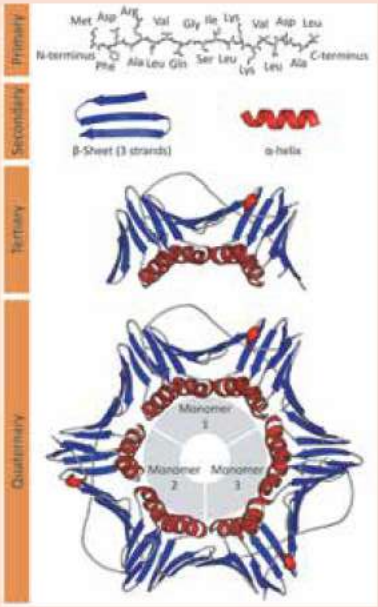
Structure

Primary – the order of amino acids

Secondary – alpha helices or beta sheets

Tertiary – the 3D shape of the protein

Quaternary – two or more polypeptide chains joined together



Condensation reaction

Proteins are made from chains of amino acids that join together via a condensation reaction.

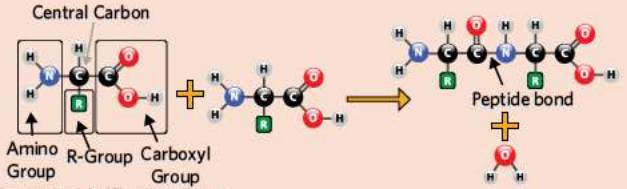


Image: gstraubi/ Shutterstock.com

CHAPTER REVIEW QUESTIONS

SECTION A (16 MARKS)

Question 1 (1 MARK)

The genetic code specifies 20 different amino acids that can form proteins. Which one of the following explains the functional diversity of proteins?

A 20 amino acids allow for a large number of different combinations of a polypeptide.

B The processes of transcription and translation determine a protein's function.

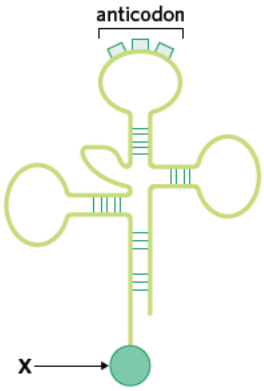
C Nucleic acids are synthesised frequently within a cell.

D Proteins cannot be inhibited or broken down.

Adapted from VCAA 2017 Sample Exam Section A Q1

Question 2 (1 MARK)

Examine the following diagram.



Structure X is a molecular monomer of

A RNA.

B proteins.

C nucleotides.

D carbohydrates.

Adapted from VCAA 2012 Exam 1 Section A Q4

Question 3 (1 MARK)

The proteome is

A the set of proteins undergoing the transcription process in an organism.

B all proteins, carbohydrates, lipids, and nucleic acids in an organism.

C the entire set of proteins expressed by an organism.

D the most common protein in an organism.

Adapted from VCAA 2011 Exam 1 Section A Q1

Question 4 (1 MARK)

A particular DNA double helix is 100 nucleotide pairs long and contains 25 adenine bases. The number of uracil bases in this DNA double helix would be

A 0.

B 25.

C 75.

D 100.

Adapted from VCAA 2012 Exam 1 Section A Q5

Question 5 (1 MARK)

Which one of the following events does not occur when lactose is present in cells?

A Lactose binds to the *lac* repressor.

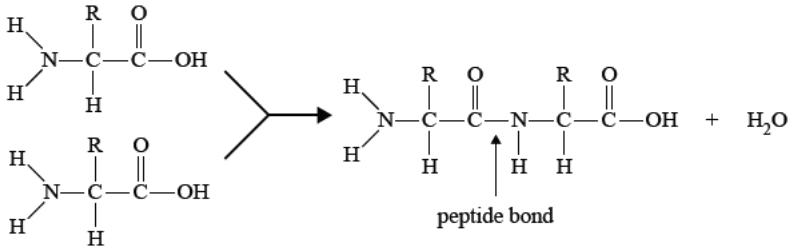
B Enzymes that breakdown lactose are produced.

C The transcription factor is inhibited from binding to the promoter.

D RNA polymerase binds to the promoter and transcribes *lacZ, lacY, and lacA*.

Adapted from VCAA 2018 Section A Q6

Question 6 (1 MARK)



Which of the following about the reaction shown is false?

A This reaction requires energy.

B This reaction produces a peptide bond.

C The product in this reaction is a nucleotide.

D This is an example of a condensation reaction.

Adapted from VCAA 2017 Sample Exam Section A Q5

Question 7 (1 MARK)

Which of the following statements about gene regulation is false?

A Constitutive genes are always transcribed.

B Structural genes code for proteins that are not involved in gene regulation.

C Regulatory genes control the expression of structural genes using transcription factors.

D Transcription factors are proteins that control gene expression at the transcription and translation stages.

Adapted from VCAA 2016 Section A Q32

Question 8 (1 MARK)

Different cells within an organism have different proteins. In some cases different proteins can be coded for by the same gene. One gene can code for several proteins because

A there are 20 amino acids.

B of alternative splicing processes.

C of the specificity of the genetic code.

D genes can alter their sequence during transcription.

Adapted from VCAA 2017 Section B Q1c

Question 9 (1 MARK)

Proteins are not part of the structure of

A the plasma membrane.

B messenger RNA.

C haemoglobin.

D antibodies.

Adapted from VCAA 2012 Exam 1 Section A Q8

Question 10 (1 MARK)

Consider the structure of a gene in a eukaryotic cell.

Which of the following is false?

A Introns undergo the transcription process.

B Exons contain the protein-coding sequence.

C A promoter region is found upstream of a gene.

D Alternative splicing results in different sets of introns being translated.

Adapted from VCAA 2017 Sample Exam Section A Q6

Use the following information to answer Questions 11 and 12.

The diagram represents one of the major macromolecule groups in living things.

Question 11 (1 MARK)

The monomers comprising the macromolecule vary in their

A sugar-phosphate backbones.

B nitrogen-containing bases.

C phosphate groups.

D sugar groups.

Adapted from VCAA 2016 Section A Q3

Question 12 (1 MARK)

A portion of the coding strand of a macromolecule has the sequence –TACGTGCTTGAT–

The mRNA strand produced from this coding strand during transcription would be

A –TACGTGCTTGAT–

B –ATGCACGAACTA–

C –AUGCACGAACUA–

D –UACGUGCUUGAU–

Adapted from VCAA 2016 Section A Q4

Question 13 (1 MARK)

Bacteria can have a gene from another species inserted (e.g. a human gene), and they can be cultured to produce a given protein in large quantities.

It is possible to introduce a human gene into bacteria because the DNA code is

A universal.

B redundant.

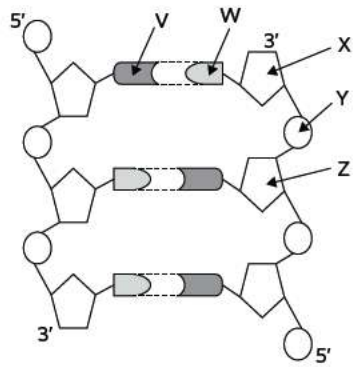
C degenerate.

D non-overlapping.

Adapted from VCAA 2013 Section A Q36

Use the following information to answer Questions 14 and 15.

The diagram represents part of a DNA molecule.



Question 14 (1 MARK)

A hydrogen bond is formed between sub-units

A X and Y.

B Y and Z.

C V and W.

D X and Y and Y and Z.

Adapted from VCAA 2015 Section A Q3

Question 15 (1 MARK)

Which of the following is false?

A Sub-unit Y is a deoxyribose sugar.

B Sub-unit X is the same in every DNA nucleotide.

C Sub-units V and W bind together via hydrogen bonds.

D This diagram displays the deoxyribose sugar-phosphate backbone.

Question 16 (1 MARK)

The codon table can be used to determine the sequence of amino acids coded for by a nucleotide sequence.

Second Base									
First Base	U		C		A		G		**Third Base**
U	UUU	phe	UCU	ser	UAU	tyr	UGU	cys	U
	UUC		UCC		UAC		UGC		C
	UUA	leu	UCA		UAA	STOP CODON	UGA	STOP CODON	A
	UUG		UCG		UAG		UGG	trp	G
C	CUU	leu	CCU	pro	CAU	his	CGU	arg	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	gin	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	ile	ACU	thr	AAU	asn	AGU	ser	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	lys	AGA	arg	A
	AUG	met (START CODON)	ACG		AAG		AGG		G
G	GUU	vai	GCU	ala	GAU	asp	GGU	gly	U
	GUC		GCC		GAC		GGC		C
	GUA		GCA		GAA	giu	GGA		A
	GUG		GCG		GAG		GGG		G

The following nucleotide sequence is found on the template strand at a particular site in the genome.

GCT TTA CGG TTA TA**T** ACC

Due to a DNA change, the bolded nucleotide in this sequence was changed from a T to a G.

What would be the result of this DNA change?

A The peptide chain would be shortened.

B The fifth amino acid would change from tyr to cys.

C The sixth amino acid would change from cys to STOP.

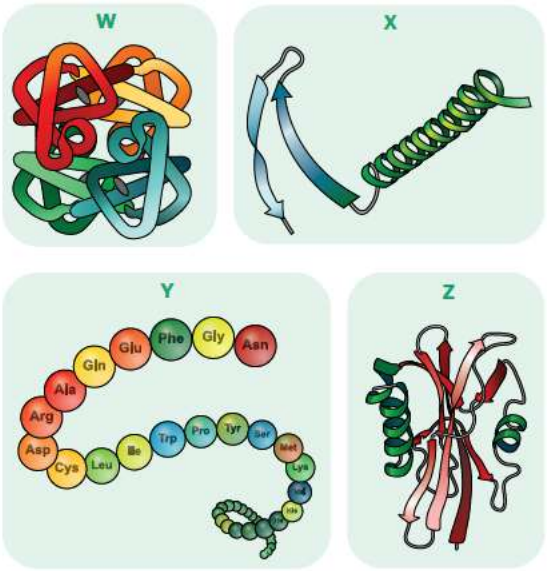
D There would be no change in the amino acid sequence.

Adapted from VCAA 2017 Section A Q27

SECTION B (24 MARKS)

Question 17 (5 MARKS)

The diagrams represent examples of four levels of structure with respect to the folding and assembly of a protein. The diagrams are not to scale.



a Identify the level of protein structure represented in the diagrams W, X, Y, and Z. (2 MARKS)

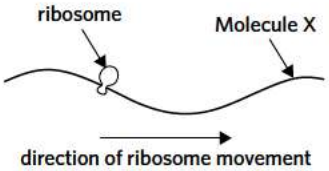
b Which diagram represents the structural level that is largely created via the interactions between R-groups? (1 MARK)

c Describe the type of bonding occurring in diagrams X and Y. (2 MARKS)

Adapted from VCAA 2015 Section B Q1

Question 18 (5 MARKS)

Ricin is a naturally occurring, powerful poison that affects eukaryotic organisms. Large mammals that ingest small amounts of ricin can die within three to five days. Studies have concluded that ricin stops the movement of a ribosome along a specific molecule. This specific molecule has been labelled Molecule X in the diagram.



a Identify Molecule X and outline its function. (2 MARKS)

b State the cellular process ricin is thought to interfere with. (1 MARK)

c Explain how ricin poisoning leads to the death of large mammals so quickly. (2 MARKS)

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q23

Question 19 (8 MARKS)

Human insulin is a macromolecule composed of two amino acid chains. The chains are connected by disulphide bonds.

a Identify the monomers that comprise the insulin molecule. (1 MARK)

b Describe the structure of the monomers of insulin, and explain how they differ from the monomers of DNA. (2 MARKS)

c The monomers of both insulin and DNA are linked together via condensation reactions to form their polymers. Outline the condensation reaction in each macromolecule. (2 MARKS)

d Insulin found in other animals varies from human insulin.
The following table compares the differences seen in the primary structure of human, cow, pig, and sheep insulin.

	Amino acid position number within	
	Alpha chain	**Beta chain**
	– 8 – 9 – 10 –	**– 30 –**
human	– thr – ser – ile –	thr
cow	– ala – ser – val –	ala
pig	– thr – ser – ile –	ala
sheep	– ala – gly – val –	ala

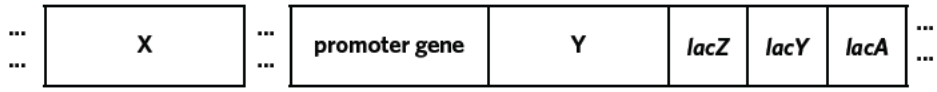
i Humans with diabetes take insulin injections to help control their blood glucose levels. If no human insulin is available, it is possible to use similar insulin from another animal. According to the table, explain which animal's insulin structure is the least similar to human insulin? (1 MARK)

ii Do cows, pigs, and sheep have an identical sequence of nucleotides at amino acid position 30 in the beta chain? Justify your response. (2 MARKS)

Adapted from VCAA 2012 Exam 1 Section B Q3

Question 20 (6 MARKS)

The *lac* operon was originally identified in *Escherichia coli*. The *lac* operon has three structural genes: *lacZ, lacY, and lacA*. The *lacZ* gene codes for the production of the enzyme β-galactosidase, which catalyses the breakdown of lactose into glucose and galactose. The diagram shows the order of the genes found in the *lac* operon. The dotted lines represent the DNA nucleotides between the genes.



a What genes of the *lac* operon do X and Y represent? (2 MARKS)

b To which gene does RNA polymerase bind during transcription? (1 MARK)

c To which gene does the *lac* repressor bind to stop transcription? (1 MARK)

d Explain how the *lac* operon functions when cell lactose levels are high. (2 MARKS)

Adapted from VCAA 2017 Section A Q2

UNIT 3 AOS 1, CHAPTER 5

Enzymes

05

5A Introducing enzymes!

5B Inhibiting enzymes

5C Coenzymes

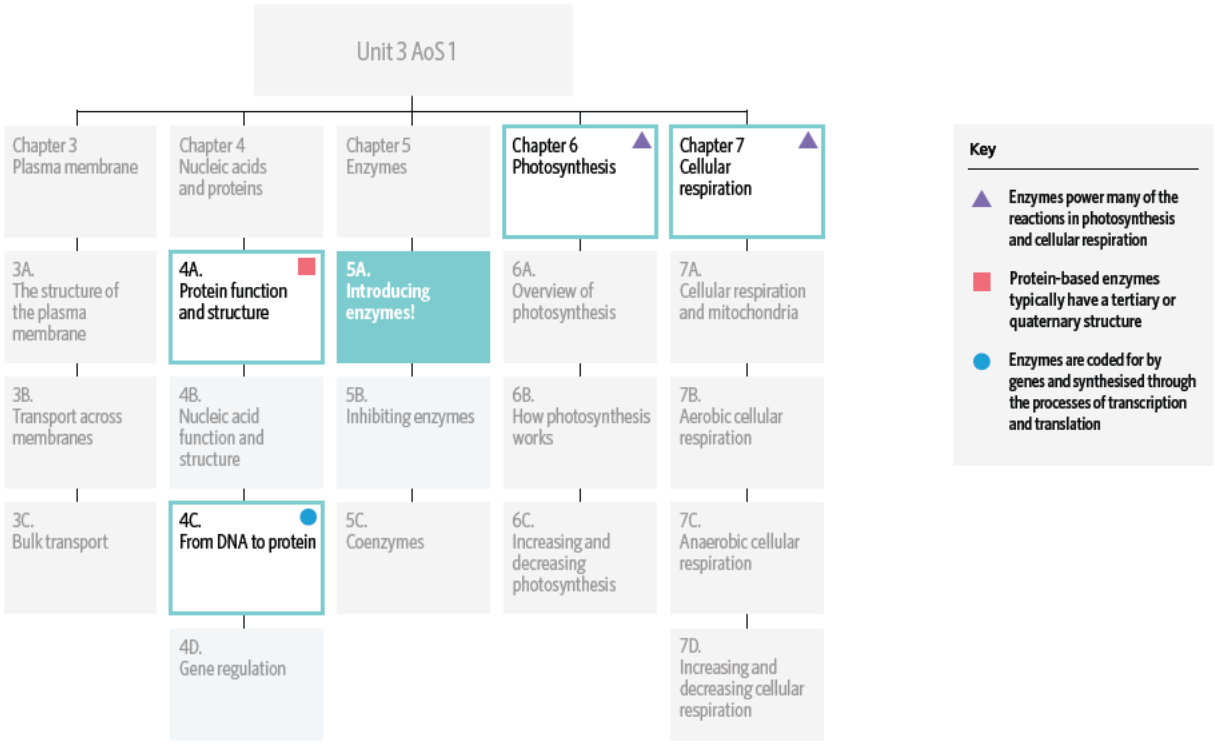
Key knowledge

- the role of enzymes as protein catalysts in biochemical pathways
- the mode of action of enzymes including reversible and irreversible inhibition of their action due to chemical competitors at the active site, and by factors including temperature, concentration, and pH
- the cycling of coenzymes (ATP, NADH, and NADPH) as loaded and unloaded forms to move energy, protons, and electrons between reactions in the cell

Image: Design_Cells/Shutterstock.com

5A INTRODUCING ENZYMES!

Need to get over the hump? Enzymes will give you a bump.



In this lesson you will learn that enzymes catalyse chemical reactions, and that their activity can be impacted by factors such as temperature and pH.

Study design dot points

- the role of enzymes as protein catalysts in biochemical pathways
- the mode of action of enzymes including reversible and irreversible inhibition of their action due to chemical competitors at the active site, and by factors including temperature, concentration, and pH

Key knowledge units

What enzymes do	3.1.13.1
Regulating enzymes	3.1.14.1

What enzymes do 3.1.13.1

OVERVIEW

Enzymes speed up biochemical reactions by lowering the activation energy required to initiate a given reaction.

THEORY DETAILS

It is estimated that every second in your body, there are 37 thousand billion billion chemical reactions occurring. These chemical reactions include DNA replication, cell communication, and the breakdown of nasty toxins in the liver. However, most of these reactions can't just happen on their own. All reactions require energy to initiate the process. This is where **enzymes** come in.

What are enzymes?

Enzymes are organic (carbon-based) **catalysts**. This means that they speed up, or **catalyse**, chemical reactions that would normally take much longer to occur. Enzymes bind to a molecule called a **substrate** (Figure 1). The substrate is the **reactant** undergoing a reaction.

enzyme an organic molecule, typically a protein, that catalyses (speeds up) specific reactions

catalyst a substance capable of catalysing reactions

catalyse to increase the rate of a reaction

substrate the reactant of a reaction that an enzyme catalyses

reactant the molecule(s) that undergoes transformation into the product. When enzymes are involved, the reactant(s) is called a substrate

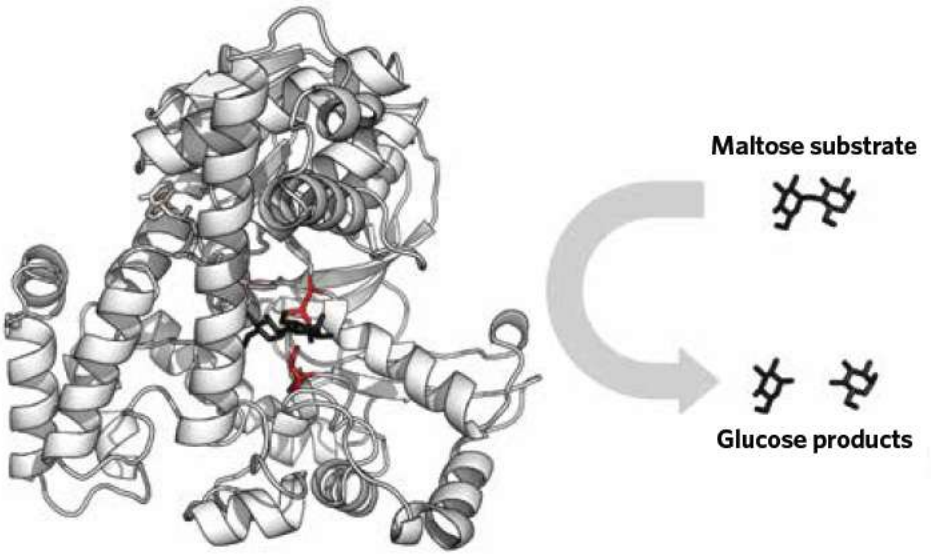


Figure 1 The enzyme glucosidase (white) with the substrate, maltose (black), bound at the active site (red)

There are a few key features of enzymes you should know:

- Enzymes are reusable. When an enzyme catalyses a reaction, the enzyme is not consumed, broken down, or turned into a **product**. Because they are not used up in the reaction, enzymes can catalyse future reactions.
- Most enzymes only bind to one specific substrate. This means that they tend to catalyse just one chemical reaction, although some enzymes are less specialised.
- Most enzyme-catalysed reactions are reversible, with the same enzyme often capable of building up larger molecules (anabolic), or breaking them down into smaller ones (catabolic).
- Enzymes catalyse reactions, but don't create new reactions. They speed up reactions that would otherwise occur naturally (given enough time) by lowering the **activation energy** of a reaction.
- Enzymes have an **active site** – the one area to which the substrate always binds and the reaction occurs. The corresponding area on a substrate is called a binding site. The enzyme's active site and substrate tend to be complementary in shape, so they can roughly fit together.
- Most enzymes are proteins. However, some RNA molecules are capable of acting as enzymes.
- All enzymes are catalysts, but not all catalysts are enzymes. Enzymes are organic catalysts, however, there are also inorganic catalysts (such as metal ions) that speed up reactions.
- Enzymes frequently influence entire biochemical pathways (e.g. Figure 4) by catalysing each step.
- Enzyme names typically end with the suffix '-ase' (e.g. catalase, polymerase, ligase, lactase). When you see '-ase', think of enzymes.
- Enzymes are typically displayed above the reaction arrow.

product the transformed molecule(s) produced in a reaction

activation energy the energy required to initiate a reaction

active site the part of the enzyme to which the substrate binds

Tip Enzymes underpin many biological processes, meaning that the word enzyme will likely appear on your exam several times in different contexts including protein synthesis (4C), gene regulation (4D), apoptosis (8C), and mutations (11A).

What enzyme-catalysed reactions look like

The active site is a pocket-like area of the enzyme's tertiary structure where the substrate fits and binds to the enzyme. Due to the compatibility of the complex three-dimensional structures, we say that an enzyme's active site and substrate are complementary in shape.

When a substrate binds to an enzyme's active site, together they form an **enzyme-substrate complex** (Figure 2). Upon binding, the active site undergoes a **conformational change** to accommodate for the substrate, and the substrate undergoes a small change in turn. Think of the change as like a handshake or a hug – both parties adjust to allow for a stronger connection. Many chemical bonds (e.g. hydrogen bonds, hydrophobic interactions) hold the substrate and active site together in the enzyme-substrate complex. The reaction proceeds and the substrate is converted into the product. The product disassociates from the complex and is released. The enzyme is then ready to bind to another substrate and repeat the process.

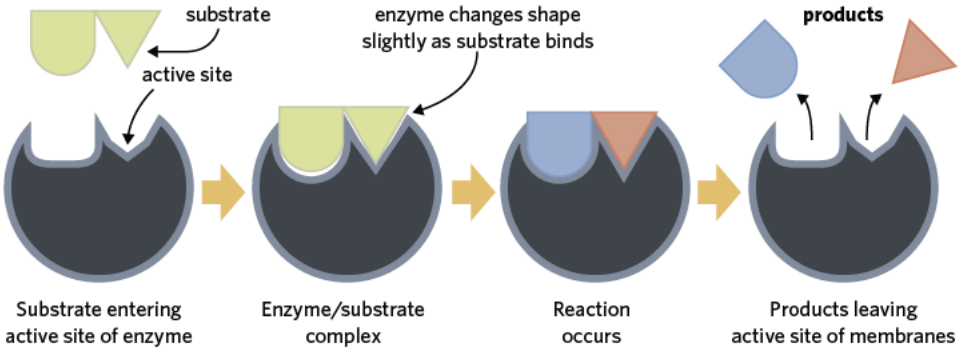


Figure 2 An enzyme undergoing a conformational change to fit to the substrate

Enzyme-catalysed reactions are incredibly similar to the chemical reactions and equations you may have come across (Figure 3). The only difference is the reactant is called the substrate. The enzyme does not make up part of the product and is written on top of the arrow.

Figure 3 The enzyme-catalysed breakdown of hydrogen peroxide

How do enzymes speed up chemical reactions?

Enzymes lower the activation energy of chemical reactions (Figure 5). Every chemical reaction requires an input of energy to start, regardless of whether it is anabolic or catabolic. This initial requirement is the activation energy, and is defined as the minimum amount of energy required to promote atoms or molecules to a state where they can undergo a chemical transformation. Think of it as the hurdle that reactants need to get over to start a chemical reaction.

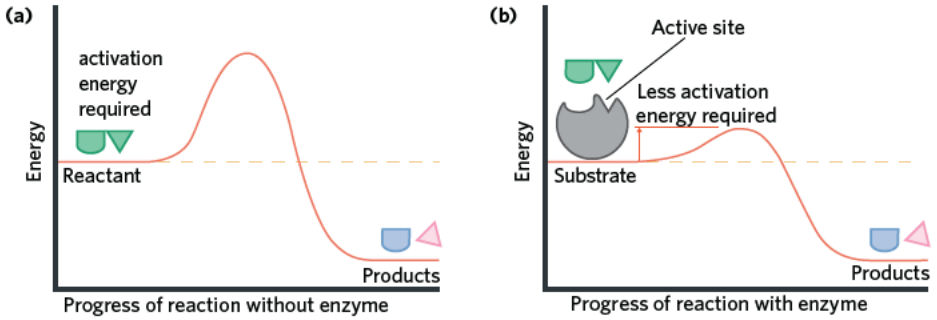
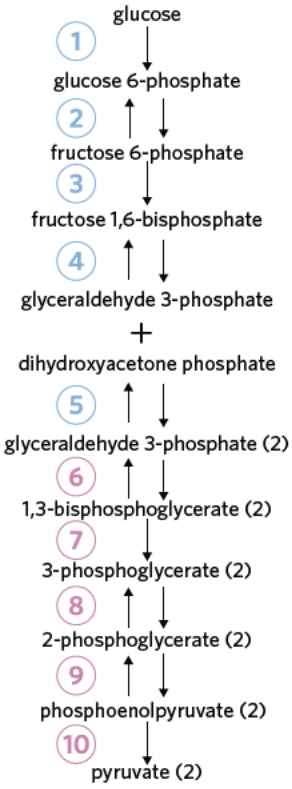


Figure 5 The activation energy required in a reaction **(a)** without and **(b)** with an enzyme

Enzymes bring reactants closer to the state they need to be in to react. In other words, they significantly reduce the size of the hurdle. This allows reactions to proceed at a much quicker rate. For example, carbonic anhydrase can catalyse the reaction of carbon dioxide and water into carbonic acid 10 million times quicker than the uncatalysed reaction.

enzyme-substrate complex the structure formed when enzyme and substrate are bound together

conformational change a change in the three dimensional shape of macromolecules such as proteins



Enzymes

1. hexokinase
2. phospho-hexose isomerase
3. phospho fructokinase-1
4. aldolase
5. triose phosphate isomerase
6. glyceraldehyde 3-phosphate dehydrogenase
7. phospho-glycerate kinase
8. phospho-glycerate mutase
9. enolase
10. pyruvate kinase

Figure 4 The pathway of glycolysis is catalysed by ten enzymes. If one enzyme is impacted, all further steps in the pathway are impacted. You don't need to memorise this, it is just an example of how enzymes catalyse multiple steps in a biochemical pathway.

lesson link Not familiar with the activation energy graph? Go check out ***lesson 2B*** to remember how chemical energy changes over the course of catabolic and anabolic reactions.

Case study

Lock and key vs induced fit

Because enzymatic activity is happening on such a minute scale, it is often difficult to understand just what is actually going on. Biologists use models to visualise what they believe is happening. It was once thought that a substrate fits into an active site perfectly, like how a key fits into a lock. This was known as the **lock and key model** of the enzyme-substrate complex. It is now believed to be incredibly rare for an enzyme and its substrate to fit together perfectly. Usually there is a slight adjustment upon binding to better fit one another. This model is known as the **induced fit model** which states that an enzyme undergoes a conformational change to become complementary in shape to the substrate.

lock and key model a theory describing the enzyme-substrate complex, where the substrate fits into the active site perfectly like a lock and key

induced fit model a theory describing the model of the enzyme-substrate complex where a change in the conformation of the active site occurs when the substrate binds

optimal the point at which, for a given condition (e.g. temperature), the maximum function of an enzyme occurs

denature to irreversibly change a protein's tertiary structure

Regulating enzymes 3.1.14.1

OVERVIEW

Enzymes have an optimal temperature and pH for catalysis. Above and below this range, their activity slows and they can denature, or stop working. Additionally, the concentrations of enzyme and substrate present impact the rate of a reaction.

THEORY DETAILS

The activity levels of an enzyme vary depending on temperature, pH, and the concentrations of the substrate and enzyme. In VCE Biology, you need to understand and explain how these four factors impact the rate of enzyme-catalysed reactions.

Temperature

As temperature increases, most chemical reactions speed up as molecules have greater kinetic energy and collide into one another more frequently. This is also true for enzyme-catalysed reactions, although only to a certain point. At the **optimal** temperature, the enzyme activity is greatest. However enzymes are proteins, and all proteins can be **denatured** at high temperatures. Denaturation is when the hydrogen bonds and hydrophobic interactions that create the tertiary and quaternary structures of a protein are broken down. This causes a conformational change in the active site, so that the substrate can no longer fit and the reaction cannot proceed, even if the conditions return to normal.

Below the optimal temperature, enzyme activity also decreases because the molecules collide less frequently. When it becomes too cold, enzymes experience little to no activity and can freeze. However, when reheated the enzymes can regain functionality as significant denaturation does not occur at low temperatures. The rapid denaturation at high temperatures, and reduced kinetic energy at low temperatures produces an asymmetrical relationship between enzyme activity and temperature (Figure 6).

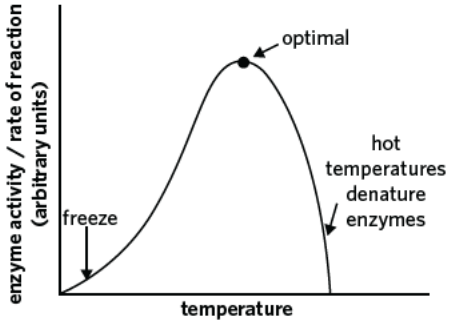


Figure 6 The relationship between enzyme activity and temperature

Tip VCAA frequently test understanding of enzymes in the form of graph-based questions, asking about the impact of factors like temperature, pH, or a change in concentration (for example, see VCAA 2018 Section A Q7).

Tip The enzymes found in humans have an optimal temperature range of 36-38°C, which means they function well at the human body temperature of 37°C. Enzymes differ greatly though; some enzymes found in bacteria that live in hot water springs have optimal temperatures above 70°C!

pH

The pH scale measures the acidity or alkalinity of a solution. Acids have low pH values (<7) and alkaline (basic) solutions have a high pH (>7). Just like with temperatures, enzymes have a specific pH at which they function optimally. Unlike with temperatures however, the denaturation of an enzyme occurs if it is exposed to an environment that is either above or below the optimal pH. The pH range of enzymes varies greatly depending on where the enzyme is located (e.g. pepsin is the main digestive enzyme in the human stomach and has an optimal pH around 1.5-2, whilst pancreatic lipase has an optimal pH of 8). Because denaturation occurs at both extremes, plotting enzyme activity (or reaction rate) against pH results in a symmetrical, bell-shaped curve (Figure 7).

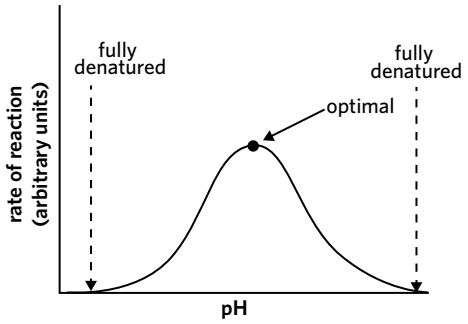


Figure 7 The relationship between enzyme activity and pH

Substrate concentration

If the enzyme concentration remains constant while the substrate concentration increases, then the reaction rate will also increase. This is because there are more reactants available to undergo the reaction (Figure 8). However, a point will be reached where there is so much substrate that every active site is constantly occupied and the reaction rate will no longer increase with more substrate. This is called the **saturation point**, as the enzymes are saturated with substrate. This results in the plateau when graphing substrate concentration against the reaction rate (Figure 9).

saturation point the point at which a substance (e.g. an enzyme) cannot receive more of another substance (e.g. a substrate)

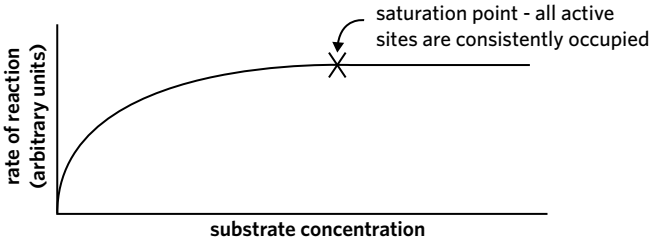


Figure 9 The rate of reaction increases as substrate concentration increases until saturation occurs.

Enzyme concentration

If the concentration of enzymes is high, then the reaction rate will be high and will occur quickly (Figure 10). This is due to the large number of active sites available for substrates to use.

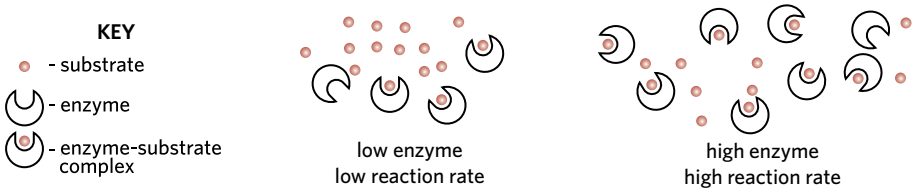


Figure 10 Increasing enzyme concentration increases the reaction rate due to more collisions.

If enzyme concentration rises while the substrate concentration is kept constant, the reaction rate will increase until enzymes are in excess, at which point the reaction rate will remain the same regardless of any continued increase in enzyme concentration (Figure 11). However, in biological systems, there are typically far more substrates than enzymes so an increase in enzyme usually always increases reaction rate.

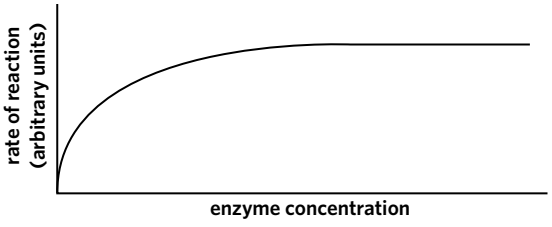


Figure 11 The relationship between enzyme activity and enzyme concentration

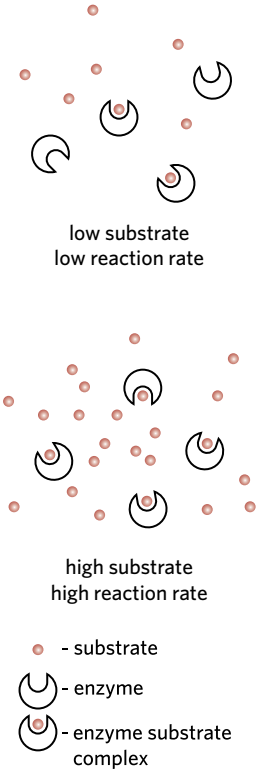


Figure 8 Increasing substrate concentration increases the reaction rate due to more frequent collisions.

Theory summary

Enzymes are organic catalysts that lower the activation energy of reactions. They are not used up in reactions, can sometimes work in both directions of a reaction and on entire pathways, and their active sites are specific to particular substrates. The activity of an enzyme is greatest at its optimal temperature, above this it begins to denature. High and low pH values can also denature enzymes. Increasing substrate concentration increases the reaction rate until saturation is reached. Increasing enzyme concentration also increases the rate of reaction, until there is not enough substrate.

5A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a molecule that an enzyme binds to and acts upon

b _____ to make a reaction occur faster

c _____ the energy needed to 'get over the hump' and start a reaction

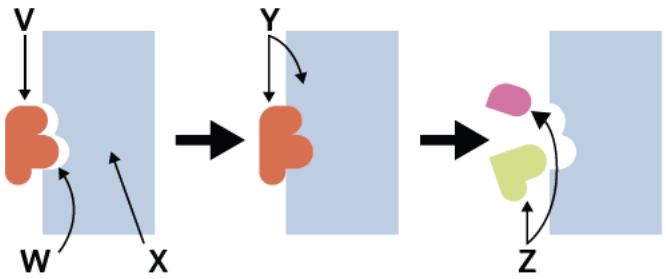
d _____ the pocket-like area where the substrate binds to an enzyme

e _____ a molecule that is produced in a biochemical reaction

f _____ the model that is widely accepted as true for an enzyme-substrate interaction

g _____ a protein that lowers the activation energy of a biochemical reaction

Question 2



Which of the following correctly identifies V-Z?

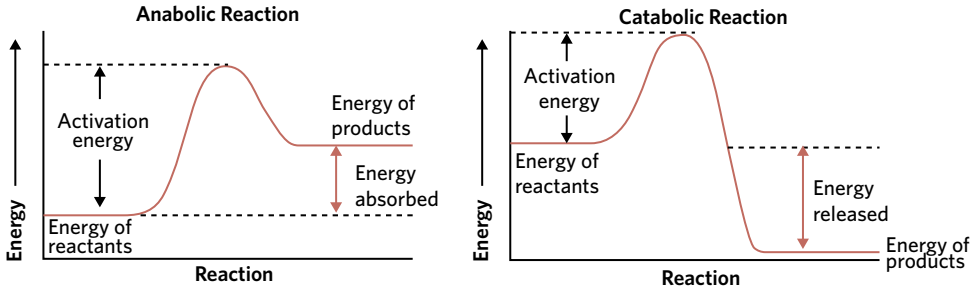
	V	W	X	Y	Z
A	Reactant	Binding site	Enzyme	Activation energy	Products
B	Substrate	Binding site	Enzyme-substrate complex	Product	Substrate
C	Substrate	Active site	Enzyme	Enzyme-substrate complex	Products
D	Reactant	Active site	Product	Enzyme-substrate complex	Substrate

Question 3

Which of the following are all true about enzymes?

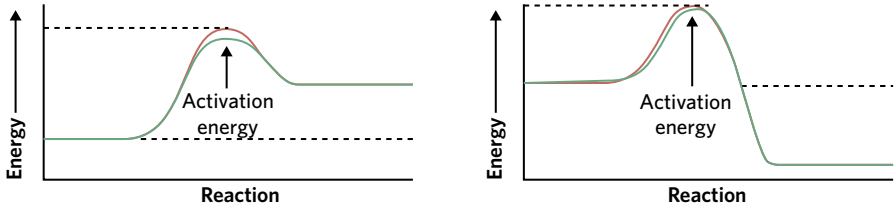
A	Decrease the activation energy	All are proteins	Act on catabolic reactions	Contain a binding site
B	Decrease the activation energy	Most are proteins	Act on both catabolic and anabolic reactions	Contain an active site
C	Raise the activation energy	All are proteins	Act on both catabolic and anabolic reactions	Contain a binding site
D	Decrease the activation energy	Most are proteins	Act on anabolic reactions	Contain an active site

Question 4

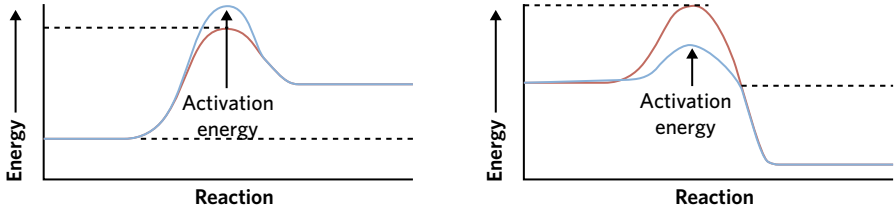


Which of the following shows an enzyme's action on both kinds of reactions?

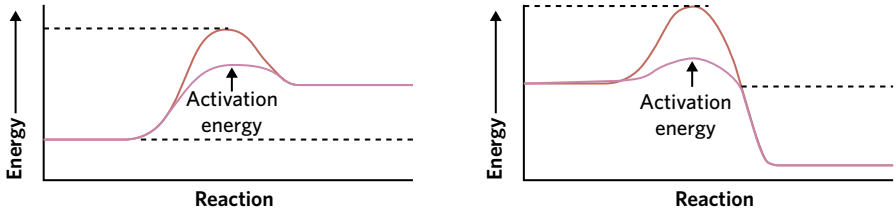
A



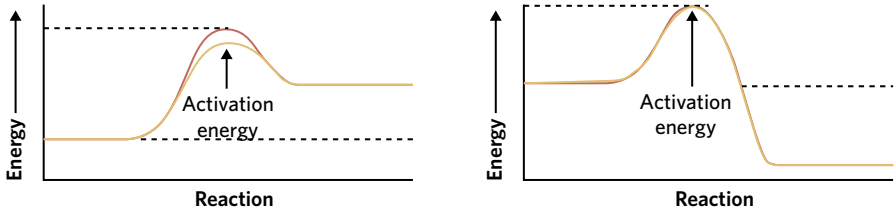
B



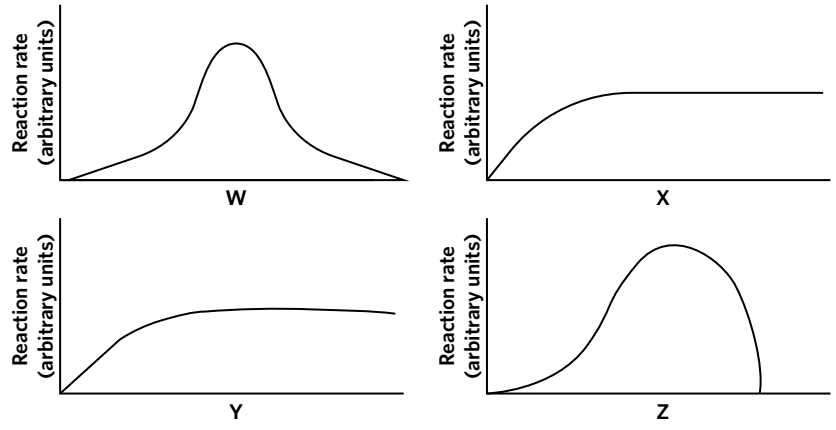
C



D



Question 5



Which of the following identifies W–Z?

	W	X	Y	Z
A	Temperature	Substrate concentration	Enzyme concentration	pH
B	pH	Enzyme concentration	Temperature	Substrate concentration
C	pH	Substrate concentration	Enzyme concentration	Temperature
D	pH	Enzyme concentration	Temperature	Substrate concentration

Exam-style questions

Within lesson

Question 6 (1 MARK)

Activation energy in a biological reaction

A is completely removed in the presence of an enzyme.

B is the energy required to finish the reaction.

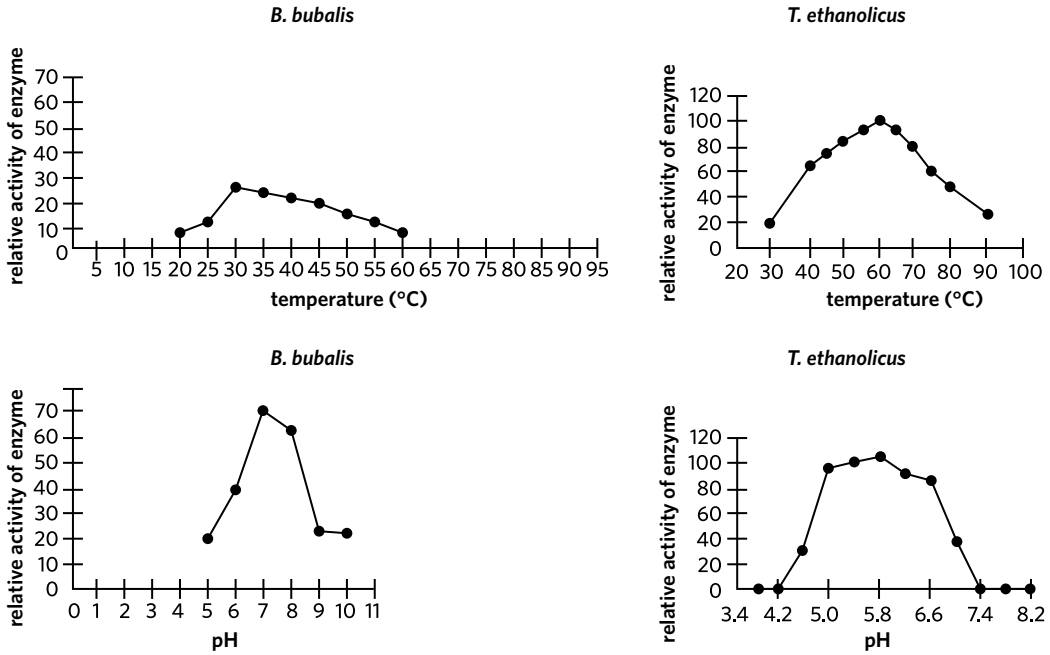
C is lowered in the presence of an enzyme.

D is involved in catabolic reactions only.

Adapted from VCAA 2008 Exam 1 Section A Q18

Question 7 (1 MARK)

The enzyme lactate dehydrogenase is found in a wide variety of organisms. It catalyses the conversion of both pyruvate to lactate, and lactate to pyruvate. The bacterium *Thermoanaerobacter ethanolicus* lives in geothermal (hot) springs. The river buffalo (*Bubalus bubalis*) is a domestic animal common in Pakistan. Scientists studying the enzyme lactate dehydrogenase from these two organisms produced the following graphs (adapted from Nadeem et al. (2011) (left) and Zhou and Shao (2010) (right)).



From the graphs, which of the following conclusions is false?

A The optimal pH of the bacterial lactate dehydrogenase is 5.8.

B Above 60°C the buffalo form of the enzyme would likely denature.

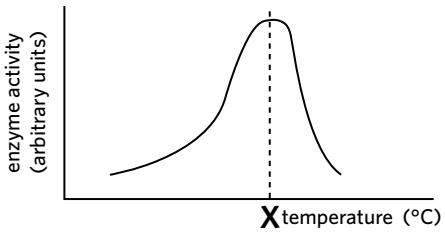
C Below 40°C the bacterial form of the enzyme would likely denature.

D The form of enzyme found in the buffalo operates over a wider pH range than the bacterial form.

Adapted from VCAA 2017 Sample Exam Section A Q9

Question 8 (1 MARK)

Scientists have found microorganisms living in hot springs of boiling water. The enzyme activity of these microorganisms was investigated over a range of temperatures. The results obtained were plotted and are shown in the following graph.



Which of the following is correct?

A Point X is the denaturation point.

B The temperature at point X is likely to be 37°C.

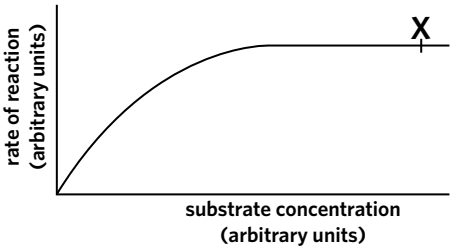
C Below point X the enzyme would likely denature.

D Point X is the optimal temperature of the enzyme.

Adapted from VCAA 2004 Exam 1 Section A Q7

Question 9 (1 MARK)

The following graph illustrates the effect of different substrate concentrations on reaction rate. In this series of experiments, the amount of enzyme, the pH, and the temperature remain constant.



At point X

A all active sites are consistently occupied.

B the substrate is the limiting reactant.

C the rate of reaction is decreasing.

D no reactions are occurring.

Adapted from VCAA 2003 Exam 1 Section A Q17

Question 10 (1 MARK)

Bacteria such as *Thermus aquaticus* live in hot springs where temperatures are around 90°C. What can be said about the temperature tolerance range of enzymes found in *T. aquaticus*?

A The enzyme's tolerance range likely centres around 90°C.

B The enzyme's tolerance range is limited to a narrow range.

C 90°C is outside the enzyme's tolerance range, however they can still operate.

D The enzymes must be capable of operating over a wide range of temperatures.

Adapted from VCAA 2006 Exam 1 Section A Q19

Use the following information to answer Questions 11 and 12.

Yeast cells divide rapidly provided they are mixed with warm water to form a suspension and sucrose is added. Sucrose is unable to cross the yeast cell membrane, and is digested into glucose and fructose by the enzyme sucrase. Sucrase is synthesised within the yeast cell but acts in the water surrounding the yeast cells.

Question 11 (1 MARK)

Warming the yeast suspension increases the rate at which sucrose is broken down to glucose and fructose because warming

A weakens the bonds within sucrase.

B increases the activation energy of the reaction.

C strengthens the bond between enzyme and substrate.

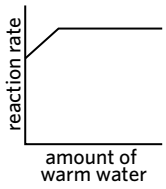
D increases the frequency of enzyme and substrate collisions.

Adapted from VCAA 2005 Exam 1 Section A Q21

Question 12 (1 MARK)

Identify the graph that shows the effect of adding more warm water, of the same temperature, to the yeast suspension.

A



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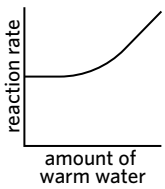

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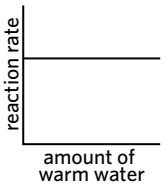

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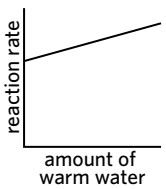


Adapted from VCAA 2005 Exam 1 Section A Q22

Question 13 (1 MARK)

Laundry powder is sometimes advertised as containing powerful enzymes that break down dirt. These enzymes are called extremozymes. They come from some species of bacteria and archaea. The following table gives the optimal functioning of enzymes from some of these species.

Species	Enzyme	Optimal temperature °C	Optimal pH
Psychrobacter sp.	J	10-30	7.0-9.0
Pseudomonas sp.	K	40	10.0
Methanococcus sp.	L	120	5.0-8.0
Cystofilobasidium sp.	M	40-42	5.0

Given this information and your knowledge of enzyme function, which of the following conclusions could be made?

A Enzyme K would likely denature in extremely acidic environments.

B Enzyme L has the widest optimal temperature range.

C Enzyme M functions well in a basic environment.

D Enzyme J is likely found in the human body.

Adapted from VCAA 2010 Exam 1 Section A Q23

Use the following information to answer Questions 14 and 15.

The enzyme lactase digests lactose.

$$\text{lactose} \xrightarrow{\text{lactase}} \text{glucose + galactose}$$

Question 14 (1 MARK)

Two test tubes were set up using 5 mL of lactose syrup and 0.5 mL of lactase extracted from humans. Test tube one was incubated at 37°C, while test tube two was incubated at 15°C. Both tubes were incubated for 10 minutes.

At the end of 10 minutes, the amount of glucose produced in test tube one when compared to test tube two would be

A equal as denaturation does not occur at low temperatures.

B equal as the two test tubes contained the same amount of lactase.

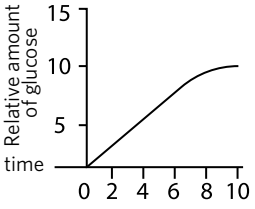
C lower as the enzyme's active site would have denatured at this temperature.

D higher as substrate collides with the enzyme at a faster rate at this temperature.

Adapted from VCAA 2009 Exam 1 Section A Q7

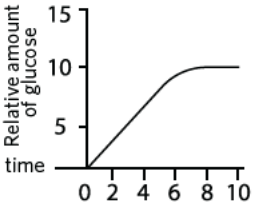
Question 15 (1 MARK)

In another experiment, test tube three was compared with test tube four. Each tube contained 5 mL of lactose syrup. Tube three contained 0.25 mL of lactase and tube four contained 0.5 mL of lactase. The two tubes were incubated at 15°C and monitored for 10 minutes. The results for test tube three are shown.



The results for test tube four would resemble which of the following graphs?

A



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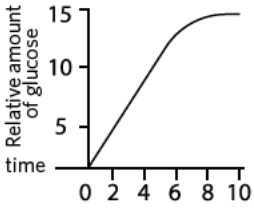

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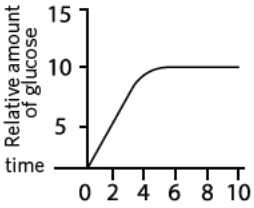

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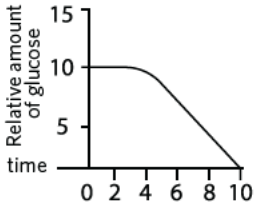


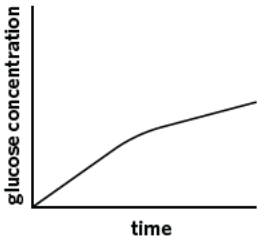
Adapted from VCAA 2009 Exam 1 Section A Q8

Question 16 (1 MARK)

The enzyme maltase catalyses the breakdown of maltose into glucose. Maltase was added to a tube containing a solution of maltose in water and incubated at 37°C. The amount of glucose produced was monitored over a period of time. Some maltose remained at the end.

The graph showing the change in glucose concentration in the tube is

A



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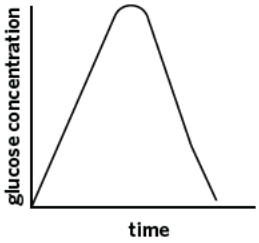

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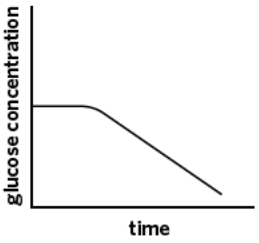

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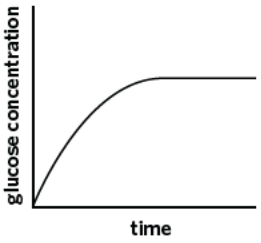
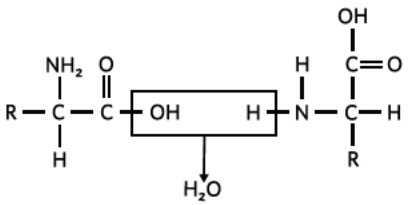


Adapted from VCAA 2008 Exam 1 Section A Q5

Multiple lessons

Question 17 (8 MARKS)

Enzymes are proteins that are formed by adjacent amino acids being joined together. The following diagram represents this joining of amino acids.



a What is the name of a reaction that forms a water molecule? (1 MARK)

b What type of bond is formed when the monomers of proteins link together? (1 MARK)

c Proteins such as enzymes can denature. Identify a condition that can denature an enzyme. (1 MARK)

d Proteins have four levels of basic structure.

I Which level of structure is represented in the diagram? (1 MARK)

II Briefly describe the four levels of protein structure. (4 MARKS)

Adapted from VCAA 2018 Section A Q3

Question 18 (7 MARKS)

Amylase is critical for catalysing the breakdown of foods in saliva.

Salivary amylase is produced when the gene *AMY1* is transcribed and translated.

The diagram shows the relative positions of the three introns and four exons in the Molecule Z that leads to the production of amylase.

A cell initiates the process of producing Molecule Z by having RNA polymerase attach to the promoter region of the *AMY1* gene.

a What molecule is Molecule Z? (1 MARK)

b Describe the next steps that occur within the nucleus to produce Molecule Z. (3 MARKS)

c Molecule Z then is transported to the ribosomes for translation. Describe the steps that occur to produce amylase from Molecule Z. (3 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q3

Key science skills

Question 19 (7 MARKS)

Many living cells produce hydrogen peroxide as a by-product of some metabolic reactions. Hydrogen peroxide is a poisonous substance for these cells and is immediately decomposed into water and oxygen by an enzyme called catalase.

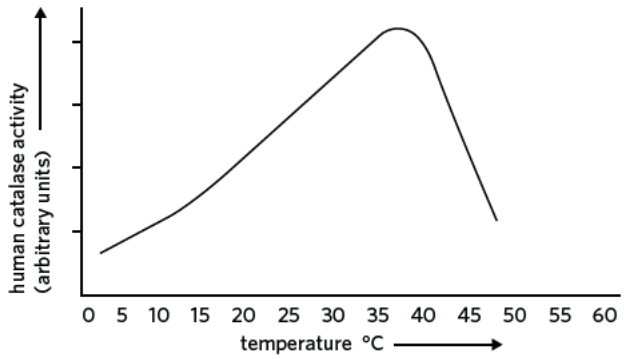
The reaction is represented by the equation

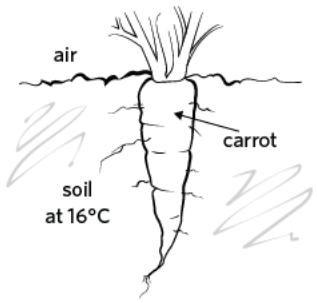
$$2\,H_2O_2 \xrightarrow{\text{catalase}} 2\,H_2O + O_2$$

a What is/are the product/s in this chemical reaction? (1 MARK)

b Explain the biological significance of the 3D shapes of catalase and hydrogen peroxide. (2 MARKS)

c The activity of catalase in humans was tested across a number of different temperatures and the results graphed. The results are shown.





Catalase is also found in many plants, including carrots.

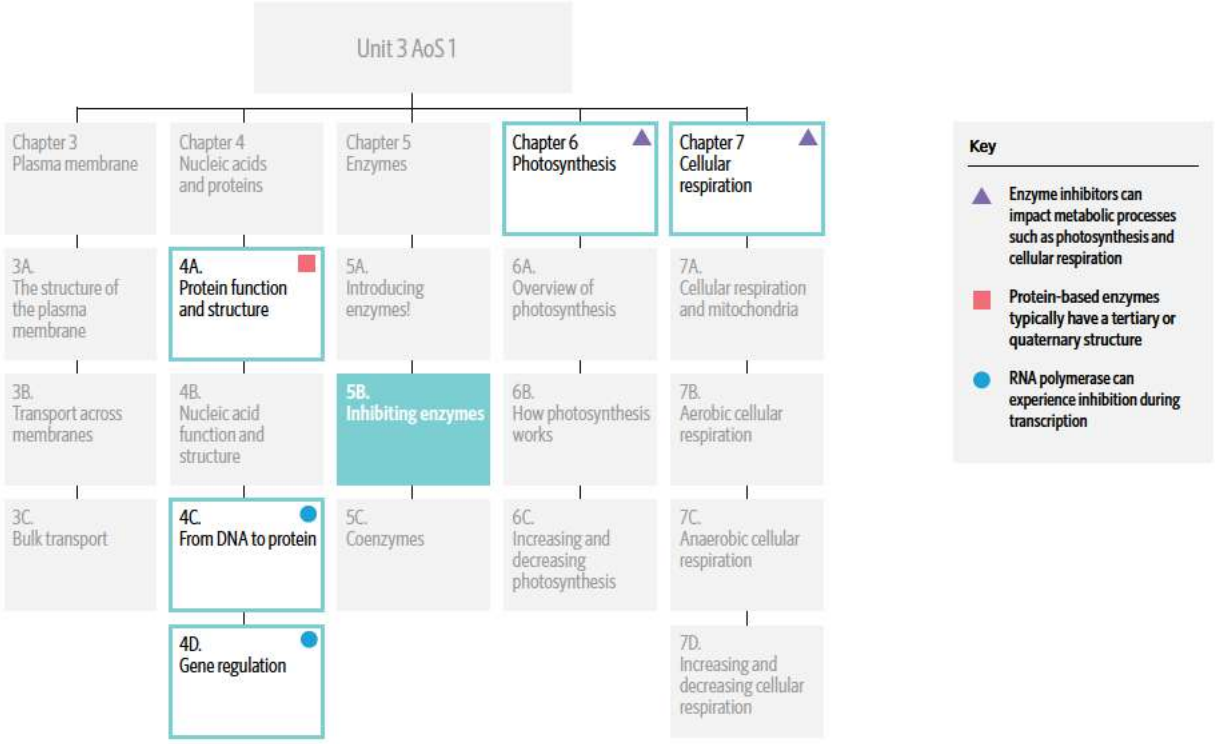
I What would you predict the shape of the temperature graph for carrot catalase activity to look like? Justify your response. (2 MARKS)

II The activity of catalase in carrot pieces was tested across a number of different temperatures. Explain how testing a total of 25 carrot pieces affects the accuracy of the experiment, compared to testing only 5 pieces of carrot. (2 MARKS)

Adapted from VCAA 2007 Exam 1 Section B Q3

5B INHIBITING ENZYMES

Like an awkward love triangle, inhibitors and substrates fight for the love of an enzyme.



In this lesson you will learn how enzymes can be impeded by competitive and non-competitive inhibitors in both reversible and irreversible ways.

Study design dot point

- the mode of action of enzymes including reversible and irreversible inhibition of their action due to chemical competitors at the active site, and by factors including temperature, concentration, and pH

Key knowledge units

Competitive vs non-competitive inhibition	3.1.14.2
Reversible vs irreversible inhibition	3.1.14.3

Competitive vs non-competitive inhibition 3.1.14.2

OVERVIEW

Enzymes can be hindered by molecules known as inhibitors. Enzyme inhibitors are categorised as either competitive or non-competitive.

THEORY DETAILS

Enzyme inhibitors are molecules that bind to an enzyme and prevent it from performing its function. When an inhibitor is bound to an enzyme, the enzyme can either no longer catalyse its specific reaction, or its functioning is greatly reduced (Figure 1).

enzyme inhibitor a molecule that binds to and prevents an enzyme from functioning

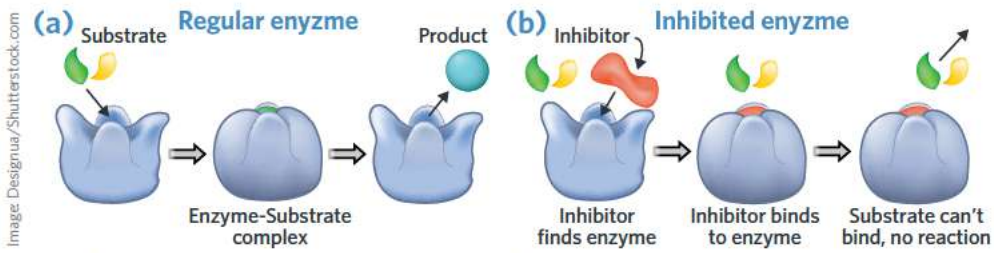


Image Designua/Shutterstock.com

Figure 1 **(a)** Regular enzyme functioning vs **(b)** competitively inhibited enzyme

Competitive inhibition

Competitive inhibition occurs when an inhibitor binds to, and directly occupies and blocks, an enzyme's active site. When an inhibitor is blocking the active site, the substrate is unable to bind with an enzyme and no reaction occurs (Figure 1). To block an active site, a competitive inhibitor has to have a shape that is complementary to the active site, and is also similar to the shape of the enzyme's substrate. Unlike the substrate, however, when an inhibitor binds to an active site it does not trigger a reaction. This form of inhibition is said to be 'competitive' because both the substrate and inhibitor are attempting to bind to the active site.

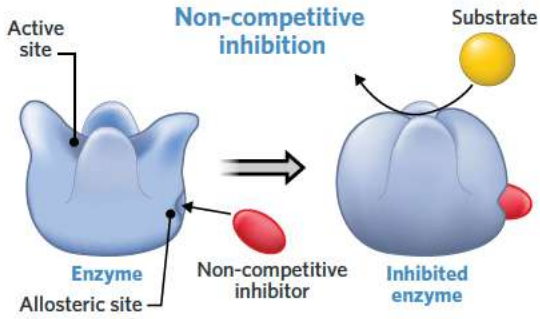


Image: Designua/Shutterstock.com

Figure 2 Non-competitive inhibition of an enzyme

Non-competitive inhibition

Non-competitive inhibition (also known as allosteric inhibition) occurs when an inhibitor binds to an enzyme at a site other than the active site (an **allosteric site**). This causes a conformational change in the active site that prevents the substrate from binding and the reaction from occurring (Figure 2).

lesson link Competitive inhibition is explored further in ***16D*** by investigating the competitive inhibitor drug Relenza.

Reversible vs irreversible inhibition 3.1.14.3

OVERVIEW

Enzyme inhibitors can also be classified according to if their effects are permanent or temporary. Reversible inhibitors bind weakly to an enzyme, allowing for the bonds to be broken and overcome. Irreversible inhibitors form strong bonds with an enzyme that cannot be broken.

competitive inhibition the hindrance of an enzyme through blocking the active site and prevention of substrate from binding

non-competitive inhibition the hindrance of an enzyme by binding to an allosteric site and changing the conformation of the active site to prevent substrate from binding

allosteric site a region on an enzyme that is not the active site

reversible inhibition enzyme inhibition that involves weaker bonds that can be overcome

irreversible inhibition enzyme inhibition that involves stronger bonds that cannot be broken

THEORY DETAILS

Reversible enzyme inhibition

Enzyme inhibition can be classified as **reversible** if the bonds formed between the enzyme and the inhibitor are weak enough to be broken. The effects of these inhibitors are not permanent and can be reversed. This means reversible inhibitors typically slow the rate of a given enzyme-catalysed reaction, but do not stop it indefinitely.

A reversible, competitive inhibitor would form a weak bond with an enzyme's active site. The weak bonds can break, which makes the active site available again for substrate or another inhibitor. This mode of inhibition will significantly slow the enzyme's action on a substrate. However, the inhibitor can have its effects overcome by increasing the amount of substrate present. This provides a greater chance of substrate binding to the enzyme and not an inhibitor (Figure 3a).

Figure 3a is an example of competitive reversible inhibition, however reversible inhibitors can act competitively or non-competitively. Unlike competitive inhibitors, a non-competitive, reversible inhibitor is not influenced by concentrations of the substrate.

Irreversible enzyme inhibition

Irreversible inhibitors will form strong bonds that are unbreakable. This means that if an irreversible inhibitor binds to an enzyme, it is unable to bind with any substrate or catalyse any reactions indefinitely. This means that regardless of how much extra substrate is present, the reaction can never occur (Figure 3b).

Most irreversible inhibitors occupy the active site of an enzyme, and so are usually classified as competitive.

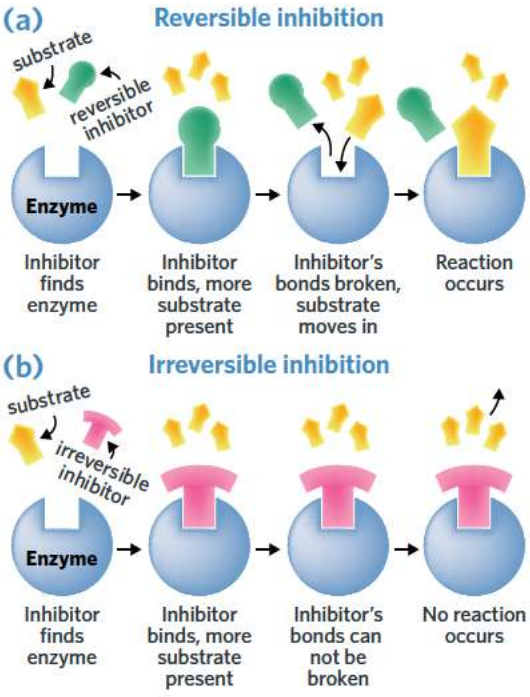


Figure 3 The difference between **(a)** reversible and **(b)** irreversible inhibition of an enzyme

Theory summary

Competitive inhibitors block an enzyme's active site, whereas non-competitive inhibitors bind to an allosteric site and induce a conformational change that disrupts the active site.

Reversible inhibitors can have their weak bonds broken; their effects can be overcome by techniques such as adding more substrate. Irreversible inhibitors form bonds that can not be broken, and stop an enzyme's functionality permanently.

Table 1 Summary of the methods of inhibition

Methods of inhibition	Competitive inhibition	Non-competitive inhibition
Reversible inhibition	Inhibitor creates a weak bond with the active site of an enzyme Increasing substrate concentration decreases effect of inhibitor	Inhibitor creates a weak bond with the allosteric site of an enzyme Increasing substrate concentration has no change on the effect of inhibitor
Irreversible inhibition	Inhibitor creates a strong bond with the active site of an enzyme The bonds cannot be broken	Inhibitor creates a strong bond with the allosteric site of an enzyme The bonds cannot be broken

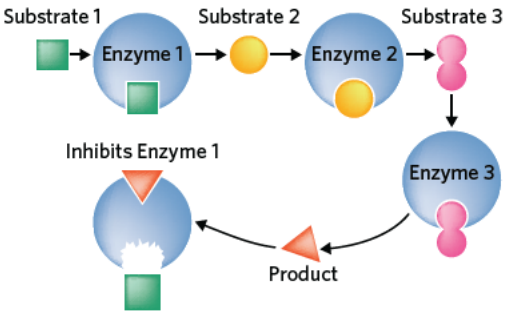


Figure 4 Enzyme inhibition can impact entire biochemical pathways, for example, the final product may allosterically inhibit the first enzyme.

5B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ inhibition of the enzyme at any location other than where the substrate binds

b _____ mode of inhibition where unbreakable bonds are formed with the enzyme

c _____ something that stops an enzyme's function

d _____ inhibition of the enzyme at the location where the substrate binds

e _____ mode of inhibition where weak, breakable bonds are formed with the enzyme

f _____ the site of binding on an enzyme for non-competitive inhibitors

Question 2

Which of the following options are all true of competitive inhibition?

A	always reversible	inhibitor shape is similar to the enzyme shape	occurs at the allosteric site	the enzyme and substrate compete
B	can be reversible or irreversible	inhibitor shape is similar to substrate shape	occurs at the active site	the inhibitor and substrate compete
C	can be reversible or irreversible	inhibitor shape is similar to substrate shape	occurs at the allosteric site	the enzyme and inhibitor compete
D	always reversible	inhibitor shape is similar to the enzyme shape	occurs at an active site	the substrate and active site compete

Question 3

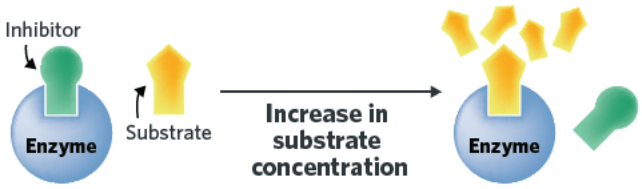
Which of the following options are all true of non-competitive inhibition?

A	can be reversible or irreversible	inhibitor shape can be different to substrate shape	occurs at the active site	causes a conformational change in the substrate
B	can be reversible or irreversible	inhibitor shape is the same as substrate shape	occurs at the active site	causes a conformational change in the active site
C	always irreversible	inhibitor shape is the same as substrate shape	occurs at the allosteric site	causes a conformational change in the substrate
D	can be reversible or irreversible	inhibitor shape can be different to substrate shape	occurs at an allosteric site	causes a conformational change in the active site

Question 4

What type of inhibitor is seen in the diagram?

A Reversible, competitive inhibition
B Irreversible, competitive inhibition
C Reversible, non-competitive inhibition
D Irreversible, non-competitive inhibition



Question 5

Which of the following are all true?

	Reversible inhibitors...	Irreversible inhibitors...	Adding more substrate can alleviate the impacts of...	Allosteric binding occurs during...
A	temporarily halt enzymatic reactions	permanently stop enzymatic reactions	non-competitive reversible inhibitors	non-competitive inhibition
B	temporarily halt enzymatic reactions	permanently stop enzymatic reactions	competitive reversible inhibitors	non-competitive inhibition
C	permanently stop enzymatic reactions	permanently stop enzymatic reactions	non-competitive irreversible inhibitors	competitive inhibition
D	temporarily halt enzymatic reactions	do not affect enzymes	competitive irreversible inhibitors	competitive inhibition

Exam-style questions

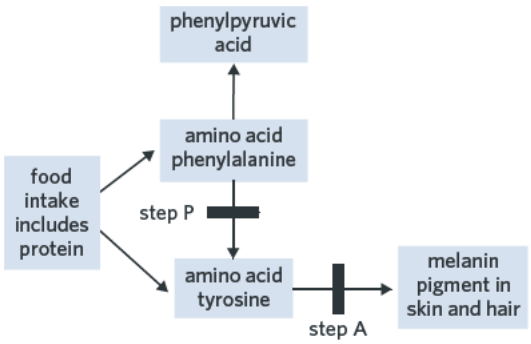
Within lesson

Question 6 (1 MARK)

The diagram shows part of a metabolic pathway involving the amino acids phenylalanine and tyrosine. One or more enzymes are involved at each step in such a pathway.

Which of the following is correct?

A Inhibiting step P would increase melanin pigment in skin and hair.
B Inhibiting step P would decrease phenylpyruvic acid concentration.
C Inhibiting step A would increase amino acid tyrosine concentration.
D Inhibiting step A would decrease amino acid phenylalanine concentration.



Adapted from VCAA 2009 Exam 2 Section B Q2

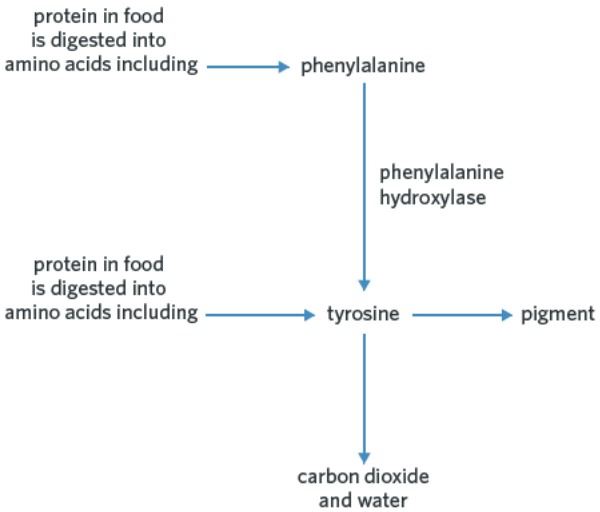
Question 7 (1 MARK)

Phenylketonuria (PKU) is a disorder in which an affected individual is unable to metabolise the amino acid phenylalanine. If phenylalanine builds up in body tissue it results in permanent damage.

Part of the metabolic pathway involved is shown.

Which of the following is false?

A Tyrosine acts as both a product and reactant in this pathway.
B Phenylalanine hydroxylase's function is inhibited in sufferers of PKU.
C Vegetarians that lack protein in their diet are more likely to suffer from PKU.
D Inhibiting phenylalanine hydroxylase reduces the production of the pigment.



Adapted from VCAA 2004 Exam 2 Section B Q3

Question 8 (1 MARK)

Casein is a major protein found in mammalian milk.

When the mammals are producing milk, the pathway for the production of casein can be represented as shown in diagram 1.

When the mammals are not producing milk, the pathway can be represented as shown in diagram 2.

diagram 1

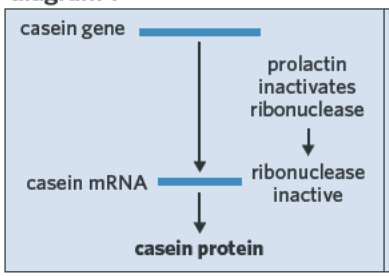
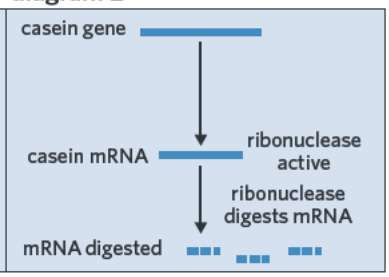


diagram 2



Which of the following conclusions is false?

A Ribonuclease is a digestive enzyme.

B Prolactin regulates the production of casein.

C Ribonuclease hinders the production of casein protein.

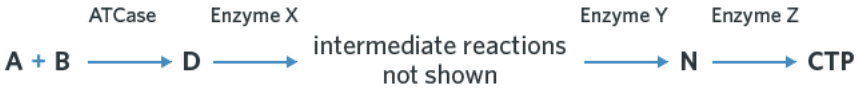
D More milk is produced when prolactin experiences inhibition.

Adapted from VCAA 2014 Section A Q24

Use the following information to answer Questions 9 and 10.

CTP is a substance used by cells to make RNA. The cell initially synthesises CTP using a metabolic pathway starting with the amino acid aspartane (A) and another complex molecule (B).

The pathway for making CTP is represented. The enzyme involved in the first step of the pathway is called ATCase.



Question 9 (1 MARK)

Inhibiting the action of Enzyme X would

A result in a buildup of molecule D.

B cause Enzyme Z to function faster.

C decrease the concentration of ATCase.

D increase the concentration of CTP produced.

Adapted from VCAA 2014 Section B Q1

Question 10 (1 MARK)

An inhibitor that competitively inhibits Enzyme X would be

A complementary to ATCase.

B similar in structure to Enzyme X.

C similar in structure to molecule D.

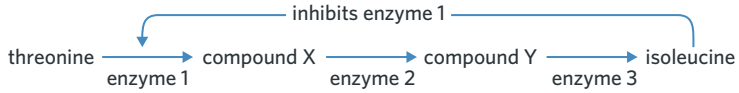
D complementary to the substrate of Enzyme Z.

Adapted from VCAA 2014 Section B Q1

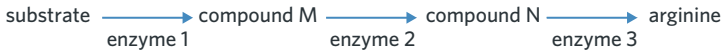
Use the following information to answer Questions 11 and 12.

In the production of isoleucine from threonine in bacteria (Biochemical Pathway 1 [BP 1]), the end product acts as a competitive inhibitor of the first enzyme in the pathway. In the production of arginine (Biochemical Pathway 2 [BP 2]), the end product has no influence on other enzymes in the pathway.

Biochemical Pathway 1 (BP 1)



Biochemical Pathway 2 (BP 2)



Question 11 (1 MARK)

It is reasonable to conclude that in

A BP 1, an increase in isoleucine results in an increase in enzyme 2.

B BP 2, an increase in arginine results in an increase in substrate.

C BP 1, isoleucine regulates the production of compound X.

D BP 2, arginine regulates the production of compound M.

Adapted from VCAA 2006 Exam 1 Section A Q25

Question 12 (1 MARK)

In BP 1, which two compounds have a complementary shape to one another?

A Enzyme 2 and isoleucine

B Enzyme 1 and isoleucine

C Enzyme 1 and enzyme 2

D Enzyme 2 and threonine

Adapted from VCAA 2006 Exam 1 Section A Q25

Multiple lessons

Question 13 (5 MARKS)

Living organisms cannot survive without the presence of enzymes.

a Outline the mode of action of enzymes in living organisms. (1 MARK)

b Describe what is meant by the term 'enzyme-substrate complex' and explain where the binding occurs. (2 MARKS)

c Drug designs can aim to inhibit the action of enzymes.

A given drug competitively inhibits an enzyme. Compare the structure of this drug to the structure of the enzyme and its substrate. (2 MARKS)

Adapted from VCAA 2008 Exam 1 Section B Q4

Question 14 (5 MARKS)

In Tay Sachs disease (TSD), the action of the enzyme that breaks down glycolipid is allosterically inhibited.

Part of the metabolic pathway for the breakdown of glycolipid is shown.

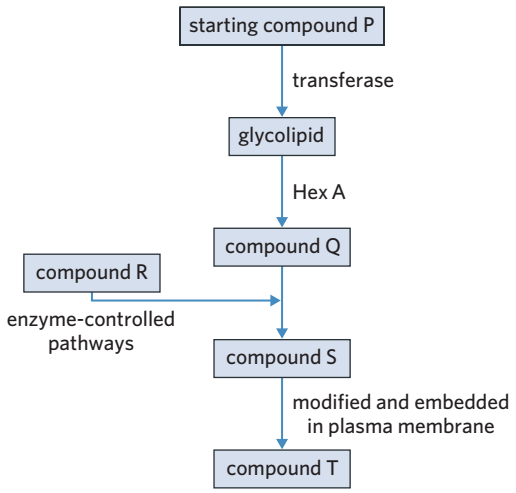
a How would the levels of compound T in sufferers of TSD compare to a healthy individual? (1 MARK)

b What is the name of the inhibited enzyme in sufferers of TSD? (1 MARK)

c How does the presence of compound R affect the concentration of compound Q? (1 MARK)

d Would increasing the concentration of transferase help alleviate the symptoms of TSD? Justify your response. (2 MARKS)

Adapted from VCAA 2010 Exam 1 Section B Q6

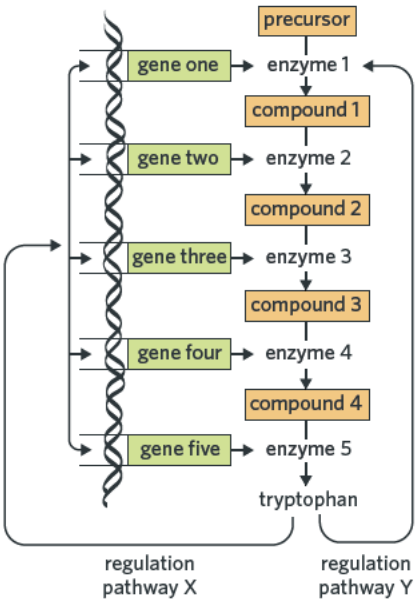


Question 15 (5 MARKS)

Gene regulation refers to genes only being activated or transcribed when required.

Bacteria require amino acids to produce proteins. For example, bacteria in a human intestine may absorb amino acids from digested food, but at times there may be a deficiency of a particular amino acid. If this is the case, the bacteria will produce the necessary amino acid themselves.

The diagram is a regulation system in a bacterial cell involving the production of the amino acid tryptophan. Note that there are two pathways (X and Y). Tryptophan is the regulatory compound in these two pathways and acts as a repressor in both.



a What happens to the production of tryptophan when either pathway X or Y are activated? (1 MARK)

b Describe the difference between the outcomes of activating pathway X or Y. (2 MARKS)

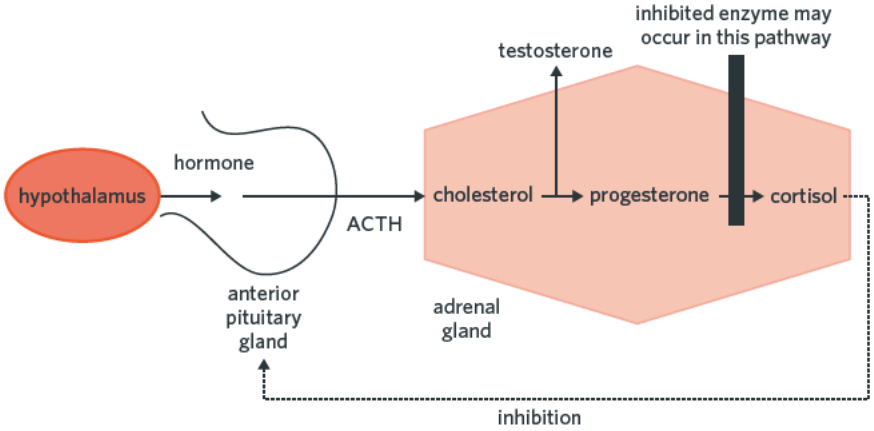
c If enzyme 4 were to become faulty or experience inhibition, what would be seen in the regulation system? (2 MARKS)

Adapted from VCAA 2007 Exam 2 Section B Q3

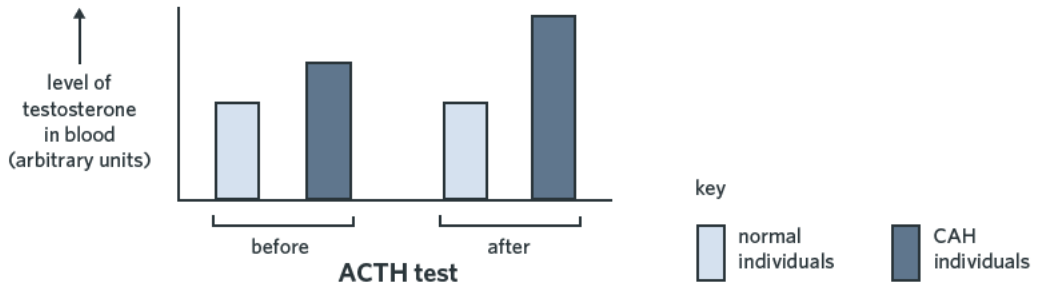
Key science skills

Question 16 (6 MARKS)

Cholesterol is usually converted to progesterone and testosterone. Progesterone is then converted to cortisol due to the action of an enzyme 21-hydroxylase. If the enzyme is inhibited, the synthesis of cortisol is reduced and an excess of testosterone is produced. This results in a disorder called congenital adrenal hyperplasia (CAH). ACTH is the hormone that stimulates this pathway. To diagnose the CAH disorder, an ACTH stimulation test is performed. Blood is measured for starting levels of testosterone. ACTH is then injected and another blood sample is taken and analysed after 60 minutes.



The graph shows the changes in testosterone levels in an ACTH stimulation test.



a Describe what is seen in the graph and compare the results of the two groups of individuals. (2 MARKS)

b In relation to the pathway, explain these trends in the graph. (2 MARKS)

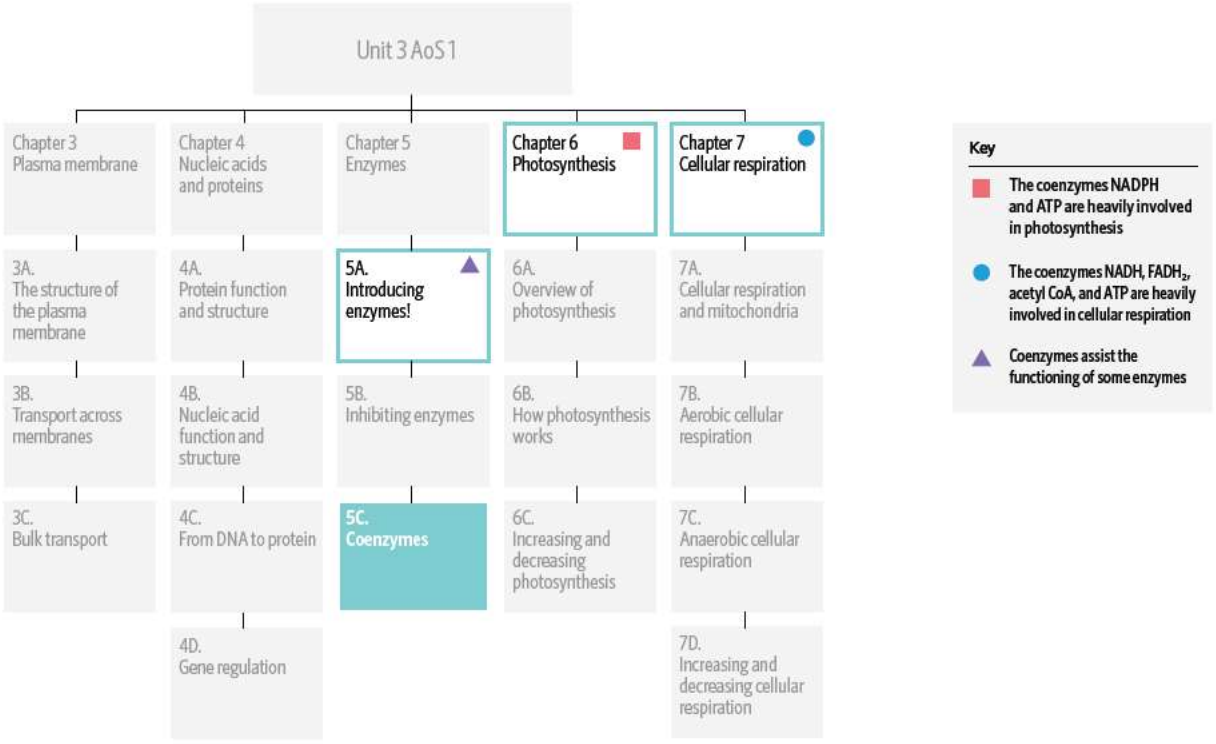
c The inhibitor is a similar shape to progesterone, and the production of excess progesterone levels does not increase the amount of cortisol produced.

Identify the type of enzyme inhibition occurring. Justify your response. (2 MARKS)

Adapted from VCAA 2010 Exam 1 Section A Q24

5C COENZYMES

A coenzyme is the wingman some enzymes need to catalyse reactions.



In this lesson you will learn how coenzymes help enzymes catalyse reactions, and how their cycling is integral to many biochemical processes.

Study design dot point

- the cycling of coenzymes (ATP, NADH, and NADPH) as loaded and unloaded forms to move energy, protons, and electrons between reactions in the cell

Key knowledge units

Coenzymes assist enzymes	3.1.15.1

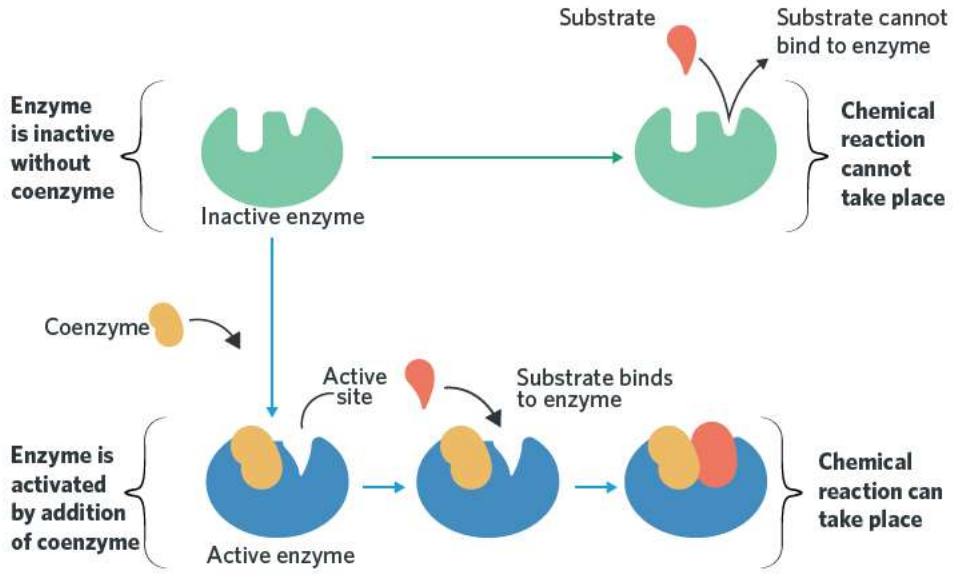


Figure 1 Some enzymes cannot function without a coenzyme

Coenzymes assist enzymes 3.1.15.1

OVERVIEW

Some enzymes require a coenzyme to catalyse reactions.

THEORY DETAILS

Some enzymes are absolute golden children. They can catalyse their substrates perfectly, without assistance, and are free to continue catalysing reactions until the day they die by denaturation or inhibition. Other enzymes are the golden child's older sibling that can never get the job done without some help. They require assistance from a **cofactor** to catalyse reactions (Figure 1).

Cofactors and coenzymes

A cofactor binds to an enzyme, allowing the enzyme-catalysed reaction to occur. Cofactors fall into two groups:

- inorganic ions such as magnesium (Mg^{2+}), copper (Cu^{2+}), and manganese (Mn^{2+})
- organic molecules such as proteins, vitamins, **ATP**, **NADH**, **NADPH**, acetyl CoA, and $FADH_2$
  - All the organic, non-protein cofactors are known as **coenzymes.**

Tip VCAA has only tested specific coenzymes in the past and not other cofactors like inorganic ions or proteins. The coenzymes $FADH_2$ and acetyl CoA are integral to cellular respiration (lesson 7B), however, VCAA does not assess them when asking questions specifically concerning enzymes. Therefore, this lesson will focus on the coenzymes ATP, NADH, and NADPH only.

In coenzyme-assisted reactions, the enzyme remains unchanged. However, the structure of the coenzyme is changed (Figure 2). During the reaction, the coenzyme binds to the active site, donates energy or molecules, and cannot be immediately reused. After the reaction, the coenzyme can be recycled by accepting energy (e.g. the bonds formed with electrons, H+, phosphate ions), so it can go on to assist in more reactions. The cycling of coenzymes is integral to certain biochemical processes.

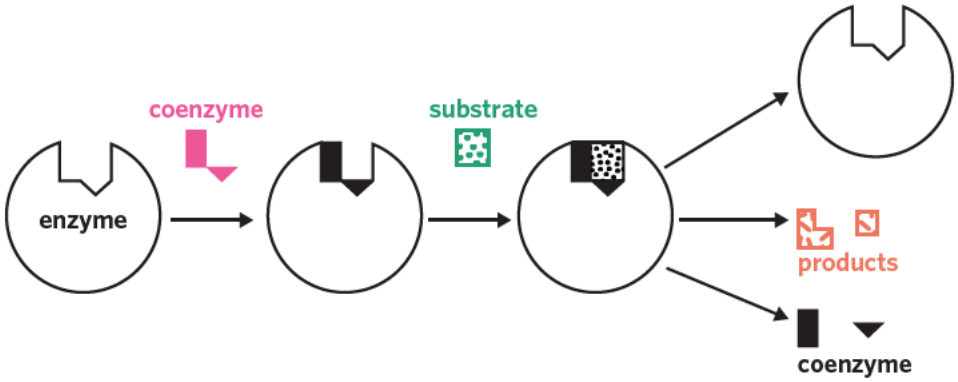


Figure 2 After a coenzyme binds to an enzyme, the substrate can bind to the active site. As the reaction progresses, the coenzyme is converted to its unloaded form.

The cycling of coenzymes

A coenzyme that can release stored chemical energy by donating chemical groups is called a **loaded** coenzyme. When a loaded coenzyme binds to an enzyme and releases energy, it becomes an **unloaded** coenzyme.

- The loaded coenzymes NADH and NADPH donate protons and electrons, becoming the unloaded coenzymes **NAD^+** and **$NADP^+$**, respectively.
- The loaded coenzyme ATP donates a phosphate group (P_i), becoming the unloaded coenzyme **ADP**.

Unloaded coenzymes can be energised and reloaded again and again (Figure 3). The process is called coenzyme cycling. The energy being transferred when cycling is stored in the bonds between the coenzyme and the donated or accepted proton, electron, or chemical group. Because of this, coenzymes are often used to store and move energy throughout a cell. Coenzymes are used so frequently that the same ATP molecule can be cycled to ADP and back, over 1000 times every day!

cofactor any organic or inorganic molecule, such as a coenzyme or metal ion, that assists enzyme function

ATP adenosine triphosphate, a high energy molecule that, when broken down, provides energy for cellular processes

NADH a coenzyme that is a proton (H^+) and electron carrier in cellular respiration

NADPH a coenzyme that is a proton (H^+) and electron carrier in photosynthesis

coenzyme a non-protein organic cofactor that assists enzyme function. They release energy and are recycled during a reaction

loaded the form of a coenzyme that can release stored chemical energy by donating a proton (H^+), electron, or chemical group

unloaded the form of a coenzyme that cannot release stored chemical energy, but is free to accept a proton (H^+), electron, or chemical group

NAD^+ the unloaded form of NADH

$NADP^+$ the unloaded form of NADPH

ADP adenosine diphosphate, the unloaded form of ATP

Tip In coenzyme-assisted reactions, enzymes are activated by energy or chemical groups that are donated by coenzymes. This can temporarily change the shape of the enzyme. Once the coenzyme is used up and leaves the enzyme, the enzyme is structurally unchanged from the beginning of the reaction.

Tip Loaded coenzymes can also be called 'charged' or 'reduced', and unloaded coenzymes can also be called 'uncharged' or 'oxidised'.

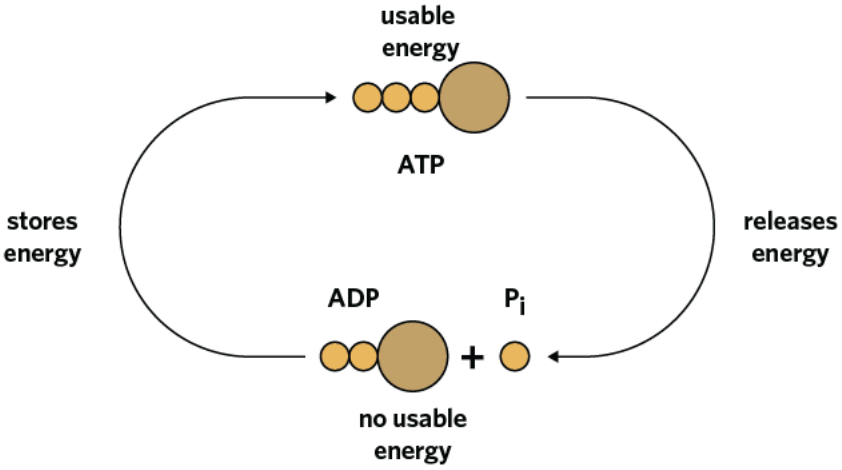


Figure 3 The cycling of ATP between loaded and unloaded forms

ATP and ADP

Adenosine triphosphate (ATP) and adenosine diphosphate (ADP) are the main energy transfer units of the cell. ATP contains three phosphate groups (triphosphate = three phosphates) and is broken down into ADP (diphosphate = two phosphates) by releasing a phosphate group, which also releases the energy stored between the second and third phosphate groups (Figure 4).

ATP is the most usable form of energy found within a cell, resulting in a large number of ATP-assisted reactions. The ATP coenzyme is often used in active transport, binding to a protein pump to facilitate a conformational change.

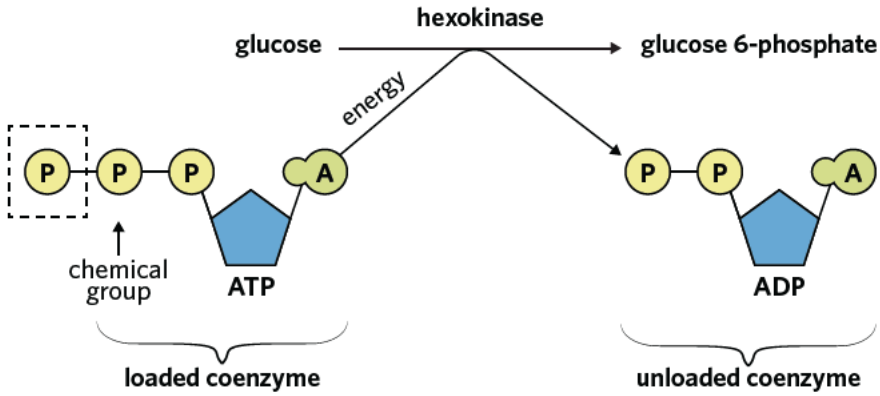


Figure 4 ATP is converted to its unloaded form, ADP, when releasing the energy required to power this hexokinase-linked reaction.

NADH and NAD^+

Nicotinamide adenine dinucleotide (NADH) is a coenzyme involved in the transport of protons and electrons during cellular respiration. NADH is the loaded form of the coenzyme and carries usable energy. NAD^+ is the unloaded form of the coenzyme and is recycled back to NADH.

NADPH and $NADP^+$

Nicotinamide adenine dinucleotide phosphate (NADPH) is very similar in structure to NADH and NAD^+, except it contains an additional phosphate group. The loaded NADPH coenzyme is involved in many processes such as lipid and carbohydrate production, as well as photosynthesis.

Theory summary

Coenzymes facilitate the function of certain enzymes. Coenzymes are altered or unloaded in a reaction, and are recycled to be used again in the next reaction. Three key coenzymes are ATP, NADH, and NADPH, which are heavily involved in respiration and photosynthesis.

Tip A good way to remember the different uses of NADH and NADPH is that NADPH is used in Photosynthesis.

lesson link The cycling of NADPH and ATP play a major role in photosynthesis (see ***chapter 6***).

lesson link The cycling of NADH and ATP play a major role in cellular respiration (see ***chapter 7***).

5C QUESTIONS

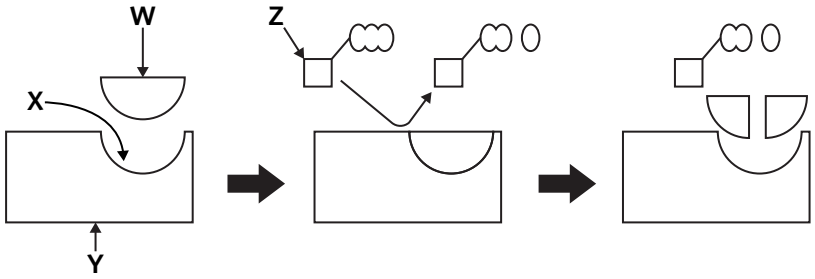
Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the form of a coenzyme which carries usable stored energy
b _____ the coenzyme used to power most cellular reactions
c _____ a non-protein organic cofactor that assists in the function of some enzymes
d _____ the form of a coenzyme which cannot release stored energy
e _____ a loaded coenzyme involved in carrying protons and electrons in photosynthesis
f _____ a loaded coenzyme involved in carrying protons and electrons in cellular respiration

Question 2



Which of the following correctly identifies the shapes W-Z?

	W	X	Y	Z
A	substrate	active site	enzyme	coenzyme
B	inhibitor	active site	coenzyme	enzyme
C	substrate	active site	enzyme	inhibitor
D	coenzyme	inhibitor	enzyme	substrate

Question 3

Which of the following are all true statements concerning coenzymes?

A	assist the function of all enzymes	are organic	are not proteins	can only be loaded
B	assist the function of some enzymes	are inorganic	are proteins	can be loaded and unloaded
C	inhibit enzyme function	are inorganic	are proteins	can only be loaded
D	assist the function of some enzymes	are organic	are not proteins	can be loaded and unloaded

Question 4

Classify each of the following statements as relating to ATP, NAD^+, or NADPH in the table.
NOTE: each statement can be classified into multiple groups.

I Is a coenzyme
II Is unloaded
III Carries electrons and protons in the photosynthesis process
IV Allows certain substrates to undergo an enzyme-catalysed reaction
V Is frequently cycled
VI Is loaded
VII Assists enzyme function
VIII Is the most usable form of stored energy

	ATP	NAD^+	NADPH
A	I, V, VI, VII, VIII	I, V, VI, VII	I, III, IV, VI, VII
B	I, IV, V, VI, VII, VIII	I, II, V	I, III, IV, V, VI, VII
C	I, II, IV, V, VII, VIII	I, II, V, VII	I, III, IV, VI, VIII
D	I, IV, VII, VIII	I, II, IV, VII, VIII	I, III, V, VI, VII

Question 5

The following steps in a coenzyme-assisted enzymatic reaction are in the wrong order.

1 The products are released from the active site

2 The reaction occurs

3 The substrate is present but cannot be catalysed by the enzyme

4 The enzyme is free to catalyse more reactions

5 A loaded coenzyme binds to the enzyme

6 An enzyme is present

7 The substrate can bind to the active site

8 The unloaded coenzyme leaves the enzyme

The correct order is

A 6, 3, 5, 7, 2, 4, 1, 8.

B 6, 3, 7, 5, 2, 1, 8, 4.

C 6, 5, 3, 7, 2, 4, 8, 1.

D 6, 3, 5, 7, 2, 1, 8, 4.

Exam-style questions

Within lesson

Question 6 (1 MARK)

The production of adenosine triphosphate (ATP) is represented by the following equation.

ADP + Pi ⟶ ATP

ATP

A is the unloaded form of ADP.

B contains four phosphate parts.

C is produced by multiple ADP monomers joining.

D provides a supply of usable energy for the cell.

Adapted from VCAA 2015 Section A Q7

Question 7 (1 MARK)

Which pair of molecules contains the greatest amount of stored energy?

A NADPH and NADH

B $NADP^+$ and NADH

C NADPH and NAD^+

D $NADP^+$ and NAD^+

Adapted from VCAA 2018 Section A Q10

Question 8 (1 MARK)

Which of the following is false when considering this reaction?

ADP + Pi ⟶ ATP

A This reaction is reversible.

B The product of this reaction stores energy.

C The product in this reaction contains three phosphate subunits.

D This reaction is catalysed by a coenzyme to produce adenosine triphosphate.

Adapted from VCAA 2011 Exam 1 Section A Q20

Question 9 (1 MARK)

NADH is a coenzyme. Which one of the following is a false statement about NADH?

A NADH is frequently cycled.

B NADH is the unloaded form of NAD^+.

C NADH contains more usable stored energy than NAD^+.

D NADH carries electrons and protons between reactions in a cell.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q5

Multiple lessons

Question 10 (1 MARK)

Sucrose (cane sugar) is a disaccharide used by plants as a transport molecule. Sucrose is formed in the following reaction.

$$\text{glucose + fructose} \xrightarrow{\text{enzyme}} \text{sucrose}$$

With reference to this process, which of the following statements is false?

A Fructose acts as a coenzyme to produce sucrose from glucose.

B The enzyme lowers the activation energy of the reaction.

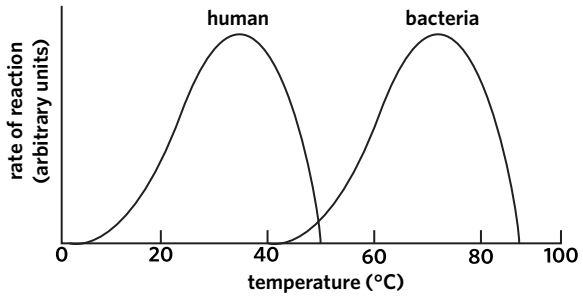
C The production of sucrose is an energy-storing reaction.

D An enzyme can be used to form sucrose.

Adapted from VCAA 2008 Exam 1 Section A Q18

Question 11 (1 MARK)

The rate of reaction of a typical human enzyme and coenzyme pairing was compared with the rate of reaction of a typical enzyme and coenzyme taken from bacteria that live in hot springs. The rates of reaction were measured over the same range of temperatures. The data obtained is shown in the following figure.



It is reasonable to conclude that

A both enzymes function well at 37°C.

B the human coenzyme is denatured at 0°C.

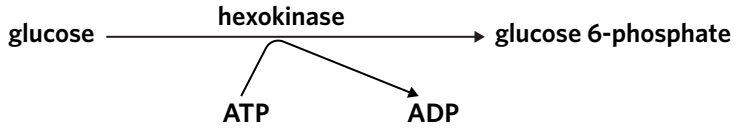
C the bacterial enzyme cannot function effectively below 40°C.

D the human enzyme functions over a much larger temperature range than the bacterial enzyme.

Adapted from VCAA 2002 Exam 1 Section A Q25

Question 12 (8 MARKS)

Examine the following reaction.



a Identify the substrate, enzyme, and coenzyme in the reaction. (2 MARKS)

b How does the structure of hexokinase compare to the structure of glucose? (1 MARK)

c Describe the role ATP plays in the reaction. (2 MARKS)

d Adenosine triphosphate contains three phosphate groups and is converted to adenosine diphosphate in this reaction, which contains two phosphate groups.

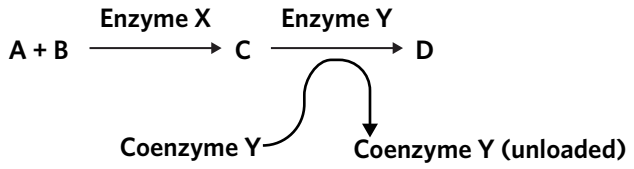
i Identify where the third phosphate group has gone in this reaction. (1 MARK)

ii Outline what happens to the ADP molecule within a cell following this reaction. (2 MARKS)

Key science skills

Question 13 (11 MARKS)

Molecule D is produced in the following reaction.



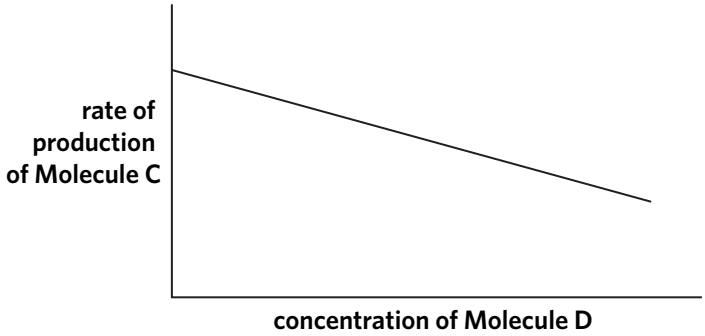
Enzymes X and Y can catalyse the production of Molecule D many times.

a What happens to Coenzyme Y when Molecule D is produced? (1 MARK)

b If none of the loaded Coenzyme Y were present, how would it impact the concentrations of molecules A, B, C, and D? Justify your response. (2 MARKS)

c Identify which enzyme, X or Y, likely contains an active site that better fits their respective substrate(s). Justify your response. (2 MARKS)

d The graph demonstrates the change in the rate of production of Molecule C in solutions with different concentrations of Molecule D. All other variables are kept constant.



Molecule D is known to have enzyme inhibiting properties.

i Identify when the consumption of Molecules A and B is greatest. (1 MARK)

ii Which enzyme in the pathway does Molecule D inhibit? Explain the effect of Molecule D on the total rate of reaction of the pathway. (2 MARKS)

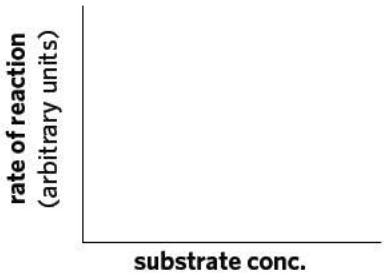
iii Scientists studying this reaction hypothesised that Molecule D was acting as a competitive inhibitor in the pathway. A study of the structures of molecules A, B, C, and D showed that Molecule D was very similar in structure to Molecule C, but shared nothing structurally in common with either Molecule A or B.
State what type of inhibitor Molecule D is likely acting as. Justify your response by referring to the information, and your knowledge of enzymes. (3 MARKS)

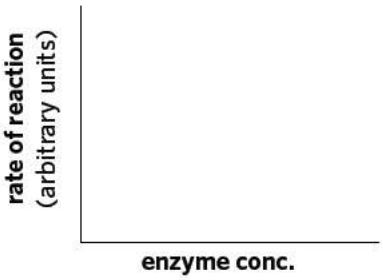
Adapted from VCAA 2014 Section B Q1

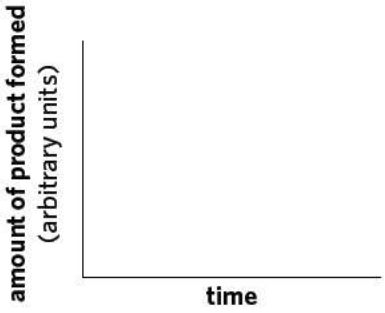
ACTIVITY

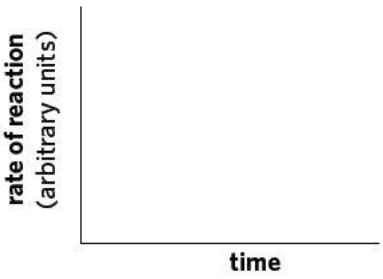
Graphing enzyme activity

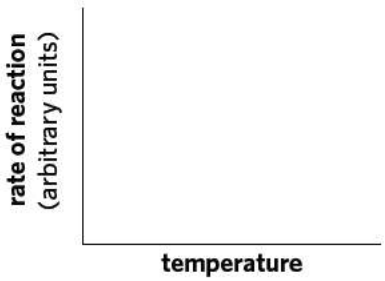
Copy the following sets of axes into your workbook and graph the relationship between the variables of an enzyme-catalyzed reaction.

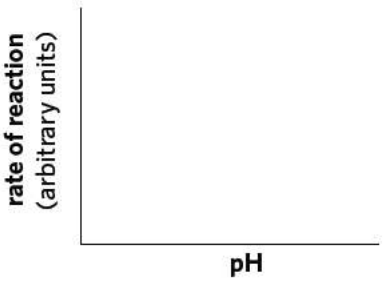


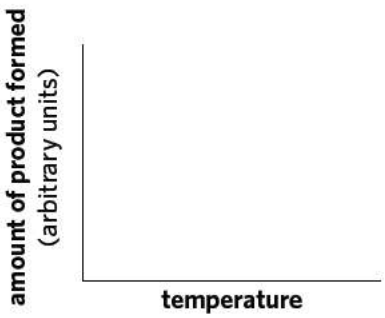


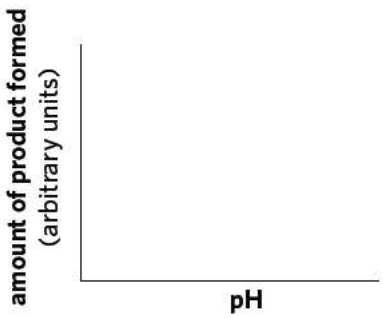




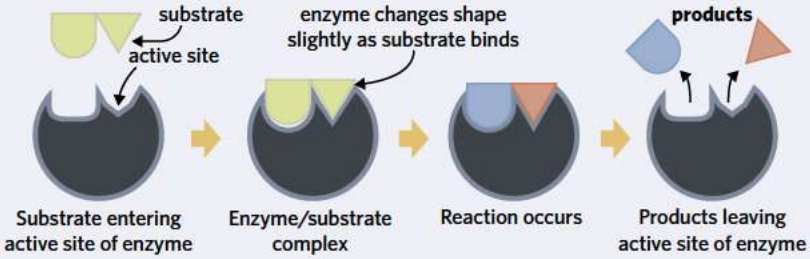








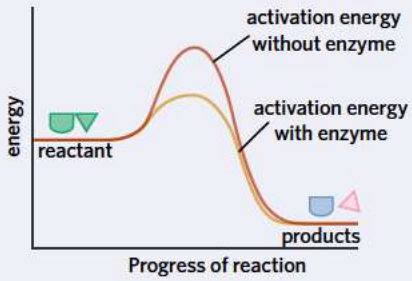
CHAPTER SUMMARY



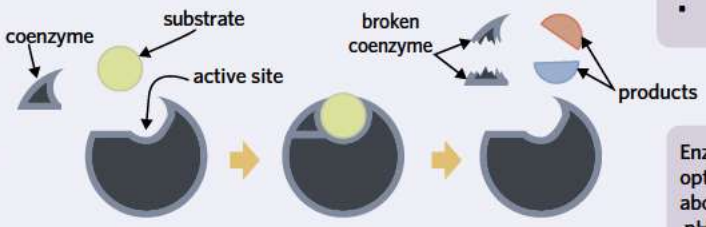
Enzymes catalyse biochemical reactions by binding to a substrate at their active site and lowering the activation energy of a reaction.

Enzymes are:
- Reusable
- Specific, to their substrate
- Proteins, mostly

They often function:
- On entire biochemical pathways
- On both direction of reactions
- With the help of a coenzyme

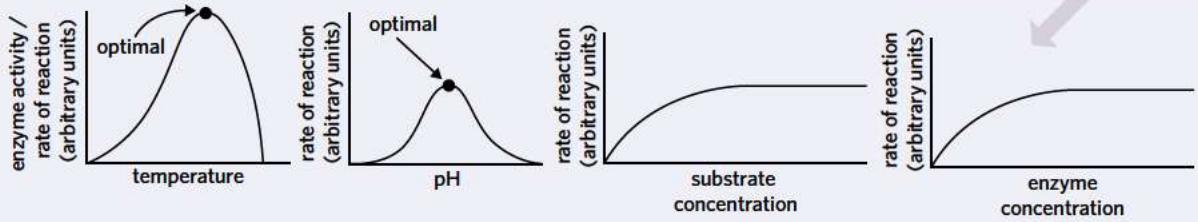


Some enzymes require a coenzyme to function.

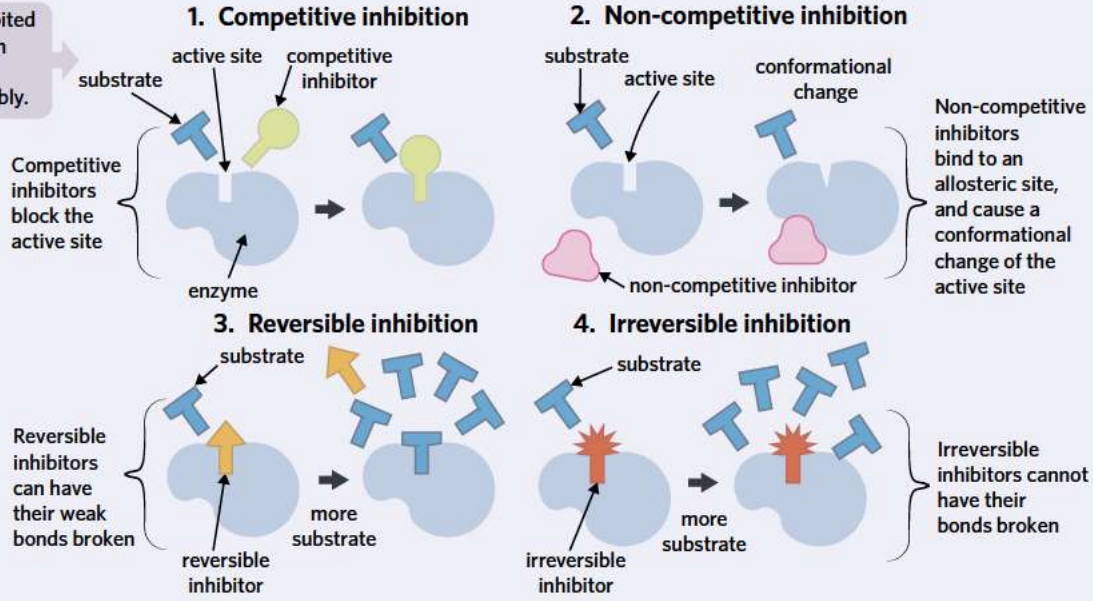


Enzyme activity is the highest at the optimal temperature, but denatures above this. Outside of the optimal pH value, enzymes begin to denature.

Increasing substrate or enzyme concentration increases the rate of reaction, until a maximum is reached.



Enzymes can be inhibited at the active site or an allosteric site, either reversibly or irreversibly.

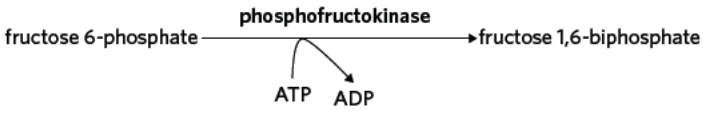


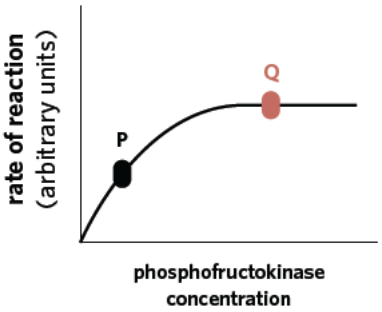
CHAPTER REVIEW QUESTIONS

SECTION A (15 MARKS)

Use the following information to answer Questions 1 and 2.

The biochemical pathway of glycolysis involves nine intermediate reaction steps. One of these steps is represented in the diagram, as well as a graph displaying the rate of the reaction.





Question 1 (1 MARK)

As the concentration of phosphofructokinase is increased from point P

A the rate of reaction will increase.
B ADP concentration will decrease.
C the rate of reaction will not change.
D fructose 6-phosphate concentration will increase.

Adapted from VCAA 2017 Section A Q5

Question 2 (1 MARK)

Based on the information in the graph, what can be concluded at point Q?

A Fructose 6-phosphate is the limiting reactant.
B The enzyme phosphofructokinase has denatured.
C Fructose 1, 6-biphosphate is the limiting reactant.
D ADP has become the limiting reactant of the reaction.

Question 3 (1 MARK)

The diagram represents a generalised biochemical process.

Which one of the following statements is correct?

A Molecule X is an enzyme.
B Structure A is a coenzyme.
C This is an example of competitive inhibition.
D Molecule X binds allosterically to the active site.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q8

Question 4 (1 MARK)

An experiment was conducted to investigate enzyme activity. A small amount of amylase solution was added to a solution of starch dissolved in water at 35 °C. It was observed that maltose was produced.

Which of the following is the enzyme in this reaction?

A water
B starch
C maltose
D amylase

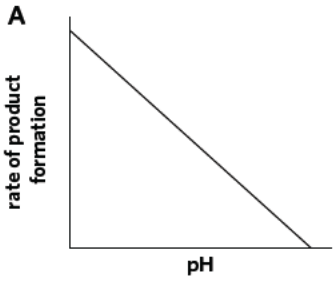
Adapted from VCAA 2015 Section A Q6

Question 5 (1 MARK)

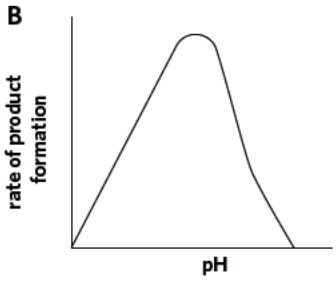
Consider an enzyme-facilitated reaction in which the concentration of the enzyme is constant.

Which of the following graphs shows the effect of increasing the pH of the solution on the rate of product formation?

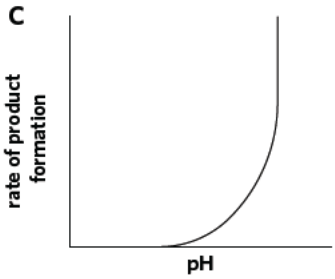
A



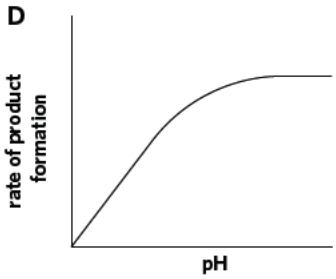
B



C



D



Adapted from VCAA 2017 Sample Exam Section A Q10

Question 6 (1 MARK)

The activity of an enzyme does not

A increase with temperature continuously, even though more collisions between enzyme and substrate occur.
B decrease with pH values outside an enzyme's optimal range.
C increase when temperature is within its optimum range.
D decrease in the presence of an inhibitor.

Question 7 (1 MARK)

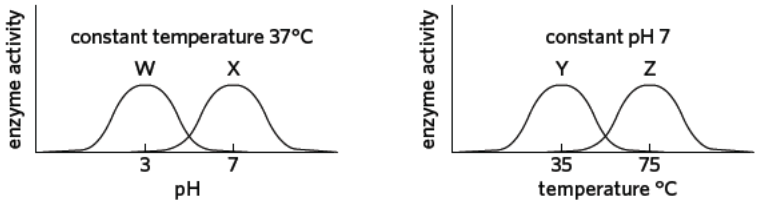
Which pair of molecules contains the least amount of usable stored energy?

A NAD^+ and ATP
B NAD^+ and ADP
C NADH and ATP
D NADH and ADP

Adapted from VCAA 2018 Section A Q10

Question 8 (1 MARK)

The following graphs show the way four enzymes, W, X, Y, and Z, change their activity on different pH and temperature situations.



Which of the following statements about the activity of the four enzymes is correct?

A The optimal pH of enzyme Z is 3.

B Enzyme W functions well in an alkaline environment.

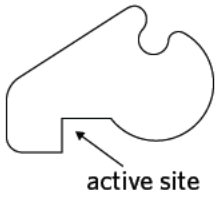
C At pH 5, enzyme X has greater activity than enzyme W.

D Enzyme Y is more likely to be found in the human body than enzyme Z.

Adapted from VCAA 2014 Section A Q13

Question 9 (1 MARK)

A drug molecule has been designed to inhibit the activity of an enzyme. The shape of the enzyme is shown. The position of the active site is labelled.



Which of the following is the most likely shape for a drug molecule that is capable of competitively inhibiting the enzyme?

A 

B 

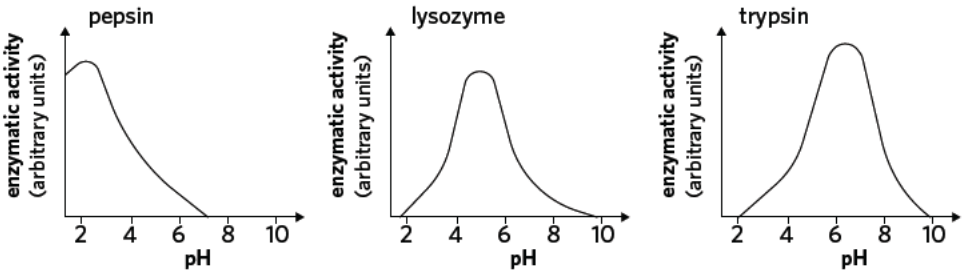
C 

D 

Adapted from VCAA 2013 Section A Q1

Question 10 (1 MARK)

Examine the following graphs.



From these graphs it is reasonable to infer that at a pH of 6

A all the lysozyme would be denatured.

B trypsin converts a large amount of substrate.

C all three enzymes would lack a functional active site.

D the active site of pepsin would bind well to the substrate.

Adapted from VCAA 2011 Exam 1 Section A Q16

Question 11 (1 MARK)

ATP is a coenzyme. The production of adenosine triphosphate (ATP) is represented by the following equation.

$$ADP + P_i \rightarrow ATP$$

The production of ATP

A only occurs in eukaryotes.

B is an energy-storing process.

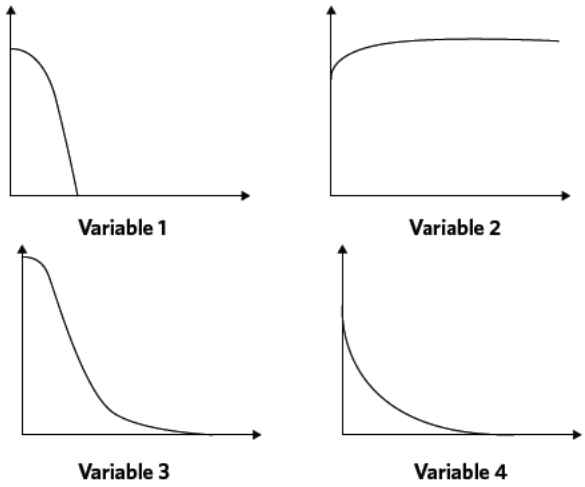
C is an energy-releasing process.

D can only progress at temperatures above 35 °C.

Adapted from VCAA 2015 Section A Q7

Use the following information to answer Questions 12 and 13.

Four students performed a series of experiments to investigate the effects of four different variables on the rate of an enzyme-catalysed reaction. In each experiment the students increased one of the following variables: temperature, pH, enzyme concentration, and the concentration of a known enzyme inhibitor. Each experiment started at a pH and temperature value known to be within the optimal range of the enzyme. When starting each experiment, one student made the mistake of not recording the data for the first several minutes. The students still displayed their results in a series of graphs, as shown, but the reaction rate was high when recording started. Each graph is a line of best fit.



Question 12 (1 MARK)

The students did not label the horizontal axis on any of their four graphs. The next day, the students could not agree on which variable should be labelled on the horizontal axis of each graph. The students made the following suggestions as to what each variable could be.

Student	Variable 1	Variable 2	Variable 3	Variable 4
Sammy	temperature	enzyme concentration	pH	inhibitor concentration
Daniel	enzyme concentration	inhibitor concentration	pH	temperature
Chloe	pH	enzyme concentration	inhibitor concentration	temperature
Ruby	temperature	pH	enzyme concentration	inhibitor concentration

Which student correctly identified all four variables on the horizontal axes?

A Sammy

B Daniel

C Chloe

D Ruby

Adapted from VCAA 2018 Section A Q7

Question 13 (1 MARK)

What type of error was made by not recording data at the beginning of the experiment?

A systematic error

B theoretical error

C personal error

D random error

Question 14 (1 MARK)

A molecule that takes part in many biochemical reactions is $NADP^+$.

Which of the following is false?

A $NADP^+$ carries additional energy when protons and electrons are added to it.

B Energy is stored when $NADP^+$ is converted to NADPH.

C $NADP^+$ has a higher energy when it is unloaded.

D NADPH is the loaded form of $NADP^+$.

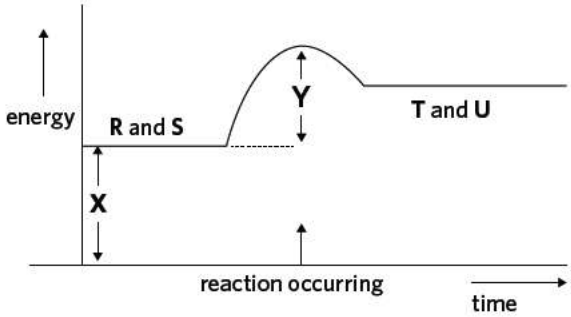
Adapted from VCAA 2017 Section A Q16

Question 15 (1 MARK)

Consider the following reaction in which substrate molecule R and substrate molecule S are converted into product molecule T and product molecule U.

R and S → T and U

The following graph shows the energy available in the molecules against time.



Based on the information in this graph, which of the following is false?

A Molecules T and U have more total energy than R and S.

B An enzyme could be added to lower the value of Y.

C Y represents the activation energy.

D This reaction is energy releasing.

Adapted from VCAA 2013 Section A Q8

SECTION B (25 MARKS)

Question 16 (9 MARKS)

A group of students wanted to investigate the activity of an enzyme that catalyses the breakdown of hydrogen peroxide into water and oxygen.

The students measured oxygen concentration using an oxygen sensor. The oxygen sensor fits into the top of a conical flask, as shown in the diagram.

The students set up three conical flasks with the contents listed in the table.

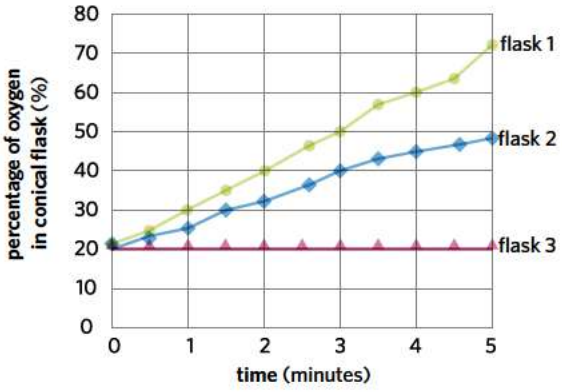
The buffer solutions and the distilled water did not react with the hydrogen peroxide.

All three conical flasks were at room temperature.

The students recorded the concentration of the oxygen over a five minute period.

The results of the experiment are shown in the graph.

Flask	Contents of flask
1	50 mL of 3% hydrogen peroxide solution 2 mL of enzyme solution 50 mL of neutral pH buffer solution
2	50 mL of 3% hydrogen peroxide solution 2 mL of enzyme solution 50 mL of high pH buffer solution
3	50 mL of 3% hydrogen peroxide solution 2 mL of enzyme solution 50 mL of low pH buffer solution



a State the dependent and independent variables in this experiment. (2 MARKS)

b The students hypothesised that the enzyme would have the highest activity in a high pH buffer. Do the results support their hypothesis? Justify your response. (2 MARKS)

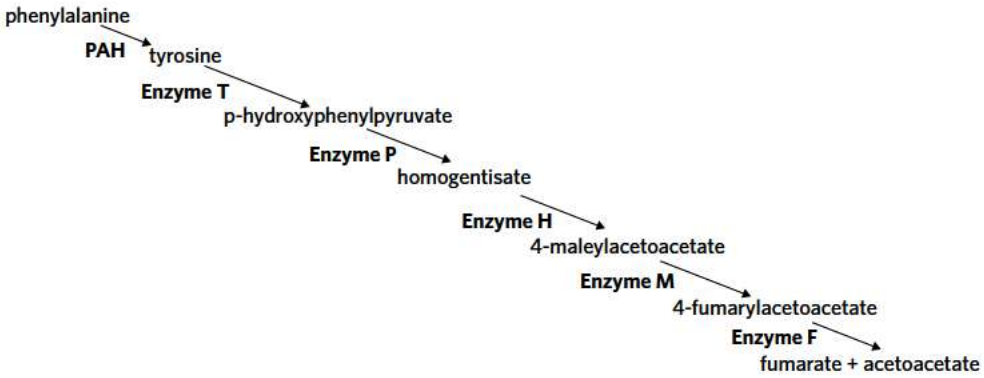
c The class teacher told the students they should use a control. Describe how a control could be implemented and outline its purpose. (2 MARKS)

d The students were required to write a report on their experiment. What conclusion could they draw from their experiment about the enzyme's activity? In your response, refer to: the variables identified in part a, the accuracy of the students' hypothesis in part b, and the results seen in the graph. (3 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q11

Question 17 (6 MARKS)

A genetic disease called phenylketonuria (PKU) may occur in babies. Affected individuals produce little or none of the enzyme phenylalanine hydroxylase (PAH). PKU is caused by the effects of too much of the amino acid phenylalanine building up in the body. Phenylalanine enters the body because it is abundant in a normal protein-rich human diet. Phenylalanine is metabolised in the biochemical pathway shown.



a Explain how the concentration of PAH affects the concentrations of fumarate and acetoacetate. Justify your response. (2 MARKS)

b Enzymes are biological molecules that catalyse reactions but are susceptible to several types of inhibition. Describe the difference between reversible and irreversible enzyme inhibition. (2 MARKS)

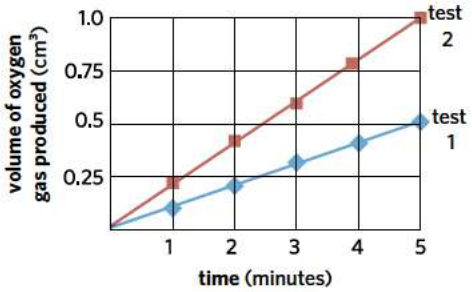
c If a known competitive inhibitor of PAH was introduced to a baby's system, would they be more or less likely to suffer the symptoms of PKU? Justify your response. (2 MARKS)

Adapted from VCAA 2017 Sample Exam Section B Q2a

Question 18 (10 MARKS)

Hydrogen peroxide is a toxic by-product of many biochemical reactions. Human cells break down hydrogen peroxide into water and oxygen gas with the help of the intracellular enzyme catalase. The optimum pH of catalase is 7.

A biology student, Student Z, measured the activity of catalase by recording the volume of oxygen gas produced from the decomposition of hydrogen peroxide when a catalase suspension was added. The catalase suspension was made from ground, raw potato mixed with distilled water. The student performed two tests and graphed the results.



Test 1 used 5 mL of 3% hydrogen peroxide solution and 0.5 mL of catalase suspension. The test was conducted at 20 °C in a buffer solution of pH 7.

Test 2 was carried out under identical conditions to Test 1, except for one factor that the student changed.

Student Z forgot to record which variable was changed in Test 2. The next day, Students A and B came across their unfinished results. Student A stated that the change in Test 2 was likely due to a change in the buffer solution's pH. Student B stated that the change was more likely due to a change in the temperature in which the experiment was conducted under.

a Using the data, describe the changes in levels of oxygen from Test 1 to Test 2. (2 MARKS)

b Justify whether the results support Student A or Student B. (2 MARKS)

c Catalase is a common enzyme found in nearly all living organisms including humans.

- **I** Given catalase is at its optimum temperature when functioning in a human, what would its optimum temperature be? (1 MARK)
- **II** Explain why catalase is able to catalyse more reactions at this temperature. (1 MARK)

d The students set up a third test that used 5 mL of 3% hydrogen peroxide solution and 0.5 mL of catalase suspension, but was conducted at 5 °C in a buffer solution of pH 7. Describe where the results for Test 3 would lie on the graph. Justify your response. (2 MARKS)

e Outline what can be concluded from this experiment. (2 MARKS)

Adapted from VCAA 2017 Section A Q6

UNIT 3 AOS 1, CHAPTER 6

Photosynthesis

06

6A Overview of photosynthesis

6B How photosynthesis works

6C Increasing and decreasing photosynthesis

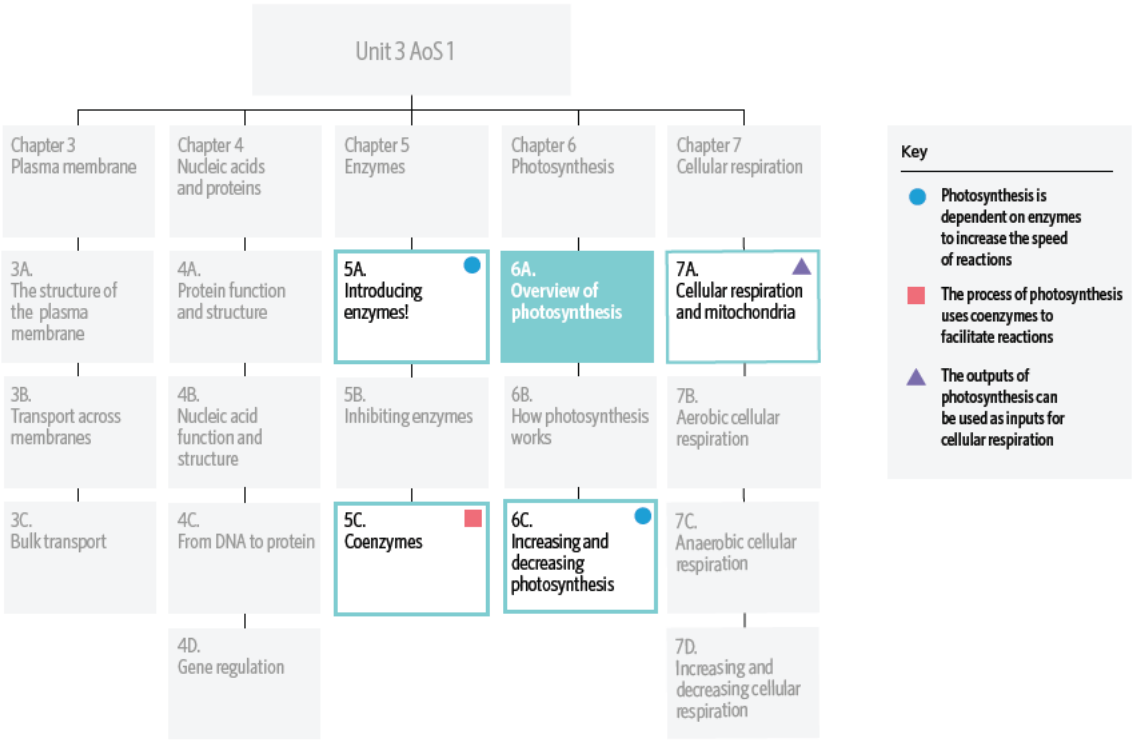
Key knowledge

- the purpose of photosynthesis
- chloroplasts as the site of photosynthesis, an overview of their structure and evidence of their bacterial origins
- inputs and outputs of the light dependent and light independent (Calvin cycle) stages of photosynthesis in C3 plants (details of the biochemical pathway mechanisms are not required)
- factors that affect the rate of photosynthesis, including light, temperature, and carbon dioxide concentration

Image: Sander van der Werf/Shutterstock.com

6A OVERVIEW OF PHOTOSYNTHESIS

Masterchef for plants wouldn't be very interesting. The same ingredients would be served up every week - sunlight, CO_2, and water.



In this lesson you will be learning how the chloroplasts of plants synthesise glucose from carbon dioxide, sunlight, and water.

Study design dot points

- the purpose of photosynthesis
- chloroplasts as the site of photosynthesis, an overview of their structure and evidence of their bacterial origins

Key knowledge units

Purpose of photosynthesis	3.1.16.1
Structure of chloroplasts	3.1.17.1
Origin of chloroplasts	3.1.17.2

Purpose of photosynthesis 3.1.16.1

OVERVIEW

The purpose of photosynthesis is to turn carbon dioxide, water, and light energy into oxygen, more water, and, most importantly, glucose (food!). Photosynthesis is the only biological process that can capture energy that originates from the sun and convert it into chemical compounds for metabolism.

THEORY DETAILS

Photosynthesis is undertaken by plants, algae, and photosynthetic bacteria such as cyanobacteria. These organisms are referred to as photoautotrophs, meaning that they use light to manufacture their own food. Animals, fungi, and most bacteria are known as heterotrophs since they are dependent on the glucose produced by photoautotrophs to survive. This is why the photosynthesis reaction is fundamental to life on Earth.

In essence, photosynthesis uses the inputs of carbon dioxide and water to produce the outputs of glucose, oxygen, and water.

photosynthesis the process of capturing sunlight energy to power the production of glucose and oxygen from carbon dioxide and water

However, for this process to occur, sunlight is required to energise the reaction. This complex biochemical reaction can be broken into two stages, the **light-dependent** and **light-independent** stages, which both occur in the chloroplast of a photosynthetic cell.

light-dependent stage the first stage of photosynthesis, where light energy splits water molecules inside the thylakoid membranes

light-independent stage the second stage of photosynthesis where carbon dioxide is used to form glucose in the stroma of the chloroplast. Also known as the **Calvin cycle** or the **dark stage**

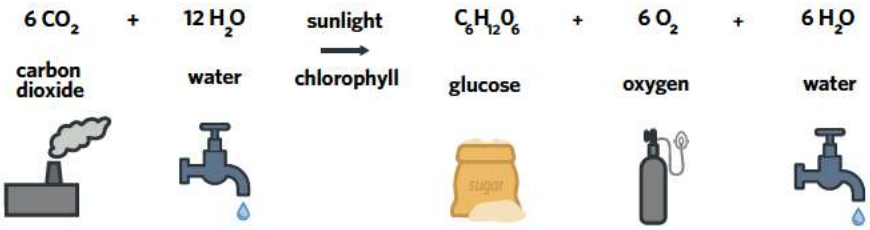


Image: creativeicon/Shutterstock.com

Figure 1 The equation of photosynthesis

Tip Figure 1 displays the expanded equation of photosynthesis.

Because there are water molecules on both sides of the equation, some of the H_2O can be cancelled out (not written, even though it is there). This results in the simplified equation:

$$6\,CO_2 + 6\,H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6\,O_2$$

Don't forget to write 'sunlight' above the arrow and 'chlorophyll' below the arrow.

Plants source carbon dioxide from the atmosphere. They do this by opening tiny pores in their leaves known as **stomata** (singular: stoma). These pores open to collect carbon dioxide and close to prevent water loss or pathogen invasion. The root hairs of plants absorb water from the soil and transport it through the xylem to the parts of the plant that photosynthesise. Photosynthesis primarily occurs in leaves, which typically have a large surface area to maximise the amount of light that can be absorbed.

stoma (pl. stomata) small pores on the leaf's surface that open and close to regulate gas exchange

Once the process is complete, the outputs are either released or stored by the plant for future use. Glucose, which is the primary product of photosynthesis, is either used immediately as a source of energy for cellular respiration, stored as starch, or used to form more complex molecules such as cellulose. Water and oxygen can be used for other cellular processes, or released through stomata as gas into the atmosphere.

Structure of chloroplasts 3.1.17.1

OVERVIEW

All plants and algae contain chloroplasts. These chloroplasts are the site of all stages of photosynthesis.

chloroplast a membrane-bound organelle only found in plant and algal cells that is the site of photosynthesis

THEORY DETAILS

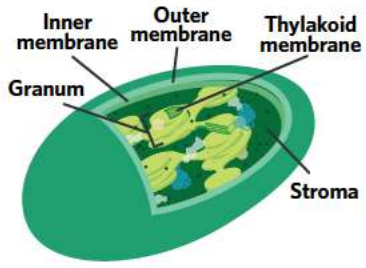


Figure 2 A labelled diagram of the structures of a chloroplast

Chloroplasts are made up of many different structures. The **thylakoids** are the site of the light-dependent stage of photosynthesis and contain **chlorophyll** embedded in their membrane. These thylakoids stack together to form a **granum**.

The empty space within the chloroplast contains a fluid matrix known as the **stroma**, which is filled with many enzymes and solutes. This is the site of the light-independent stage of photosynthesis. Furthermore, the entire chloroplast is enclosed by an inner and outer membrane.

thylakoid a flattened sac-like structure inside the chloroplast. Each thylakoid is made up of a chlorophyll-containing membrane enclosing a lumen. Thylakoids are the location of the light-dependent stage of photosynthesis

chlorophyll a chemical found in the thylakoids of chloroplasts. It is responsible for absorbing light energy in photosynthesis

granum (pl. grana) a stack of thylakoids

stroma the fluid substance that makes up the interior of the chloroplasts. It is the site of the light-independent stage of photosynthesis

Origin of chloroplasts 3.1.17.2

OVERVIEW

Nearly two billion years ago, chloroplasts existed as unicellular organisms until they were engulfed by a host cell.

THEORY DETAILS

Scientists believe that chloroplasts originated as free-living photosynthetic bacteria that were engulfed by a larger host cell approximately two billion years ago. The two cells gained mutual benefit, with the larger host cell gaining a new method of sourcing food and the photosynthetic microbe gaining safety and protection. This idea is known as the **endosymbiosis** theory.

endosymbiosis when one organism lives inside another in a mutually beneficial relationship

Evidence that supports the endosymbiosis theory includes:

- chloroplasts have their own circular double-stranded DNA (cpDNA) which is not enclosed in a nuclear membrane (similar to bacteria)
- chloroplasts and bacteria both replicate through binary fission, unlike plant, animal, fungi, and algae cells which replicate through mitosis or meiosis
- chloroplasts have their own ribosomes that share characteristics with bacterial ribosomes
- chloroplasts have their own DNA and ribosomes, so can produce specialised proteins through transcription and translation independently from the rest of the cell
- the outer membrane of chloroplasts contains transport proteins called porins. The only other place porins are found is in the cell membranes of prokaryotes
- chloroplasts have a double membrane which is similar to gram-negative cyanobacteria
- chloroplasts are a similar size to bacteria.

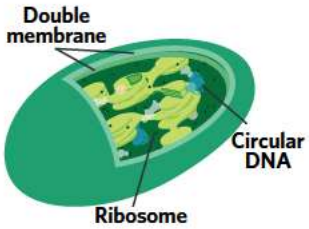


Figure 3 A labelled diagram of the structures of a chloroplast which support the endosymbiosis theory

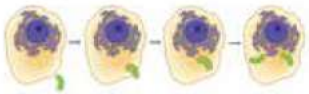


Image: Jamilia Marini/Shutterstock.com

Figure 4 The engulfment of a chloroplast by a host cell

Through these pieces of evidence, scientists recognise that prokaryotes and chloroplasts are similar and that chloroplasts are equipped to survive independently. Therefore, we can conclude that it's likely that chloroplasts originated from prokaryotic ancestors.

Theory summary

Photosynthesis is a vital biochemical reaction for plants that takes place in the chloroplasts of a cell and provides a source of glucose. Inside the chloroplasts, thylakoids and the stroma are the key locations of these complex reactions. Finally, the origins of the chloroplasts are explained by the endosymbiosis theory.

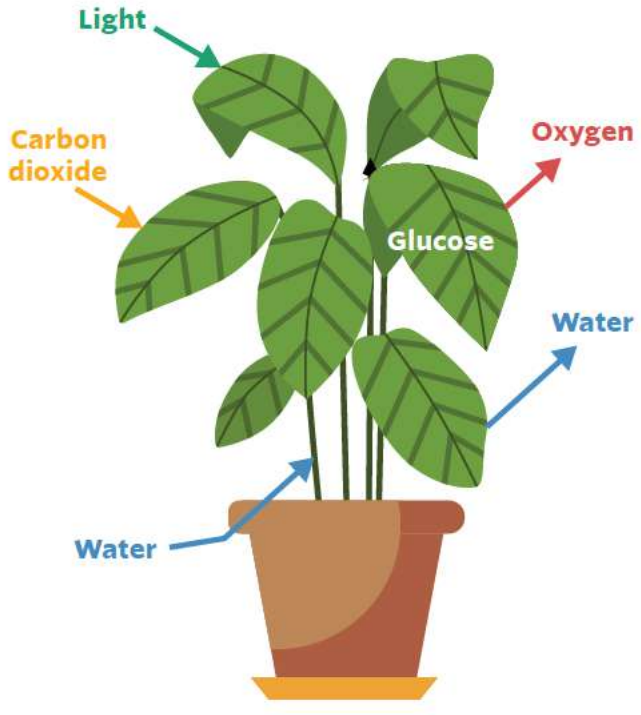


Image: Glinskaja Olga/Shutterstock.com

Figure 5 The inputs and outputs of photosynthesis

6A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a singular stack of thylakoids
b _____ a green coloured, membrane-bound organelle that is found in plant cells
c _____ the theory that suggests chloroplasts were engulfed by another organism
d _____ a sugar molecule that is an output of photosynthesis
e _____ a molecule which is both an input and an output of photosynthesis
f _____ the location of the light-independent stage of photosynthesis
g _____ the location of the light-dependent stage of photosynthesis
h _____ the chemical contained in the thylakoid membrane which absorbs sunlight

Question 2

Which of the following correctly expresses the simplified equation of photosynthesis?

A $6\,CO_2 + 6\,H_2O \rightarrow C_6H_{12}O_6 + 6\,O_2$
B $6\,CO_2 + 12\,H_2O \rightarrow C_6H_{12}O_6 + 6\,O_2 + 6\,H_2O$
C $6\,CO_2 + 6\,O_2 \rightarrow C_8H_{16}O_8 + 6\,H_2O$
D $6\,CO_2 + 6\,O_2 \rightarrow C_6H_{12}O_6 + 6\,H_2O$

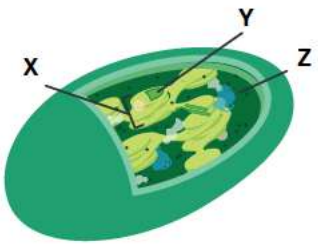
Question 3

Which of the following statements about photosynthesis is false?

A Photosynthesis produces energy from glucose.
B Photosynthesis converts sunlight energy in order to create glucose.
C Photosynthesis uses inorganic inputs to produce an organic product.
D Photosynthesis requires sunlight to energise the reactions.

Question 4

Complete the following diagram by identifying X, Y, and Z.



	X	Y	Z
A	Stroma	Granum	Thylakoid
B	Stroma	Thylakoid	Granum
C	Granum	Stroma	Thylakoid
D	Granum	Thylakoid	Stroma

Question 5

Which of the following options shows the inputs and outputs of photosynthesis.

	Inputs	Outputs
A	Carbon dioxide Water	Glucose Water Oxygen
B	Oxygen Water	Glucose Water Carbon dioxide
C	Carbon dioxide Water	Glucose Carbon dioxide Oxygen
D	Glucose Oxygen	Carbon dioxide Water

Question 6

Which of the following options are all features of chloroplasts that support the endosymbiosis theory?

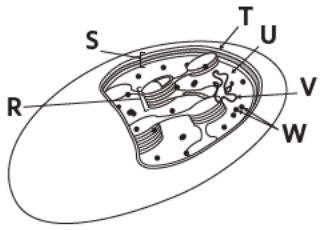
A	Double membrane-bound	Contain their own circular DNA	Contain ribosomes	Contain a flagellum
B	Respire to produce energy	Separate via binary fission instead of mitosis	Double membrane-bound	Produce their own RNA and proteins
C	Double membrane-bound	Contain their own circular DNA	Contain ribosomes	Very similar size to bacteria
D	Separate via binary fission instead of mitosis	Contain chlorophyll	Contain their own circular DNA	Double membrane-bound

Exam-style questions

Within lesson

Use the following information to answer Questions 7–9.

The diagram shows the structures of a chloroplast, labelled R-W.



Question 7 (1 MARK)

The region labelled U is called the

A thylakoid.
B stroma.
C grana.
D matrix.

Question 8 (1 MARK)

Which combination of structures could be used as evidence for the bacterial origin of chloroplasts?

A S and W
B R and W
C U and V
D R and T

Adapted from VCAA 2018 Section A Q13

Question 9 (1 MARK)

The light-dependent stage of photosynthesis occurs at

A R.
B S.
C T.
D U.

Adapted from VCAA 2018 Section A Q14

Question 10 (1 MARK)

A student was investigating four cell types from different organisms. She recorded the results of her microscopic examination of the cells in the table.

	Cell W	Cell X	Cell Y	Cell Z
Ribosomes	few	many	absent	few
Chloroplasts	present	absent	absent	present
Nucleus	present	present	absent	present

Given this information, which one of the following is the correct conclusion that can be drawn from this data?

A Cell W could be a stomach cell from an insect.

B Cell X could be a leaf cell of a fern.

C Cell Y could be an underground root cell from a corn plant.

D Cell Z could be a leaf cell from a gum tree.

Adapted from VCAA 2015 Section A Q12

Question 11 (1 MARK)

Evidence for the bacterial origin of chloroplasts is not supported by the observation that both chloroplasts and bacteria

A contain ribosomes.

B are bound by a double membrane.

C divide by binary fission.

D have a cell wall.

Adapted from VCAA 2017 Section A Q12

Question 12 (1 MARK)

Which of the following correctly describes the primary function of a chloroplast?

A site where ATP for a cell is generated

B solar energy is converted into chemical energy

C site of protein synthesis

D storage of wastes and other materials

Adapted from VCAA 2005 Exam 1 Section B Q1

Question 13 (6 MARKS)

Elysia chlorotica is a bright green sea slug, with a soft leaf-shaped body. It has a lifespan of 9 to 10 months. This sea slug is unique among sea slugs as it is able to survive on 'solar power'. *E. chlorotica* acquires chloroplasts from the algae it eats, and stores them in the cells that line its digestive tract.

Young *E. chlorotica* fed with algae for two weeks can survive on 'solar power'.

a What is the product of photosynthesis that provides the energy which enables *E. chlorotica* to survive for so long without eating? (1 MARK)

b Write the simplified worded equation for photosynthesis. (1 MARK)

c These slugs survive on 'solar power'.

- **i** Name the organelle in the digestive tract of *E. chlorotica* which allow them to survive on 'solar power'. (1 MARK)
- **ii** Most scientists believe this organelle originally survived as a unicellular bacterium. State one piece of evidence that supports this theory. (1 MARK)

d Would *E. chlorotica* need to eat as much, more than, or less than a closely related black sea slug? Justify your response. (2 MARKS)

Adapted from VCAA 2010 Exam 1 Section B Q3a

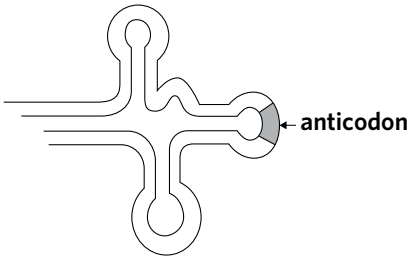
Multiple lessons

Question 14 (9 MARKS)

Chloroplasts contain their own DNA, referred to as cpDNA. The theory of endosymbiosis is supported by a chloroplast's ability to produce its own intra-organelle proteins. Therefore, chloroplasts can produce their own RNA and contain many ribosomes.

Researchers noted that the formation of these proteins requires the use of different types of Molecule X.

Molecule X



a What is the name of Molecule X? (1 MARK)

b What role does Molecule X play in the production of intra-organelle proteins? (3 MARKS)

c The coding information in the cpDNA is initially copied to another molecule (Molecule W). However, Molecule W has a different nucleotide sequence from the coding section of the cpDNA molecule.

Describe how Molecule W is synthesised. (3 MARKS)

d Identify and explain two other pieces of evidence that support the theory of endosymbiosis in chloroplasts. (2 MARKS)

Adapted from VCAA 2016 Section B Q6

Key science skills

Question 15 (7 MARKS)

Timmy is learning about photosynthesis and wants to find out if plants require light to grow. He uses two tomato plantlings, known as *Solanum lycopersicum*, to perform his experiment.

Timmy measures both plantlings from the base of the stem to the tip and records his results. He then waters each plant with 5 mL of water and places one under a lamp, and the other in a completely dark room.

After 24 and 48 hours, Timmy waters each plant with another 5 mL of water. Once three days have passed, he re-measures each plant from base to tip of the stem and records the results.

His results are presented in the table.

	Before Experiment	**After 3 Days**	**Growth**
Plant A - Under Lamp	7cm	13cm	6cm
Plant B - Dark Room	7.5cm	8cm	0.5cm

a State the independent and dependent variables in this experiment. (1 MARK)

b State what Timmy's hypothesis should be. (1 MARK)

c Identify and explain how Timmy could make his experiment more reliable. (2 MARKS)

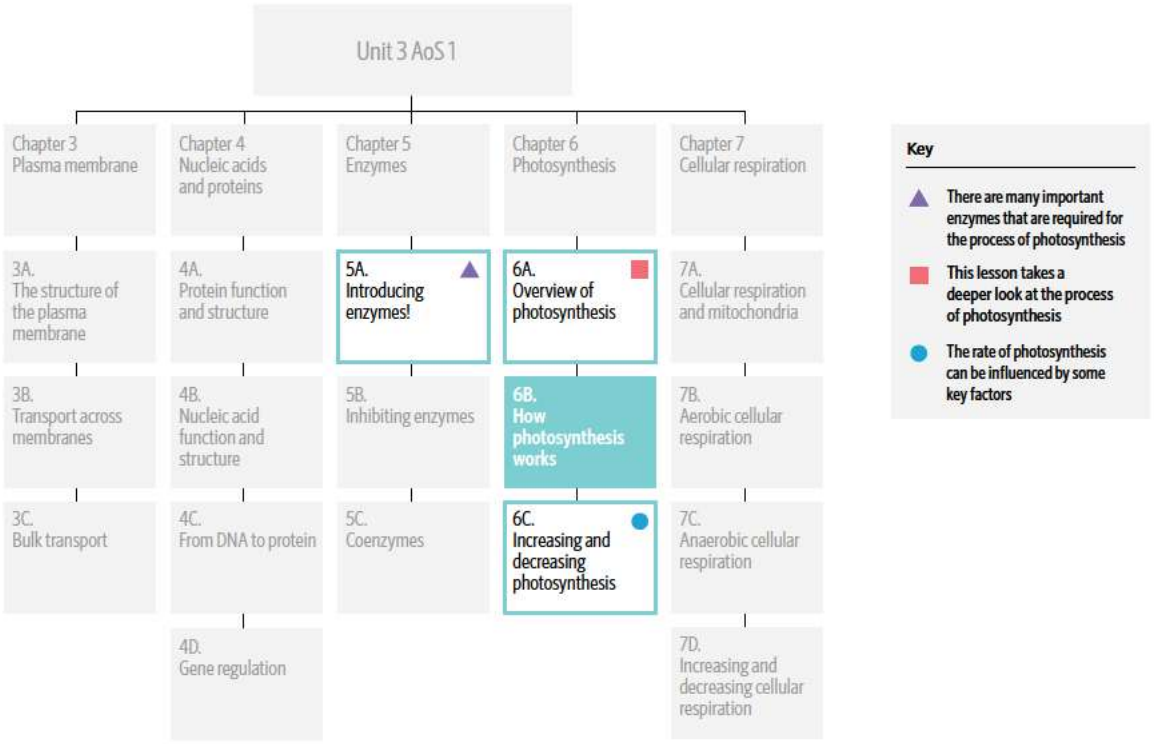
d Outline one way that Timmy can ensure precision in his results. (1 MARK)

e What results would disprove Timmy's hypothesis? (2 MARKS)

Adapted from VCAA 2018 Section B Q11

6B HOW PHOTOSYNTHESIS WORKS

Plant 1: 'Are you hungry?'
Plant 2: 'Hmm I could use a light snack.'



In this lesson you will learn about the chemical processes within the chloroplast that occur as part of photosynthesis.

Study design dot point

- inputs and outputs of the light-dependent and light-independent (Calvin cycle) stages of photosynthesis in C3 plants (details of the biochemical pathway mechanisms are not required)

Key knowledge units

Light-dependent reactions	3.1.18.1
Light-independent reactions	3.1.18.2

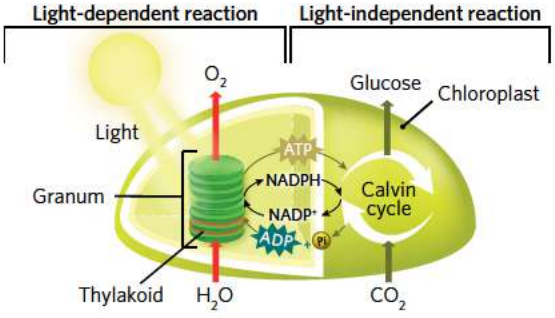


Image: Designua/Shutterstock.com

Figure 1 An overview of the photosynthesis pathway in the chloroplast

Light-dependent reactions 3.1.18.1

OVERVIEW

In the first stage of photosynthesis, plants are dependent on light to split water into oxygen and hydrogen. This is known as the light-dependent stage, which occurs on the thylakoid membranes of the chloroplast.

THEORY DETAILS

As the name implies, the **light-dependent stage** of photosynthesis only occurs when light is present. This stage occurs on the **chlorophyll**-filled **thylakoid** membranes which make up the **grana** inside a chloroplast. The purpose of this first stage is to generate high energy molecules like **NADPH** and ATP to power the second stage.

The inputs of the light-dependent reactions are:

- twelve water (H_2O) molecules
- twelve $NADP^+$
- twelve ADP + P_i.

The outputs of the light-dependent reactions are:

- six oxygen (O_2) molecules
- twelve NADPH
- twelve ATP.

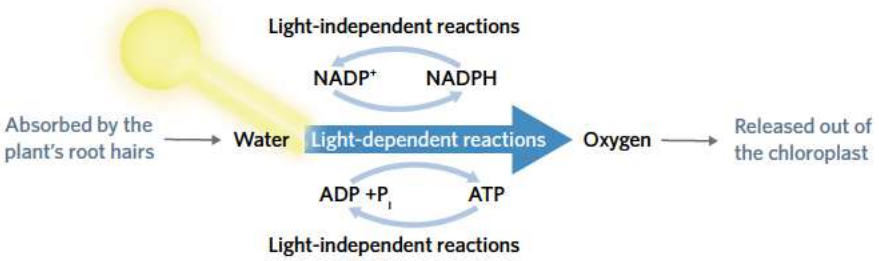


Figure 2 Summary of the light-dependent reactions of photosynthesis

The steps in the light-dependent stage are:

1. Inside the thylakoid, light energy splits water into H^+, electrons, and oxygen. It also excites the electrons in chlorophyll, which is embedded in the thylakoid membrane.
2. The oxygen is released from the chloroplast. It will either diffuse out of the **stomata** into the environment or be used as an input for cellular respiration (you will learn more about this in Chapter 7).
3. The H^+ and electrons (from water and chlorophyll) are used to generate the high energy coenzyme NADPH ($NADP^+ + H^+ \rightarrow NADPH$) and ATP ($ADP + P_i \rightarrow ATP$). This is possible through a series of interactions with proteins in the thylakoid membrane, and movement of H^+ down its concentration gradient (Figure 3).
4. ATP and NADPH coenzymes then move on to the **light-independent stage**.

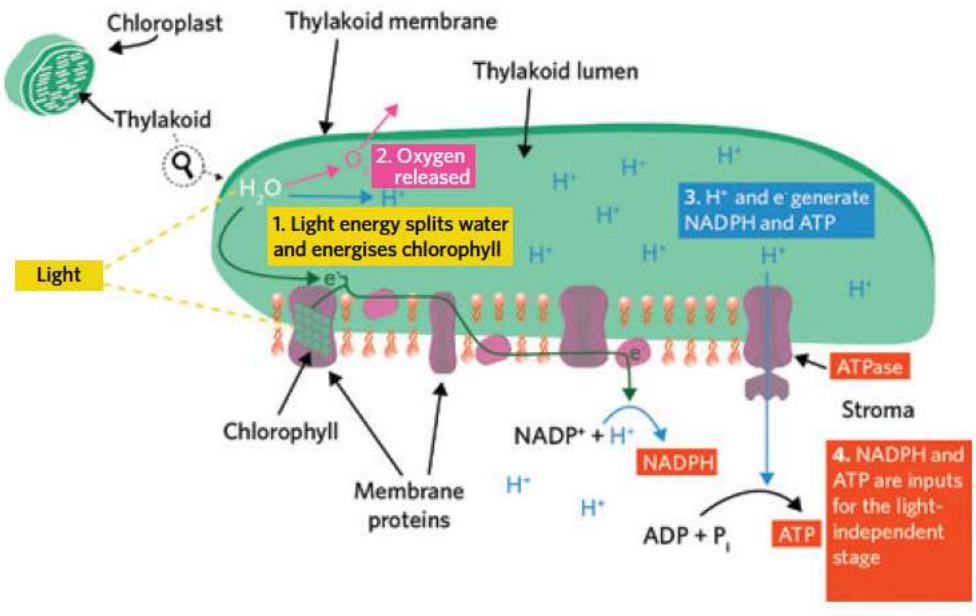


Figure 3 An overview of some of the processes that occur during the light-dependent reactions. You do not need to know all the mechanisms, but an understanding of the process can help you remember the inputs and outputs.

light-dependent stage the first stage of photosynthesis, where light energy splits water molecules inside the thylakoid membranes

chlorophyll a chemical found in the thylakoids of chloroplasts. It is responsible for absorbing light energy in photosynthesis

thylakoid a flattened sac-like structure inside the chloroplast. Each thylakoid is made up of a chlorophyll-containing membrane enclosing a lumen. Thylakoids are the location of the light-dependent stage of photosynthesis

granum (pl. grana) a stack of thylakoids

NADPH a coenzyme that is a proton (H^+) and electron carrier in cellular respiration

photolysis of water the reaction by which water is split into hydrogen and oxygen using light energy

lesson link Refer back to ***6A*** to revise the structures of the chloroplast.

stoma (pl. stomata) small pores on the leaf's surface that open and close to regulate gas exchange

light-independent stage the second stage of photosynthesis where carbon dioxide is used to form glucose in the stroma of the chloroplast. Also known as the **Calvin cycle** or the **dark stage**

Tip VCAA do not expect you to remember the biochemical processes involved in both the light-dependent and light-independent reactions (e.g. Figure 3 is not examinable). However, by understanding these processes it will help you to remember the inputs and outputs, which is what VCAA will assess you on.

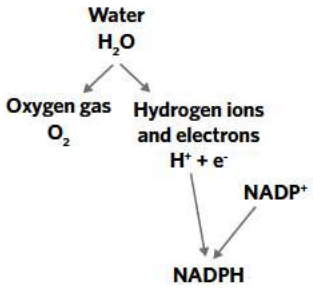


Figure 4 Splitting of water into oxygen and NADPH

Light-independent reactions 3.1.18.2

OVERVIEW

During the second stage of photosynthesis, glucose is produced from carbon dioxide, NADPH, and ATP through a cycle of reactions occurring in the stroma of the chloroplast.

THEORY DETAILS

Unlike the light-dependent reactions, the light-independent reactions do not require light to occur. Instead, they are energised by the ATP produced in the light-dependent stage. They take place in the **stroma**, the fluid-filled space in the chloroplast, and involve a cyclic reaction called the Calvin cycle.

The inputs of the light-independent reactions are:

- six carbon dioxide (CO_2) molecules
- twelve NADPH
- twelve ATP.

The outputs of the light-independent reactions are:

- glucose ($C_6H_{12}O_6$)
- six water (H_2O) molecules
- twelve $NADP^+$
- twelve ADP + P_i.

Within the light-independent stage, the following three processes occur:

- Carbon dioxide molecules enter the light-independent stage which is powered by ATP. During these reactions, the carbon atoms of the CO_2 molecules form chains, eventuating in glucose molecules (Figure 6).
- NADPH formed in the light-dependent reactions unload their hydrogen ions and electrons to produce glucose.
- The additional oxygen molecules from CO_2 and hydrogen ions from NADPH bind together to create water.

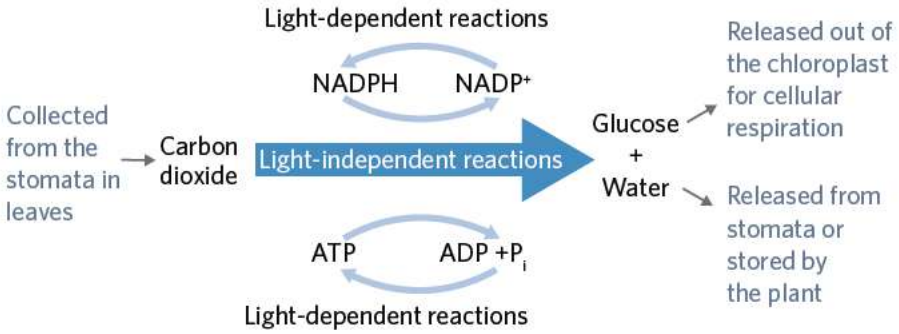


Figure 7 Summary of the light-independent reactions of photosynthesis

Theory summary

For a plant to ultimately produce glucose, it must undertake both the light-dependent and light-independent stages of photosynthesis.

Table 1 The inputs and outputs of the two stages of photosynthesis

	Location	Input	Outputs
Light-dependent stage	Grana / thylakoid membranes	12 H_2O 12 $NADP^+$ 12 ADP + P_i	6 O_2 12 NADPH 12 ATP
Light-independent stage	Stroma	6 CO_2 12 NADPH 12 ATP	$C_6H_{12}O_6$ 12 $NADP^+$ 12 ADP + P_i 6 H_2O

stroma the fluid substance that makes up the interior of the chloroplasts. It is the site of the light-independent stage of photosynthesis

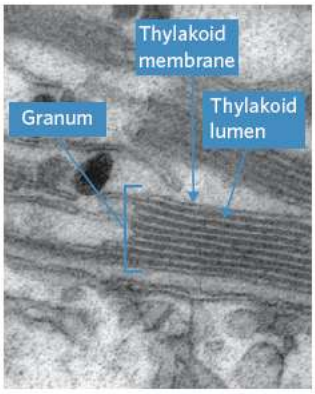


Figure 5 An electromicrograph of thylakoids in a chloroplast

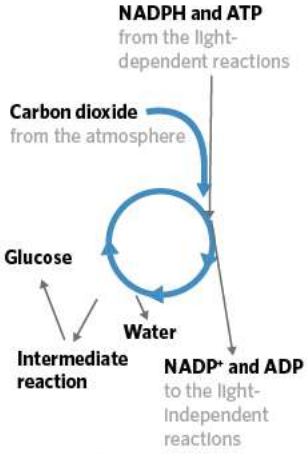


Figure 6 The light-independent reactions

6B QUESTIONS

Theory review questions

Question 1

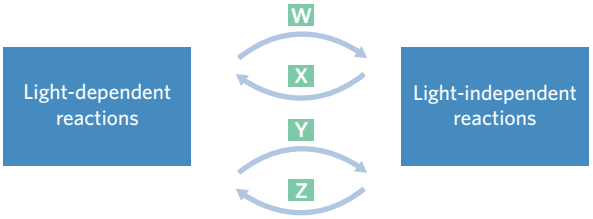
What are the key terms from the lesson that match the following definitions?

a _____ the primary product of photosynthesis
b _____ the alternative name for the light-independent stage of photosynthesis
c _____ the loaded form of a molecule responsible for transporting electrons and protons around chloroplasts
d _____ the stage of photosynthesis that occurs in the stroma of the chloroplast
e _____ the inorganic molecule that is a gaseous input of the light-independent reactions
f _____ phospholipid bilayer that is embedded with chlorophyll

Question 2

Fill in the correct coenzymes into the diagram.

	W	X	Y	Z
A	ATP	ADP + P_i	NADH	NAD^+
B	ADP + P_i	ATP	$NADP^+$	NADPH
C	ATP	ADP + P_i	NADPH	$NADP^+$
D	ATP	ADP + P_i	$NADP^+$	NADPH



Question 3

Complete the following table describing the inputs of each stage in photosynthesis.

	J	K
A	NADPH	CO_2
B	$NADP^+$	CO_2
C	NADPH	O_2
D	$NADP^+$	O_2

Inputs	
Light-dependent	**Light-independent**
H_2O	**K**
J	NADPH
ADP + P_i	ATP

Question 4

Complete the following table describing the outputs of each stage in photosynthesis.

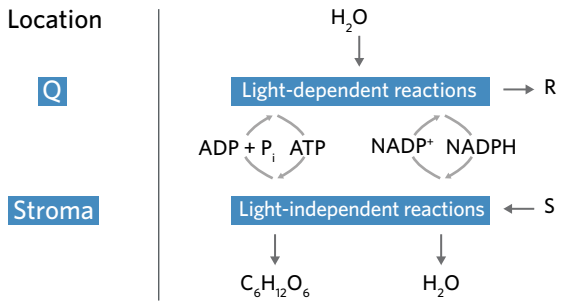
	K	L	M
A	Oxygen	Glucose	Carbon Dioxide
B	Hydrogen	Carbon Dioxide	Oxygen
C	Carbon Dioxide	Oxygen	Water
D	Oxygen	Glucose	Water

Outputs	
Light-dependent	**Light-independent**
K	**L**
NADPH	$NADP^+$
ATP	ADP + P_i
	M

Question 5

Complete the following diagram describing the process of photosynthesis.

	Q	R	S
A	Thylakoid membrane	CO_2	CO_2
B	Thylakoid membrane	O_2	CO_2
C	Cytosol	O_2	O_2
D	Cytosol	CO_2	O_2



Question 6

Classify each of the following statements as either part of the light-dependent or light-independent stage.

NOTE: Not all statements must be categorised into a column.

I Carbon dioxide is used to produce glucose and water

II This process occurs in the stroma

III Oxygen that is released into the environment exits through the stomata

IV The grana is the site of this stage

V The purpose of light energy is to split water

VI NADH is produced

VII ADP + P_i are produced

	Light-dependent stage	Light-independent stage
A	I, II, VII	III, IV, V, VI
B	III, IV, V, VI	I, II, VII
C	I, III, IV	II, V, VI
D	III, IV, V	I, II, VII

Question 7

The following steps of photosynthesis are in the wrong order.

1 Carbon dioxide enters the Calvin cycle

2 Oxygen is either released into the atmosphere or used as an input in cellular respiration

3 Glucose is produced

4 Light energy is absorbed by chlorophyll

5 Hydrogen ions bind to $NADP^+$ to form the loaded carrier, NADPH

6 Water molecules are split into oxygen and hydrogen

The correct order is:

A 4,6,2,5,1,3

B 4,6,2,5,3,1

C 4,3,2,5,6,1

D 6,4,2,5,3,1

Exam-style questions

Within lesson

Question 8 (1 MARK)

Which of the following statements about photosynthesis in chloroplasts is correct?

A The stroma is the site of the light-dependent stage.

B Chlorophyll in the grana traps light for use during the light-independent stage.

C The light-independent stage produces ATP for use during the light-dependent stage.

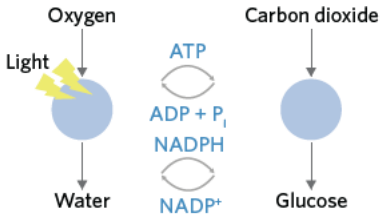
D The light-dependent stage forms NADPH for the light-independent stage to produce glucose.

Adapted from VCAA 2016 Section A Q11

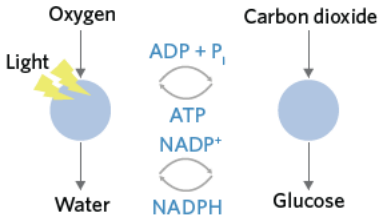
Question 9 (1 MARK)

Which of the following diagrams represent the inputs and outputs of photosynthesis?

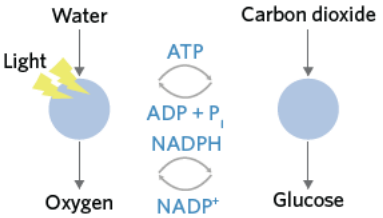
A



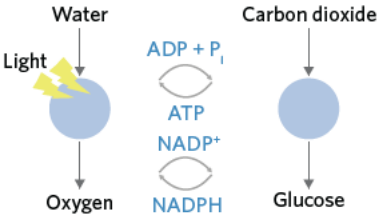
B



C



D



Adapted from VCAA 2018 Section A Q15

Question 10 (4 MARKS)

Two students noticed bubbles forming on the submerged leaves of an *Elodea* plant growing in an aquarium. The bubbles seen on the leaves were the result of a gas which formed within the cells of the leaves.

There was a bright light shining on the aquarium which did not affect the temperature of the water.

a Describe why the light shining on the aquarium is important to the *Elodea* plant. (2 MARKS)

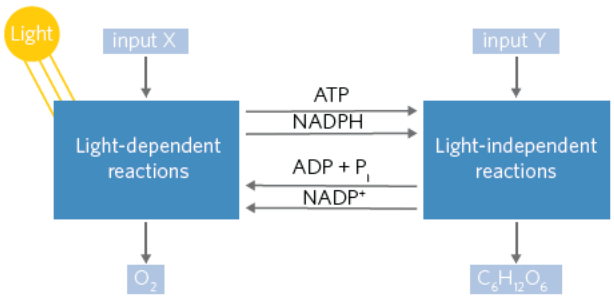
b Name the two stages of photosynthesis. (1 MARK)

c Explain why bubbles where produced. (1 MARK)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q1

Question 11 (7 MARKS)

Although photosynthesis is often summarised by a single equation, the process occurs in two distinct phases; the light-dependent stage and the light-independent stage. These two phases can be summarised in diagrammatic form as follows.



a The diagram shows input X and Y.

- **i** What is input X? (1 MARK)
- **ii** What is input Y? (1 MARK)
- **iii** What occurs to input Y during the light-independent stage? (2 MARKS)

b Scientists radioactively label the oxygen in one of the inputs to track what output it becomes. The radioactive oxygen was found in the glucose produced by the plant. Identify which input contained radioactively-labelled oxygen. Justify your response. (3 MARKS)

Adapted from VCAA 2005 Exam 1 Section B Q3

Question 12 (5 MARKS)

Complete the following tables by referring to your knowledge of photosynthesis.

Name of the stage of photosynthesis that occurs at the stroma		
Two input molecules that are required for reactions at the stroma	1_____	2_____
Two output molecules from the reactions at the stroma	1_____	2_____

Name of the stage of photosynthesis that occurs at the grana		
Two input molecules that are required for reactions at the grana	1_____	2_____
Two output molecules from the reactions at the grana	1_____	2_____

Adapted from VCAA 2015 Section B Q3

Multiple lessons

Question 13 (1 MARK)

A molecule that plays a role in many biochemical reactions is ATP.

It is correct to state that

A ADP becomes ATP when it is loaded with electrons.

B energy is released when ATP is converted to ADP.

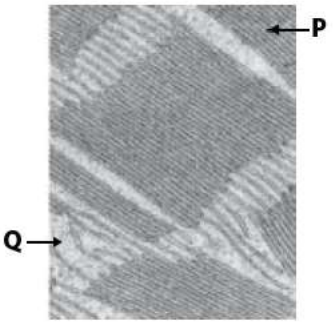
C ADP has a higher energy content than ATP.

D ADP contains three phosphate molecules.

Adapted from VCAA 2017 Section A Q16

Question 14 (1 MARK)

The following image shows a portion of an electron photomicrograph of a chloroplast.



Region P and Q are both locations for stages of photosynthesis. By referring to your knowledge of photosynthesis, it is reasonable to conclude that

A carbon dioxide is an input at region P.

B sunlight is absorbed at region Q.

C oxygen is an output at region Q.

D water is split at region P.

Adapted from VCAA 2006 Exam 1 Section A Q18

Key science skills

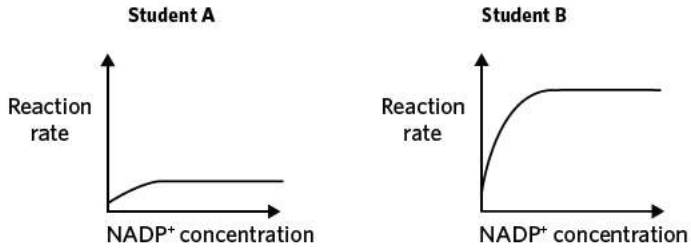
Question 15 (5 MARKS)

Two students set up an experiment to measure the reaction rate of the light-dependent stage of photosynthesis. Grana were removed from chloroplasts and suspended in solution that was sealed from the environment. The thylakoids were then exposed to different concentrations of $NADP^+$ and the rate of the reaction was measured by calculating the concentration of oxygen. Students A and B were both given grana from the same sample of chloroplasts and both followed the same method.

a Identify the independent and dependent variables. (2 MARKS)

b Identify a variable in this experiment that each student must control in order for their results to be comparable. (1 MARK)

c The results of both students can be seen in the graphs.

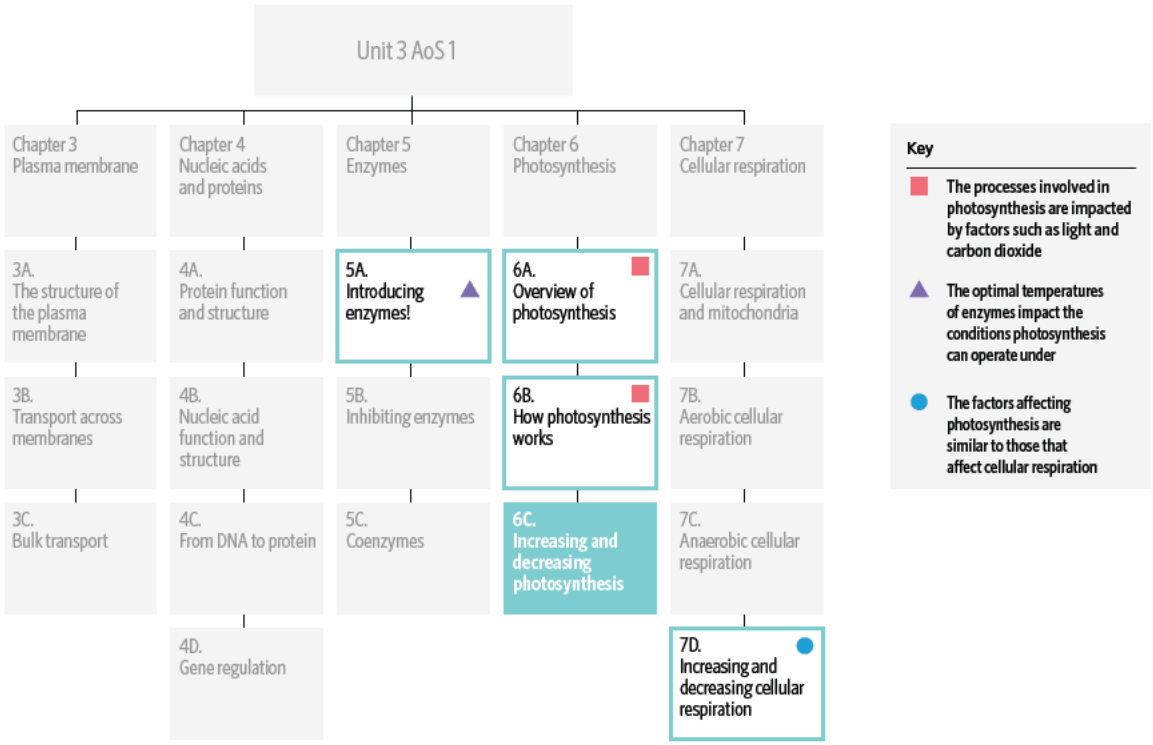


Given that both students had the same experimental setup and method, describe a possible error that one of the students could have experienced and explain how it could have created the difference in results. (2 MARKS)

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q5

6C INCREASING AND DECREASING PHOTOSYNTHESIS

Bamboo can grow up to 91 cm per day at a rate of 0.00004 km/hr. To do this, it needs lots of carbon dioxide, light, water, and just the right temperature.



In this lesson you will learn that the rate of photosynthesis is dependent on the amount of light available, the concentration of carbon dioxide, and temperature.

Study design dot point

- factors that affect the rate of photosynthesis, including light, temperature, and carbon dioxide concentration

Key knowledge units

Effect of carbon dioxide concentration on photosynthesis	3.1.19.1
Effect of light on photosynthesis	3.1.19.2
Effect of temperature on photosynthesis	3.1.19.3

Effect of carbon dioxide concentration on photosynthesis 3.1.19.1

OVERVIEW

Plants take in carbon dioxide and release oxygen when undergoing photosynthesis in their chloroplasts. As the amount of carbon dioxide increases, the rate of photosynthesis increases, up until a certain point.

THEORY DETAILS

The photosynthesis equation shows us that, along with water and light, carbon dioxide (CO_2) is a key requirement for photosynthesis (Figure 1). Plants get CO_2 from the air, and it diffuses in through open **stomata**. If stomata are closed or there are low CO_2 levels in the environment, CO_2 may limit the rate of photosynthesis.

stoma (pl. stomata) small pores on the leaf's surface that open and close to regulate gas exchange

$$6\,CO_2 + 12\,H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6\,O_2 + 6\,H_2O$$

Figure 1 The overall equation of photosynthesis

Consider Figure 2. Notice that the rate of photosynthesis increases as CO_2 increases up until point X. This is because the **chloroplast** has more of the input CO_2, so more photosynthesis can occur per unit of time.

chloroplast a membrane-bound organelle only found in plant cells that is the site of photosynthesis

limiting factor the factor that restricts the reaction rate in a given process

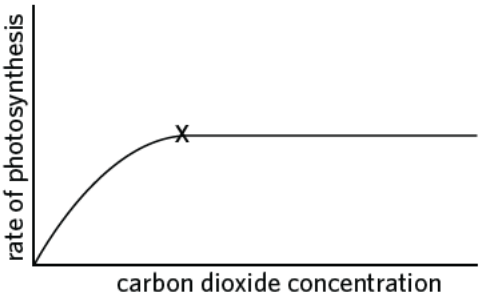


Figure 2 Photosynthesis rate increases with CO_2 concentration until plateauing.

After point X the rate of photosynthesis plateaus. There are two things that can cause this plateau in the graph:

1. If water and light are unlimited, the maximum rate of photosynthesis can be reached when increasing CO_2. This is because the enzyme-catalysed systems within the chloroplast are operating as fast as they possibly can.
2. Another requirement of photosynthesis, such as water or light, has become the **limiting factor** in the reaction.

In reality, there is usually a limited supply of inputs and therefore the plateau on the graph is typically caused by a limiting factor. It is important to note that water is typically in surplus, so this plateau when increasing CO_2 is often caused by the reaction becoming light-limited.

lesson link Enzymes and enzyme-catalysed reactions are covered in ***lesson 5A***.

Effect of light on photosynthesis 3.1.19.2

OVERVIEW

Light is required for the light-dependent reactions of photosynthesis to occur. Without it, the reaction rate is limited. As light increases, photosynthesis rate increases, until a certain point.

Tip It is important to note that VCAA frequently test this topic using graphs. The rate of photosynthesis can be measured in a number of ways, so the y axes may be labelled with variables other than 'rate of photosynthesis' (e.g. uptake of CO_2, CO_2 consumed, O_2 produced, O_2 output).

THEORY DETAILS

You are always told to give your plants plenty of sunlight, and there is a reason why they always die when you inevitably don't. Plants need light to photosynthesise, so the amount or intensity of light can affect the rate of photosynthesis.

Consider Figure 3. As light intensity increases, the rate of photosynthesis increases up until point X. This is because light is a key requirement for photosynthesis, so more light results in faster photosynthesis.

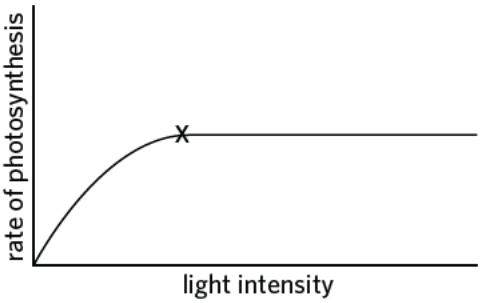


Figure 3 The rate of photosynthesis has a positive relationship with light until reaching a plateau at point X.

Just like the graph of CO_2 concentration, a plateau is seen on the graph. There are two things that can cause the plateau:

1. If water and CO_2 are unlimited, the maximum rate of photosynthesis can be reached by increasing light intensity. This is due to the chloroplast's enzymes operating at full capacity. When this happens, it is known as a light-saturation curve, as the plant is saturated with light.
2. Another input, typically CO_2 (as water is usually in surplus), has become the limiting factor in the reaction.

Analogy

It is important to note that photosynthesis is still occurring at high intensities of light, however increasing the light from point X does not speed up the photosynthesis process. Think of it as reaching the speed limit on a highway – your car is still moving at a fast rate, but it is not speeding up.

Case study

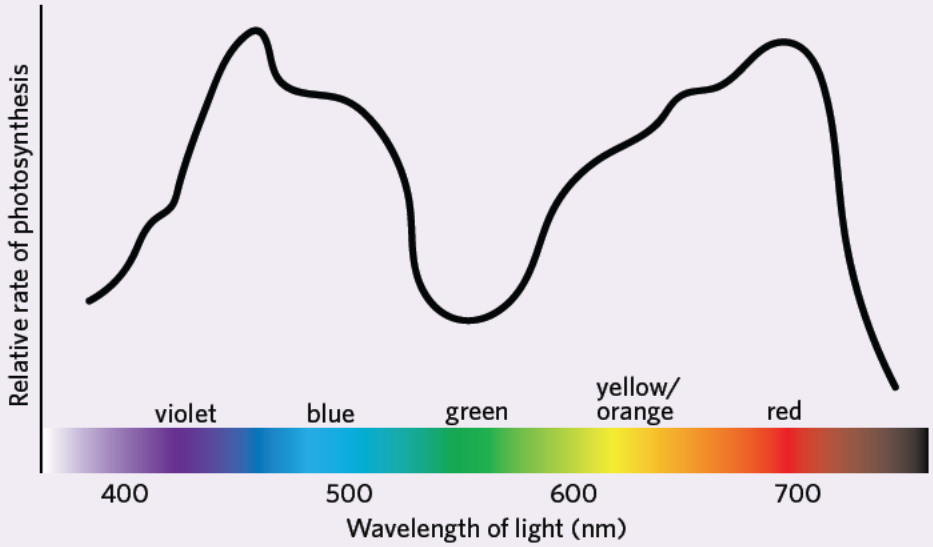


Figure 4 Photosynthesis rate is dependent on the wavelength of light.

Companies responsible for commercially growing plants know that it is not just the intensity of light that influences photosynthesis rate - the wavelength (and therefore colour) of light also impacts this process. Figure 4 shows that the greatest rate of photosynthesis occurs when a plant is exposed to violet or red light, and that the rate of photosynthesis is relatively low under green light (most green light is reflected, which is why we see leaves as green). VCAA have not tested photosynthesis rates under differing wavelengths in the past, however you may come across SACs that investigate this and it is important to note that photosynthesis rate depends on a variety of factors.

Effect of temperature on photosynthesis 3.1.19.3

OVERVIEW

Photosynthesis involves the use of many enzymes which function best within their optimal temperature range and can be denatured at high temperatures.

THEORY DETAILS

The photosynthesis process uses enzymes to catalyse reactions. Without them, photosynthesis would not occur. Enzyme activity is affected by temperature. As a result of this, the rate of photosynthesis is greatest when the temperature matches the enzyme's **optimal** temperature.

optimal the point at which, for a given condition (e.g. temperature), the maximum function of an enzyme occurs

denature to irreversibly change a protein's tertiary structure

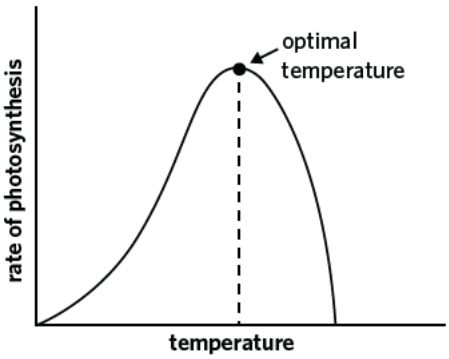


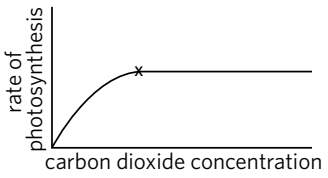
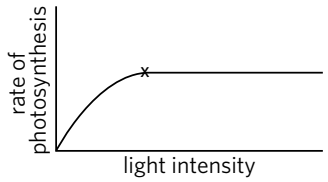
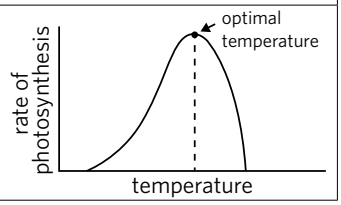
Figure 5 Photosynthesis rate is greatest at the enzyme's optimal temperature.

Consider Figure 5. You will notice that the rate of photosynthesis increases toward the enzyme's optimal temperature due to more frequent enzyme-substrate collisions. However, above the optimal temperature, enzymes begin to **denature** and are unable to function. This causes a steep drop-off in photosynthesis rate as temperature increases beyond the optimal point.

Theory summary

The rate at which plants undergo photosynthesis can vary depending on a few key factors. As carbon dioxide concentration increases, the photosynthesis rate also increases until a maximum is reached. The same can be said for light intensity. Photosynthesis rate is greatest when the temperature corresponds to the optimal temperature of the enzymes within the cells, and decreases when the enzymes denature.

Table 1 Summary of factors impacting photosynthesis rate

	Increasing the factor	Decreasing the factor	Graph of factor against reaction rate
Carbon dioxide concentration	Increases photosynthesis rate until a plateau is reached	Decreases photosynthesis rate	
Light	Increases photosynthesis rate until a plateau is reached	Decreases photosynthesis rate	
Temperature	Increases rate when below the optimal, decreases rate when above optimal	Decreases rate due to fewer enzyme-substrate collisions	

6C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ pores on a leaf that are involved with the exchange of water and carbon dioxide

b _____ the organelle where light energy is used to produce glucose

c _____ the temperature where the enzyme function is highest

d _____ a conformational change in an enzyme due to extreme high temperatures

Question 2

Which of the following are all true about the rate of photosynthesis?

A	Can reach a maximum rate with an increase in light intensity	Water is usually the limiting factor	Always increases with temperature	CO_2 concentration impacts reaction rate
B	Is slowed in the presence of bright light	Water is usually in large supply	Always increases with temperature	CO_2 concentration impacts reaction rate
C	Can reach a maximum rate with an increase in light intensity	Water is usually in large supply	Increases with temperature until the optimal is reached	CO_2 concentration impacts reaction rate
D	Can reach a maximum rate with an increase in light intensity	Water is usually the limiting factor	Increases with temperature until the optimal is reached	CO_2 concentration does not impact reaction rate

Question 3

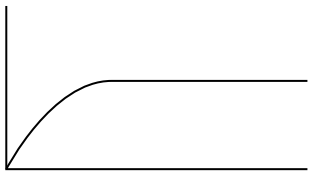
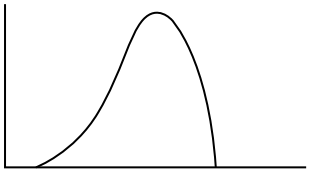
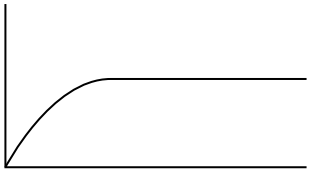
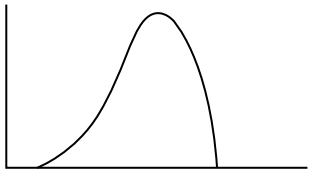
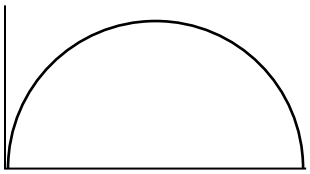
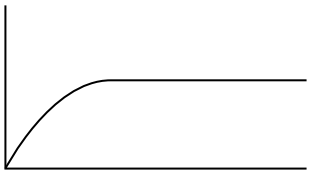
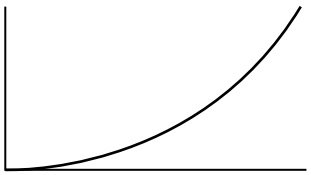
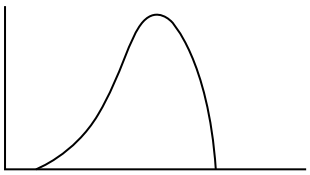
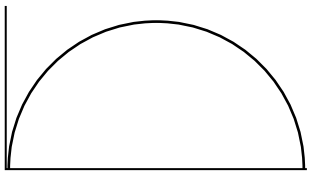
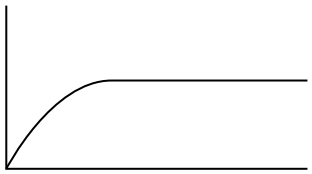
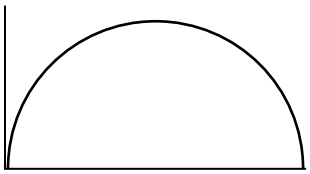
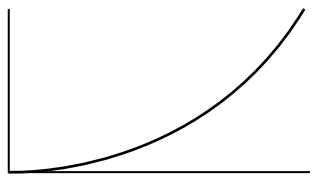
Fill in the blanks in the following sentences.

As carbon dioxide levels increase, the rate of photosynthesis generally _____**I**_____. This is also true for _____**II**_____, although only to a certain point, as when it becomes too _____**III**_____ the _____**IV**_____ can denature.

	I	II	III	IV
A	increases	light intensity	hot	chloroplasts
B	increases	temperature	hot	enzymes
C	decreases	light intensity	hot	enzymes
D	increases	temperature	cold	chloroplasts

Question 4

Which of the following displays the correct graphs of photosynthesis rate against increasing factor?

	Light	Temperature	CO_2
A			
B			
C			
D			

Question 5

In the table, classify each of the following statements as relating to CO_2 concentration, light intensity, or temperature, when considering photosynthesis rate. NOTE: each statement can be classified into multiple groups.

I is an input in the photosynthesis equation

II affects the rate of photosynthesis

III has a photosynthesis rate graph that rises then falls

IV a decrease usually lowers photosynthesis rate

V can be lost or gained through stomata

VI an increase can denature enzymes

VII has a photosynthesis rate graph that plateaus

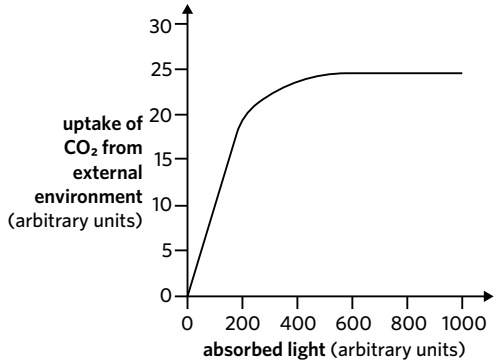
	CO_2	Light	Temperature
A	I, II, IV, V, VI, VII	II, III, IV, V	II, III, IV, VI
B	I, II, IV, V, VII	I, II, IV, VII	II, III, IV, VI
C	I, III, IV, V	I, II, V, VII	I, II, III, VII
D	I, II, IV, V, VII	I, II, III, IV	I, II, IV, VII

Exam-style questions

Within lesson

Use the following information to answer Questions 6 and 7.

The graph shows the uptake of carbon dioxide by a leaf from its external environment as light intensity is altered. All other variables are kept constant throughout the experiment.



Question 6 (1 MARK)

The plateau in the graph can be explained by

A the given leaf being unable to take up more than this level of CO_2.

B the enzymes within the chloroplasts being inhibited.

C light intensity becoming the limiting factor.

D the uptake of carbon dioxide increasing.

Question 7 (1 MARK)

The greatest rate of photosynthesis is seen

A at 200 arbitrary units of light.

B only at 800 arbitrary units of light.

C when the graph touches the x-axis.

D from approximately 500 arbitrary units of light onwards.

Question 8 (1 MARK)

A decrease in temperature from a plant's optimal range decreases the rate of photosynthesis.
The rate of photosynthesis decreases because

A CO_2 cannot be released from the leaves.

B there is less atmospheric O_2 surrounding the plant.

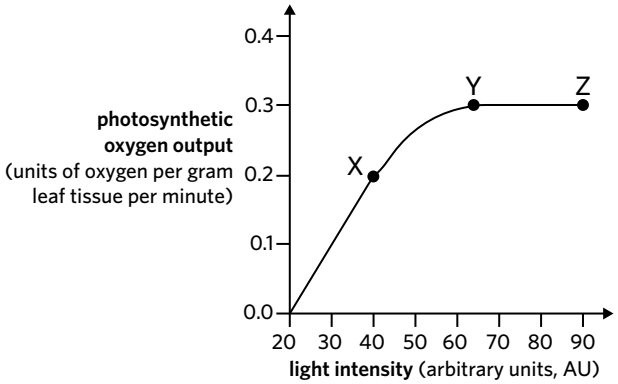
C the enzymes within the chloroplast catalyse at a slower rate.

D high temperatures are required to form the bonds within glucose.

Adapted from VCAA 2014 Section A Q8

Use the following information to answer Questions 9 and 10.

The graph shows the photosynthetic output of oxygen in spinach leaves as light intensity is increased. Temperature is kept constant during the experiment.



Question 9 (1 MARK)

Which one of the following conclusions can be made based on the graph?

A Photosynthesis at point X is limited by the temperature.

B An increase in temperature results in the output of oxygen at point Z.

C At point Z the light-independent stage of photosynthesis is not occurring.

D Above 70 AU of light intensity there is no increase in photosynthesis rate.

Adapted from VCAA 2017 Section A Q13

Question 10 (1 MARK)

At point Y

A an increase in light will increase the rate of glucose production.

B carbon dioxide is being consumed at a faster rate than at point Z.

C light intensity is no longer the limiting factor of photosynthesis rate.

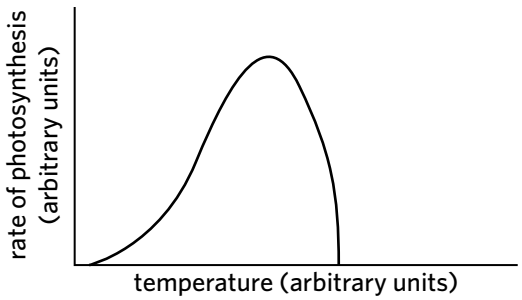
D light intensity has become the limiting factor of photosynthesis rate.

Adapted from VCAA 2017 Section A Q13

Multiple lessons

Question 11 (5 MARKS)

A group of scientists wanted to test the effects of temperature on the rate of photosynthesis. They conducted an experiment on isolated chloroplasts, where they kept the light intensity and the concentrations of carbon dioxide and water constant. After the experiment, the following graph was produced.



a Explain why this trend on the graph was seen. (2 MARKS)

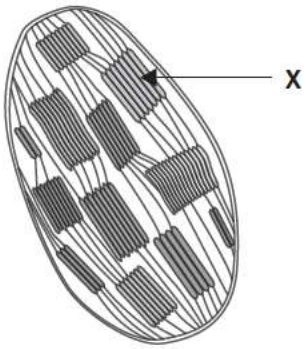
b Enzymes are integral to life.

i Outline the function of enzymes in biological systems. (1 MARK)

ii Name two loaded coenzymes that are important in the photosynthesis process. (2 MARKS)

Question 12 (7 MARKS)

The diagram shows an organelle found in plant cells.



a Structure X is involved in converting light energy into glucose.

I Identify structure X. (1 MARK)

II Which stage of photosynthesis occurs here? (1 MARK)

b All plants undergo photosynthesis to generate energy.

I Write the simplified chemical equation for photosynthesis. (1 MARK)

II What is the purpose of photosynthesis in plants? (1 MARK)

c Describe how an increase in light intensity, temperature, and CO_2 concentration each affect the rate of photosynthesis. Assume the other factors are unlimited. (3 MARKS)

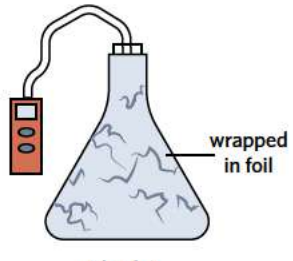
Adapted from VCAA 2011 Exam 1 Section B Q7

Key science skills

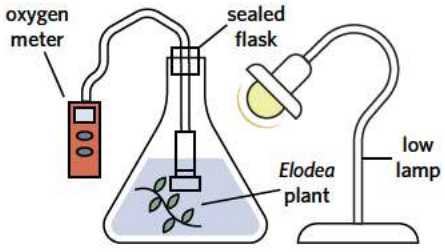
Question 13 (10 MARKS)

Three students, Harris, Jasper, and Davis, wanted to test the rate of photosynthesis of a green leafy plant as the intensity of light changed. They set up four identical sealed flasks containing a healthy sample of an aquatic *Elodea* plant.

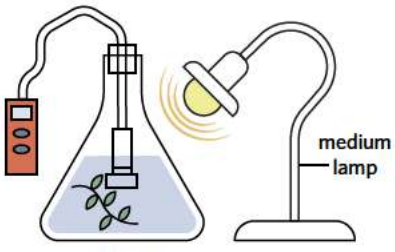
The flasks were labelled 1-4 and set up on a bench in a classroom. Each flask was then exposed to a different intensity of light. Three lamps were used that contained a 'low', 'medium', and 'high' setting. Flask 2 was placed next to a lamp on low, Flask 3 a medium, and Flask 4 a high. Flask 1 was not exposed to any light, as the flask was wrapped in aluminium foil. Each beaker contained a dissolved oxygen meter that recorded the levels of oxygen over time. The flasks were left to sit for only half an hour, as the oxygen meter continuously recorded the rate of oxygen production. A summary of the experimental setup is shown.



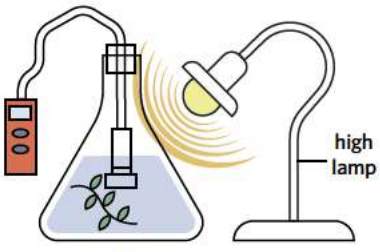
Flask 1



Flask 2



Flask 3



Flask 4

a Identify the purpose of the oxygen meter. (1 MARK)

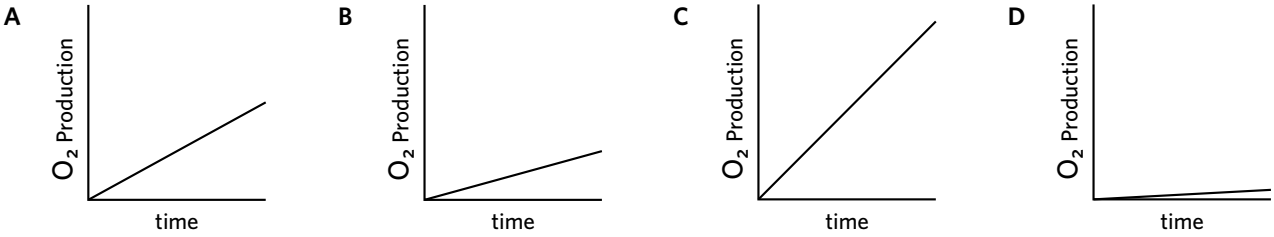
b What was the purpose of Flask 1? (1 MARK)

c Identify why the flasks were sealed in the experiment. (1 MARK)

d In which flask is the fastest rate of photosynthesis expected to be seen? Justify your response. (2 MARKS)

e Identify three variables that need to be controlled for all flasks in this experiment. (3 MARKS)

f Foolishly, the students forgot to return to their experiment and observe the results. When they returned the following period, the flasks had been packed away and all that remained from the experiment was the data from the oxygen meters. Luckily, the students were able to access the rate of oxygen production over the first half an hour of their experiment and produced the following graphs.



Due to their mistakes, there was confusion as to which graph corresponded to which flask. The three students made the following suggestions.

Student	Graph A	Graph B	Graph C	Graph D
Harris	Flask 2	Flask 4	Flask 1	Flask 3
Jasper	Flask 3	Flask 1	Flask 4	Flask 2
Davis	Flask 3	Flask 2	Flask 4	Flask 1

Which student is most likely correct? Justify your response. (2 MARKS)

ACTIVITY

Experimenting with photosynthesis

Introduction

When plants photosynthesise, the mesophyll cells in the leaf (the cells that contain chlorophyll) produce oxygen. The amount of oxygen produced can be inferred by the buoyancy of the leaf tissue in water. The more oxygen that has formed in the spaces inside the leaf tissue, the more buoyant the leaf tissue will be.

In order for photosynthesis to take place, mesophyll cells need a source of carbon dioxide, water, and light. For this experiment you will add the leaf discs to water that contains sodium bicarbonate, which is a source of carbon dioxide for the leaf tissue. The light will be supplied by a lamp.

Materials and apparatus

- leaves (choose leaves that are thin, smooth, and dark on the top surface but paler underneath)
- a large syringe (without the needle)
- several small beakers
- drinking straw
- stopwatch
- lamp
- 2% sodium bicarbonate solution (with a small amount of dishwashing detergent added to reduce the surface tension between the water and the leaf surface)

Procedure A: setting up the control

1. Cut 10 leaf discs from the leaf, using the drinking straw as a hole punch.
2. Remove the plunger from the syringe and drop the leaf discs into the syringe barrel.
3. Replace the plunger in the syringe, being careful not to squash any leaf discs.
4. Fill the syringe with 2% sodium bicarbonate solution, drawing up the solution by lifting up the plunger.
5. Hold a rubber stopper or finger over the opening to the syringe (where the needle would be if it had a needle) and pull firmly on the plunger to decrease the pressure of the fluid inside the syringe. This drop in pressure will draw the sodium bicarbonate solution into the leaf spaces of the leaf tissue, bathing the mesophyll cells with water and carbon dioxide.
   It may help to shake the syringe while you are pulling on the plunger to help agitate any gas particles that are in the leaf tissue. Continue to pull on the plunger for 30 seconds. After 30 seconds release the pressure. If the leaf discs do not sink to the bottom, repeat the procedure. Continue to pull on the syringe plunger and release it at 30 second intervals, until the leaf discs sink in the syringe. When they sink, you will know that the leaf spaces are filled with fluid.
6. Place the leaf discs in a small glass beaker filled with sodium bicarbonate solution. Spread them out so that they do not interfere with each other.
7. Place the beaker under the lamp. Using a stopwatch, record how long it takes for five of the discs to rise to the surface.

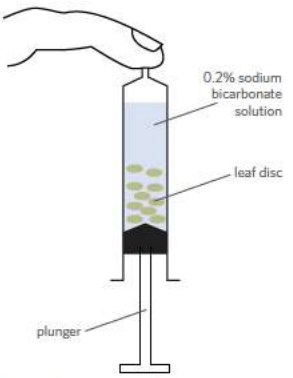


Figure 1 Initial setup in the plunger

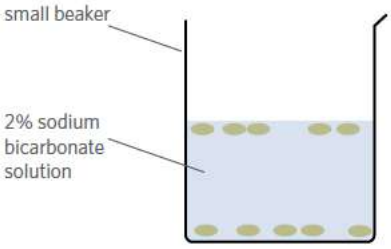


Figure 2 Experimental setup of the beaker

Procedure B: designing an experiment

8. The procedure above will act as the control for your experiment. Select one independent variable (either light intensity, carbon dioxide concentration, or temperature) and design an experiment that involves changing this independent variable. Make sure that you have accounted for all other potential uncontrolled variables.
9. Write a title, aim, and hypothesis for your experiment in your log book.
10. Repeat the experiment and control a number of times.
11. Tabulate and graph your results in your log book.
12. In your log book, write a detailed discussion that explains your results and reflects on your hypothesis. Evaluate your experiment, critically examining the procedure you followed and discussing its strengths and limitations.
13. Finish this entry in your log book by writing a conclusion that restates your results, summarising how your independent variable affects your dependent variable, and suggesting an area for future research.

CHAPTER SUMMARY

6A

PHOTOSYNTHESIS

$$6\,CO_2 + 12\,H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6\,O_2 + 6\,H_2O$$

carbon dioxide + water → glucose + oxygen + water

6B

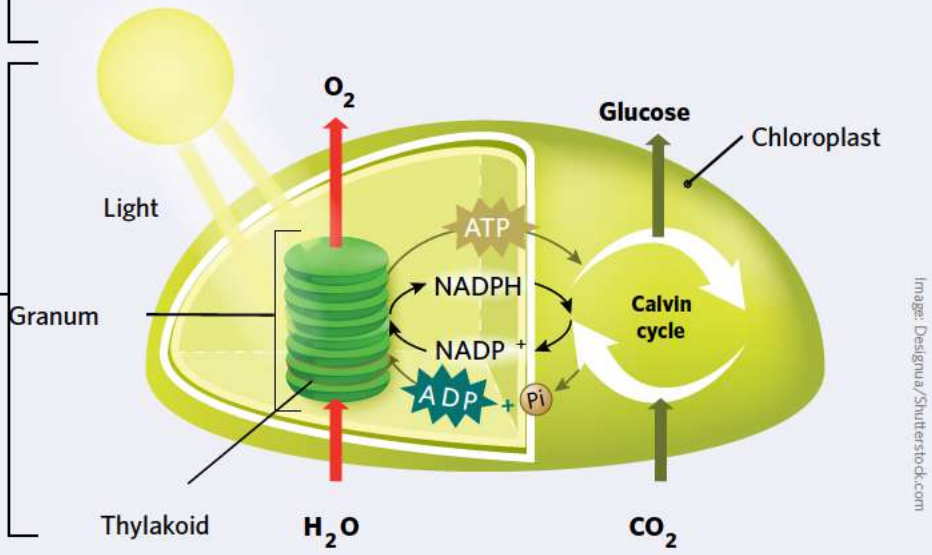


Image: Designua/Shutterstock.com

6C

	Location	Inputs	Outputs
Light-dependent stage	Grana / thylakoid membranes	12 H_2O 12 $NADP^+$ 12 ADP + P_i	6 O_2 12 NADPH 12 ATP
Light-independent stage	Stroma	6 CO_2 12 NADPH 12 ATP	$C_6H_{12}O_6$ 12 $NADP^+$ 12 ADP + P_i 6 H_2O

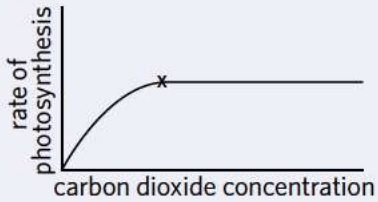
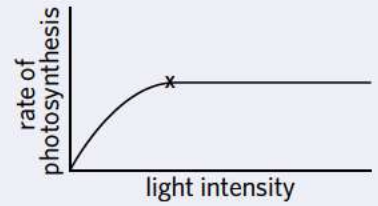
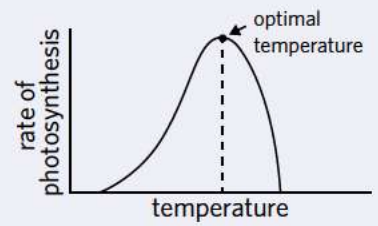
Endosymbiosis theory

Chloroplasts are believed to have existed as prokaryotic organisms until they were engulfed by a host cell.

Evidence that supports this theory includes the fact that chloroplasts:

- have their own circular double-stranded DNA
- replicate through binary fission like bacteria
- have their own ribosomes
- can produce their own proteins
- have a double-membrane like gram-negative bacteria
- are a similar size to bacteria

Factors affecting the rate of photosynthesis

	Trend	Graph of factor against reaction rate
Carbon dioxide concentration	As concentration increases, the rate of photosynthesis will increase until it plateaus due to a limiting factor	
Light	As light increases, the rate of photosynthesis will increase until it plateaus due to a limiting factor	
Temperature	As temperature moves futher away from optimal range, the rate of photosynthesis decreases	

CHAPTER REVIEW QUESTIONS

SECTION A (13 MARKS)

Question 1 (1 MARK)

An animal cell can be distinguished from a plant cell because of the absence of

A a cytosol.
B a nucleus.
C ribosomes.
D chloroplasts.

Adapted from VCAA 2005 Exam 1 Section A Q1

Use the following information to answer Questions 2 and 3.

Although photosynthesis is often summarised by a single equation, the process occurs in two distinct phases: the light-dependent stage and the light-independent stage.

Question 2 (1 MARK)

Which one of the following describes one input and one output of the light-dependent reaction?

	Input	Output
A	Light	O_2
B	H_2O	O_2
C	CO_2	H_2O
D	O_2	H_2O

Question 3 (1 MARK)

The enzymes that are required for the light-independent stage of photosynthesis are found in the

A stroma.
B cytosol.
C stomata.
D thylakoid membrane.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q4

Question 4 (1 MARK)

Which of these can be considered a by-product of photosynthesis?

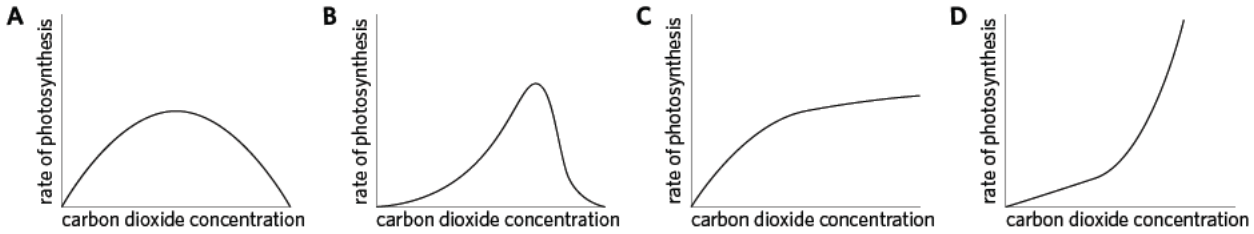
A ATP
B Oxygen
C Glucose
D Carbon dioxide

Adapted from VCAA 2004 Exam 1 Section B Q3e

Question 5 (1 MARK)

Josh set up an experiment to measure the reaction rate of photosynthesis. Each plant was exposed to differing concentrations of carbon dioxide and the rate of reaction was measured.

Which of the following graphs correctly represents the relationship between carbon dioxide concentration and the rate of photosynthesis?



Question 6 (1 MARK)

An increase in available light increases the rate of photosynthesis. The rate of photosynthesis increases because

A the rate of the light-dependent reactions on the thylakoid membranes of the chloroplasts increases.

B water loss from the leaf decreases, resulting in the availability of water for photosynthesis increasing.

C the increased CO_2 level lowers the pH inside the chloroplasts and increases the rate of enzyme-catalysed reactions.

D the rate of the light-independent reactions in the stroma increases with the increase in available light.

Adapted from VCAA 2014 Section A Q8

Question 7 (1 MARK)

If a plant was exposed to a very limited supply of CO_2, which stage of photosynthesis would be primarily affected?

A Light-dependent stage

B Light-independent stage

C Both stages equally

D Neither stage as CO_2 is an output

Question 8 (1 MARK)

During photosynthesis in chloroplasts, energy is used to split water, forming oxygen and hydrogen ions.

The hydrogen produced

A is released into the atmosphere.

B binds to NAD^+ to form NADH and is used in the light-independent stage.

C binds to $NADP^+$ to form NADPH and is used in the light-independent stage.

D binds to ADP to form ATP and is used in the light-dependent stage.

Adapted from VCAA 2014 Section A Q7

Question 9 (1 MARK)

The diagram shows the reaction which causes the formation of glucose. The source of energy for this reaction is

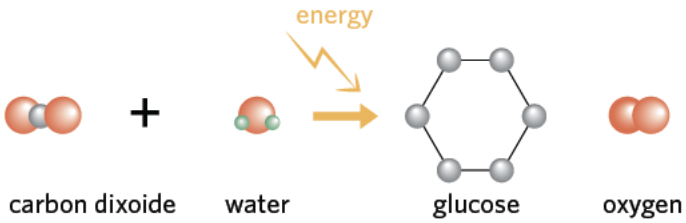
A glucose.

B NADPH.

C sunlight.

D carbon dioxide.

Adapted from VCAA 2012 Exam 1 Section A Q21



Question 10 (1 MARK)

Chloroplasts

A divide by binary fission.

B are only found in animal cells.

C are the site of cellular respiration.

D are found in all prokaryotic and eukaryotic cells.

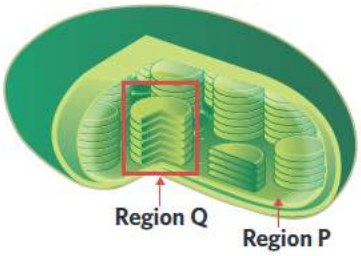
Adapted from VCAA 2003 Exam 1 Section A Q1

Question 11 (1 MARK)

The diagram shows a chloroplast.

The region labelled P is the

A cristae.
B stroma.
C granum.
D thylakoid.



Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q5a

Question 12 (1 MARK)

Plants grown in light were supplied with air containing radioactive carbon dioxide. After four hours, an analysis of the chemicals in and around the plant was undertaken.

Which one of the following would contain radioactive carbon atoms after four hours?

A Protein
B Glucose
C Oxygen gas
D Water

Adapted from VCAA 2016 Section A Q10

Question 13 (1 MARK)

A variegated leaf from a plant is shown.

Cells from section M and K were examined and simple sketches were produced.

From this information, it can be concluded that

A energy can only be extracted from glucose in cells from section M.
B chlorophyll is present in cells from section M but not in cells from section K.
C light-dependent reactions of photosynthesis can occur in cells from section K.
D cells in section M would be unable to carry out the light-dependent stage of photosynthesis.

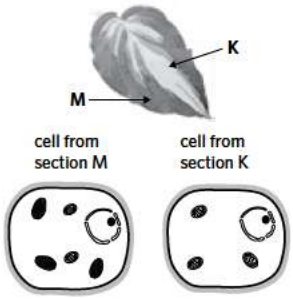


Image: Le Do/Shutterstock.com

Adapted from VCAA 2017 Section A Q15

SECTION B (27 MARKS)

Question 14 (7 MARKS)

The herbicide propanil is used in the agricultural industry to kill weeds. Propanil's mode of action involves inhibiting photosynthesis by binding to proteins in the thylakoid membranes. As a result, the Calvin cycle cannot function as it cannot be energised.

While inhibiting photosynthesis does not directly cause plant death, it can have fatal consequences.

a For which stage of photosynthesis is carbon dioxide an input, and where in the chloroplast does this occur? (2 MARKS)

b Explain how inhibiting photosynthesis in a plant would result in its death. (3 MARKS)

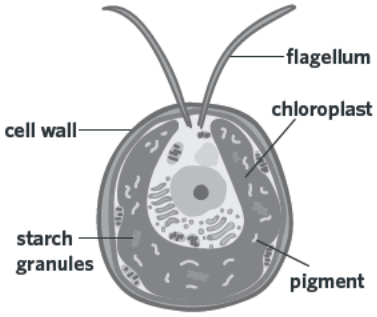
c Scientists researched whether they could reverse the inhibition of the enzymes in the thylakoid membrane. They added a large concentration of substrate in an attempt to saturate these enzymes. They concluded that this had no effect on enzyme inhibition. They also noted that this inhibitor did not bind permanently to the enzyme.

From this information, what can you conclude about where propanil binds to the enzyme and its mode of inhibition? Explain what effect this has on enzyme structure. (2 MARKS)

Question 15 (4 MARKS)

A *Chlamydomonas* cell has a single large chloroplast containing a green pigment.

Photosynthesis and cellular respiration are two biochemical processes that are crucial for the maintenance of life on Earth. Photosynthesis takes place in two phases – a light-dependent phase and a light-independent phase. One of the products of the light-independent reaction is used in cellular respiration to provide energy for an organism.



a What is this product? (1 MARK)

b During the light-dependent stage of photosynthesis, water is split into hydrogen ions and oxygen gas. These hydrogen ions are required in the light-independent stage.

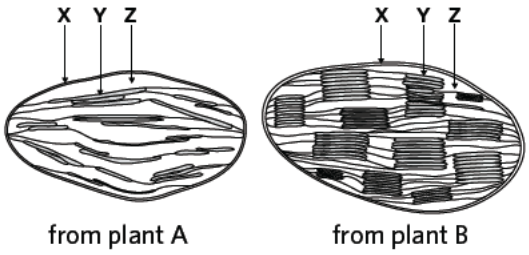
I Name the loaded form of the proton carrier used during photosynthesis. (1 MARK)

II State the net production of this proton carrier for the full photosynthesis reaction. Justify your response. (2 MARKS)

Adapted from VCAA 2004 Exam 1 Section B Q3e

Question 16 (7 MARKS)

The bird's-nest fern, *Asplenium nidus*, usually grows in deeply shaded rainforests and has dark green fronds. Sometimes it is found in open, sunny locations by roadsides where it tends to have lighter coloured fronds. Two birds-nest ferns, one from each of the two habitats described were examined. A sample of cells from a frond of each of the ferns was collected. These cells were examined under an electron microscope and a typical chloroplast from each habitat (deeply shaded rainforest and sunny location) was drawn.



a Which of the labelled parts (X, Y, or Z) are the locations of the light-independent stage? Name the part. (1 MARK)

b Which drawing, A or B, shows a chloroplast from the roadside habitat? Explain the reason for your choice in terms of the relationship between structure and function. (2 MARKS)

c Other than light, identify a factor that affects the rate of photosynthesis and explain its relationship. (2 MARKS)

d It is now widely accepted by biologists that chloroplasts and mitochondria were once independent prokaryotic organisms which came to live symbiotically inside larger eukaryotic cells. This idea is known as the endosymbiotic theory.

I Name one process that occurs in chloroplasts and explain how it supports the endosymbiotic theory. (1 MARK)

II Name one structure in chloroplasts and explain how it supports the endosymbiotic theory. (1 MARK)

Adapted from VCAA 2007 Exam 1 Section B Q4

Question 17 (9 MARKS)

Patrick and Atong notice bubbles forming on the submerged leaves of an *Elodea* plant growing in an aquarium. The bubbles seen on the leaves are the result of a gas formed in the leaf cells. The temperature and pH are optimal for *Elodea*.

There is a bright light shining on the aquarium. The bright light does not affect the temperature of the water.

a State two inputs and two outputs of photosynthesis. (2 MARKS)

b Identify the gas formed on the leaves. (1 MARK)

c Identify where in the chloroplast this gas was produced. (1 MARK)

d Light is captured by a chemical in the chloroplast. Name the pigment that captures light. (1 MARK)

e Explain what is expected to occur if the light source is switched off. (2 MARKS)

f Explain why it is important that the light source does not affect the temperature of the water. (2 MARKS)

UNIT 3 AOS 1, CHAPTER 7

Cellular respiration

07

7A Cellular respiration and mitochondria

7B Aerobic cellular respiration

7C Anaerobic cellular respiration

7D Increasing and decreasing cellular respiration

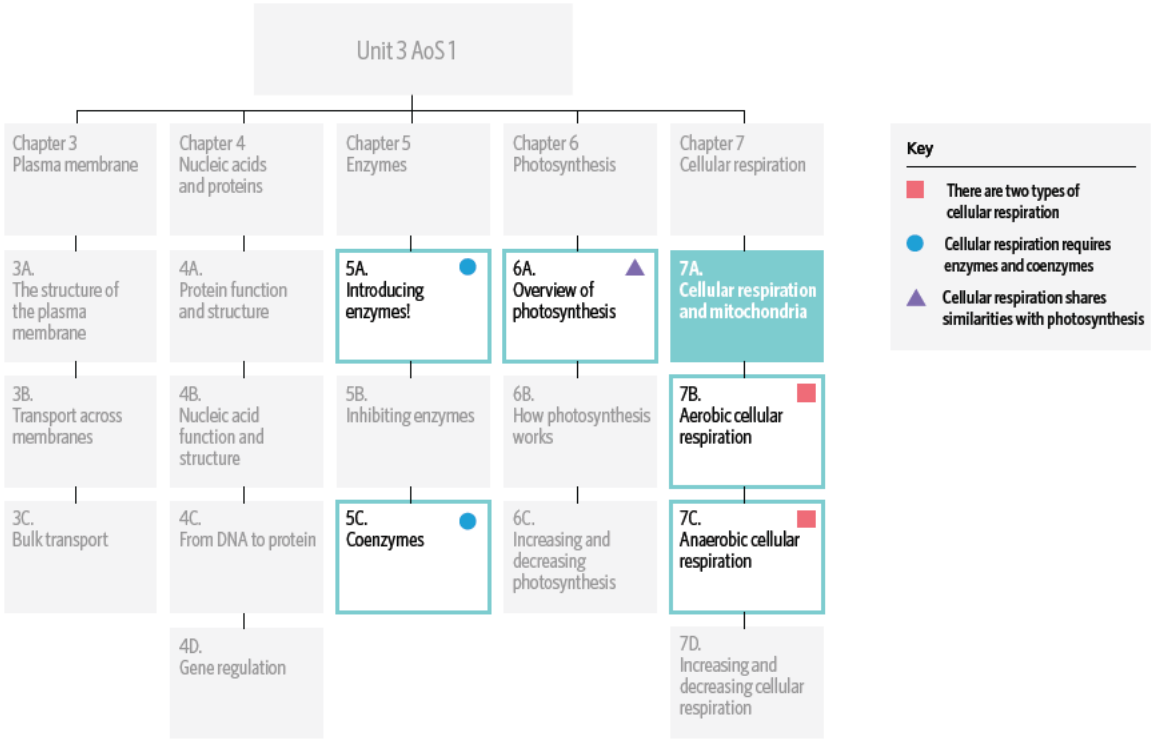
Key knowledge

- the purpose of cellular respiration
- mitochondria as the site of aerobic cellular respiration, an overview of their structure, and evidence of their bacterial origins
- the location of, and the inputs and outputs of, glycolysis including ATP yield (details of the biochemical pathway mechanisms are not required)
- the main inputs and outputs of the Krebs (citric acid) cycle and electron transport chain including ATP yield (details of the biochemical pathway mechanisms are not required)
- the location of anaerobic cellular respiration, its inputs, and the difference in outputs between animals and yeasts including ATP yield
- factors that affect the rate of cellular respiration, including temperature, glucose availability, and oxygen concentration

Image: Chase Dekker/Shutterstock.com

7A CELLULAR RESPIRATION AND MITOCHONDRIA

Mitochondria are the powerhouse of the cell. Mitochondria are the powerhouse of the cell. Mitochondria are the powerhouse of the cell.



In this lesson you will learn why cells undergo cellular respiration, what mitochondria are, and where mitochondria came from.

Study design dot points

- the purpose of cellular respiration
- mitochondria as the site of aerobic cellular respiration, an overview of their structure, and evidence of their bacterial origins

Key knowledge units

Purpose of cellular respiration	3.1.20.1
Structure of mitochondria	3.1.22.1
Origin of mitochondria	3.1.22.2

Purpose of cellular respiration 3.1.20.1

OVERVIEW

The purpose of cellular respiration is to break down high energy compounds (such as glucose) to produce the molecule ATP, which is a more usable form of energy. Cellular respiration is vital to all forms of life and occurs in two distinct pathways: aerobic respiration or anaerobic respiration.

THEORY DETAILS

All cells require energy to power cellular processes. This energy is obtained from the breakdown of organic compounds via the biochemical pathway of **cellular respiration**. These organic compounds are usually energy-rich six-carbon carbohydrate molecules, such as **glucose**, which are obtained from food. The end result of the respiration pathway is the synthesis of **ATP** molecules, which are used to power many cellular reactions.

cellular respiration the biochemical process in all living things that converts glucose into ATP. Can be aerobic or anaerobic respiration

glucose a six-carbon carbohydrate that comes from the food we eat

ATP adenosine triphosphate, a high energy molecule that, when broken down, provides energy for cellular processes

Glucose can be broken down to produce ATP via **aerobic cellular respiration** or **anaerobic cellular respiration**. The main difference between each pathway is the presence of oxygen. Aerobic respiration requires oxygen, whereas anaerobic respiration does not.

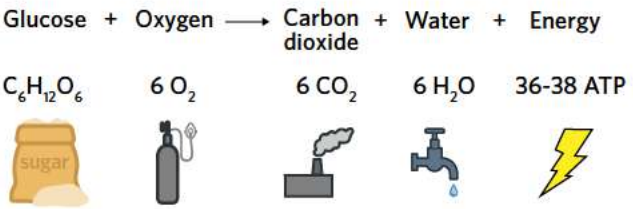


Figure 1 The equation for aerobic cellular respiration in eukaryotes

Aerobic respiration produces a large number of ATP molecules per glucose molecule. This is why it's important for humans to breathe in oxygen. The process is similar in all aerobically respiring organisms. Without oxygen, anaerobic respiration is still possible. The anaerobic respiration pathway produces less ATP, and is different in yeast and plants compared to animals (Figure 2).

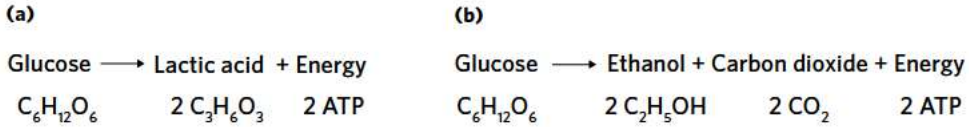


Figure 2 **(a)** Anaerobic cellular respiration in animals **(b)** anaerobic cellular respiration in plants and microorganisms (such as yeast)

It is important to note that the equations are summarising the respiration pathways, and the actual pathways are much more complex. Aerobic cellular respiration occurs in three distinct stages - glycolysis, the Krebs cycle, and the electron transport chain (ETC). Glycolysis takes place in the cytosol of the cell whilst the Krebs cycle and ETC occur within the mitochondria of a cell. Anaerobic respiration takes place in the cytosol, and does not require mitochondria.

Many people assume that the equation for aerobic cellular respiration is the reverse of the photosynthesis equation. This is untrue. They share a number of similarities, however, the individual processes are not the opposite of each other, and very different structures are involved. Photosynthesis requires water as an input and output whilst water is only an output of aerobic cellular respiration.

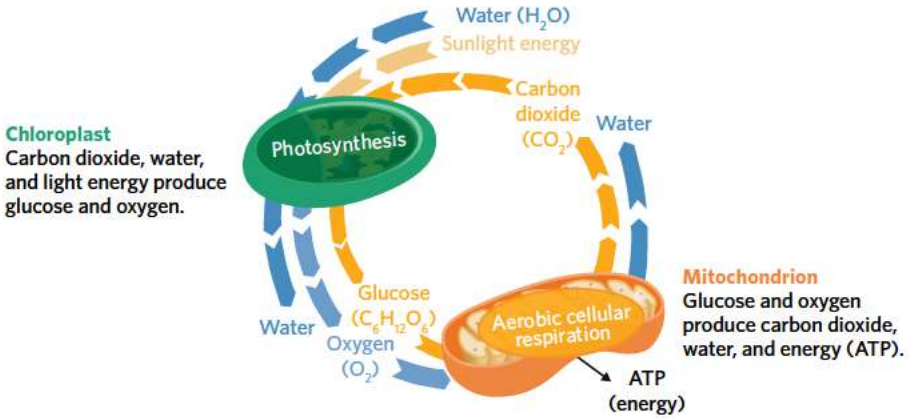


Figure 3 Photosynthesis and cellular respiration are related processes.

Nevertheless, Figure 3 shows that photosynthesis and cellular respiration are related, as each process can use some of the other's outputs as inputs. For plants or algae (organisms with chloroplasts), this means that they don't need to source all their photosynthesis and respiration inputs from the environment.

Structure of mitochondria 3.1.22.1

OVERVIEW

Mitochondria are membrane-bound organelles that are the site of aerobic cellular respiration. The mitochondrion consists of an outer and inner membrane, an intermembrane space, and the mitochondrial matrix.

aerobic cellular respiration cellular respiration that occurs in the presence of oxygen. It involves three stages, during which glucose and oxygen are converted into ATP, CO_2, and water

anaerobic cellular respiration cellular respiration that occurs in the absence of oxygen. It involves glycolysis, followed by further reactions that convert pyruvate into lactic acid, or ethanol and carbon dioxide. Also known as **fermentation**

Tip We can also use fats and occasionally proteins to produce ATP by cellular respiration. However, if available, a cell will preferentially use glucose during cellular respiration.

lesson link In ***5C*** we learned that the coenzyme ATP is used to power cellular processes. The energy within ATP is stored in the bonds between the second and third phosphate group and is released when these bonds are broken (ATP → ADP + P_i + energy for cellular reactions). While it doesn't contain as much energy as glucose, ATP has a more convenient amount of energy for typical cellular reactions.

lesson link The individual stages and processes within aerobic ***(7B)*** and anaerobic ***(7C)*** respiration are explored in the coming lessons.

Tip It is important to note that most prokaryotes respire anaerobically, however, some can aerobically respire despite not having mitochondria. Some prokaryotes can even undertake both respiration types. Most anaerobic bacteria respire similarly to plants and yeast.

THEORY DETAILS

Mitochondria are made up of many different structures (Figure 4). This includes an outer and inner membrane. The space inside the inner membrane is the **mitochondrial matrix**, and is filled with a dense fluid containing many enzymes and solutes. This is the site of the second stage of aerobic cellular respiration (the Krebs cycle). The inner membrane folds into peaks and ridges called **cristae**, which facilitate the function of the third stage of aerobic cellular respiration (the electron transport chain). The intermembrane space is narrow and has a small volume compared to the matrix. It is also involved in the third stage of aerobic cellular respiration.

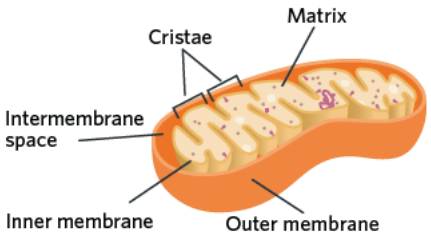


Figure 4 A labelled diagram of the structures of the mitochondria

Origin of mitochondria 3.1.22.2

OVERVIEW

Mitochondria contain many structures that suggest they lived as independent unicellular organisms before being engulfed and enslaved by a host cell.

THEORY DETAILS

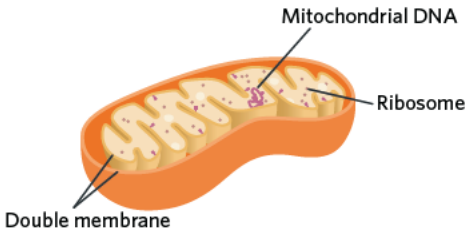


Figure 5 Certain mitochondrial structures provide evidence for the endosymbiosis theory.

Evidence suggests that the ancestors of mitochondria once existed as free-living aerobic bacteria until they were engulfed by a larger host cell approximately two billion years ago. Both the host cell and mitochondrial ancestor benefitted from the relationship, which is described as **endosymbiotic**. The host cell gained a method of producing large amounts of energy from sugar and oxygen and the aerobic microbe gained safety and protection. A similar theory explains the origins of chloroplasts, so we say that both mitochondria and chloroplasts had endosymbiotic origins and prokaryotic ancestors.

Case study

All eukaryotic cells contain mitochondria but only plants and algae have chloroplasts. This suggests that the endosymbiotic event that generated mitochondria must have happened before the endosymbiotic event that generated chloroplasts. We can display the relationship between eukaryotes, mitochondria, and chloroplasts on a simplified phylogenetic tree (the interpretation of these trees will be covered in 13A).

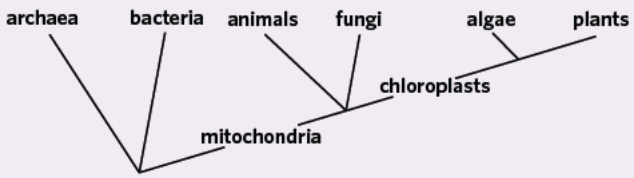


Figure 6 A phylogenetic tree depicting the evolution of mitochondria and chloroplasts

mitochondrion (pl. mitochondria) a double-membraned organelle that is the site of aerobic respiration

mitochondrial matrix the space inside the inner membrane of the mitochondria. The site of the Krebs cycle

crista (pl. cristae) the folds of the inner membrane of mitochondria. The site of the electron transport chain

endosymbiosis when one organism lives inside another in a mutually beneficial relationship

Tip Cells differ in their amount of mitochondria. A singular cell may contain one or many mitochondria depending on its energy requirements. A cell without mitochondria can still undergo anaerobic respiration.

lesson link Mitochondria share many structural similarities with chloroplasts (discussed in ***lesson 6A***), indicating that they both arose by endosymbiosis.

Evidence that supports the endosymbiotic theory includes:

- Mitochondria have their own circular double-stranded DNA (mtDNA) in the matrix which is not enclosed in a nuclear membrane (similar to bacteria).
- Mitochondria and bacteria both replicate through binary fission, unlike animal, plant, fungi, and algae cells which replicate through mitosis.
- Mitochondria have their own ribosomes in the matrix that share characteristics with bacterial ribosomes.
- As mitochondria have their own DNA and ribosomes, they can produce proteins through transcription and translation independently from the rest of the cell.
- The outer membrane of mitochondria contains transport proteins called porins. Porins are only found in the membranes of prokaryotes.
- Mitochondria have a double membrane which is similar to gram-negative bacteria.

These pieces of evidence allow scientists to recognise that prokaryotes and mitochondria are similar, and that mitochondria are well equipped to survive independently. Therefore, we can conclude that mitochondria likely originated from prokaryotic ancestors.

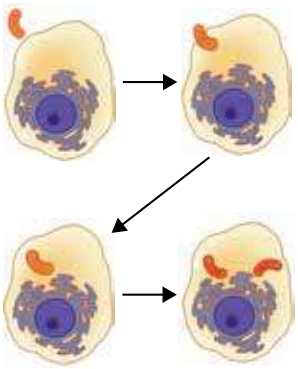


Image: Jamilia Marini/Shutterstock.com

Figure 7 The engulfment of a mitochondrion by a host cell

Theory summary

Cellular respiration is vital to all cells. There are two types of cellular respiration in eukaryotic cells, aerobic and anaerobic respiration. Aerobic respiration requires oxygen and mitochondria, which consist of the outer and inner membrane, cristae, and the mitochondrial matrix. Finally, the origins of mitochondria can be explained by the endosymbiotic theory.

7A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the sugar broken down by eukaryotes in cellular respiration

b _____ the space inside the inner membrane of the mitochondria

c _____ respiration that requires oxygen

d _____ the folds of the inner membrane of the mitochondria

e _____ the coenzyme produced in cellular respiration

f _____ respiration that does not require oxygen

g _____ a mutually beneficial relationship describing when one organism lives inside another

Question 2

Which of the following options correctly shows the inputs and outputs of anaerobic respiration in humans?

	Inputs	Outputs
A	Glucose Oxygen	Carbon dioxide Water ATP
B	Glucose	Ethanol ATP
C	Glucose	Lactic acid ATP
D	Glucose Oxygen	Lactic Acid ATP

Question 3

Which of the following correctly expresses the balanced equation for aerobic cellular respiration?

A $2\ C_6H_{12}O_6 + 6\ O_2 \rightarrow 2\ CO_2 + 6\ H_2O + 32\text{-}34\ ATP$

B $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + 36\text{-}38\ ATP$

C $6\ C_6H_{12}O_6 + O_2 \rightarrow 6\ CO_2 + H_2O + 34\text{-}36\ ATP$

D $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + H_2O + 36\text{-}38\ ATP$

Question 4

Which of the following statements about aerobic cellular respiration and photosynthesis is false?

A Water is an output of both processes.

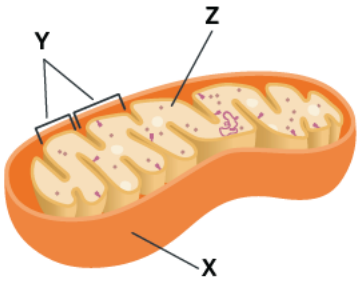
B Oxygen is an input of both processes.

C The organelles responsible for both processes show evidence of bacterial origins.

D Photosynthesis generates energy-storing molecules in the form of glucose, respiration generates energy-storing molecules in the form of ATP.

Question 5

Complete the following diagram by identifying structures X, Y, and Z.



	X	Y	Z
A	Outer membrane	Cristae	Matrix
B	Inner membrane	Cristae	Ribosome
C	Outer membrane	Matrix	Cristae
D	Outer membrane	Ribosome	Matrix

Question 6

Which of the following options are all features of mitochondria that support the endosymbiosis theory?

A	Contain ribosomes	Replicate through binary fission	Have a mitochondrial matrix	Double-membrane bound
B	Have a mitochondrial matrix	Have circular DNA	Replicate through mitosis	Contain ribosomes
C	Double-membrane bound	Contain ribosomes	Contain cristae	Replicate through binary fission
D	Replicate through binary fission	Double-membrane bound	Have circular DNA	Contain ribosomes

Exam-style questions

Within lesson

Use the following information to answer Questions 7 and 8.

A three-dimensional diagram of an organelle found in animal cells is shown.

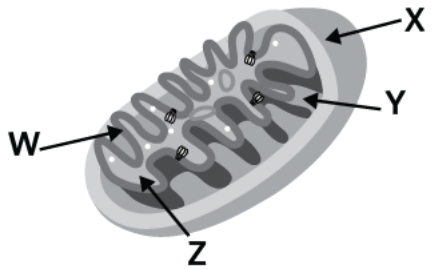


Image: Alila Medical Media/Shutterstock.com

Question 7 (1 MARK)

The region labelled X is called the

A crista.
B matrix.
C inner membrane.
D outer membrane.

Adapted from VCAA 2017 Section A Q9

Question 8 (1 MARK)

Which of the following structures represents the mitochondrial matrix?

A W
B X
C Y
D Z

Adapted from VCAA 2017 Section A Q9

Multiple lessons

Question 9 (1 MARK)

Skeletal muscle cells in the legs contract and relax rapidly during exercise and require a large supply of energy.

Which organelle would you expect to see in large numbers in skeletal muscle cells to supply this energy?

A smooth endoplasmic reticulum
B mitochondria
C chloroplasts
D nuclei

Adapted from VCAA 2014 Section A Q3c

Use the following information to answer Questions 10 and 11.

Cells from sections M and K were examined and simple sketches were produced.

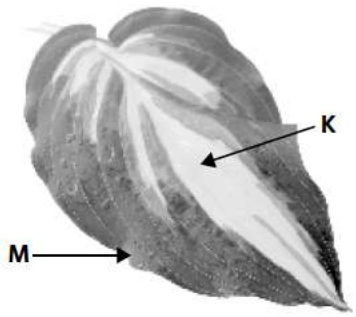
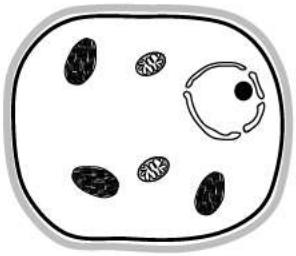
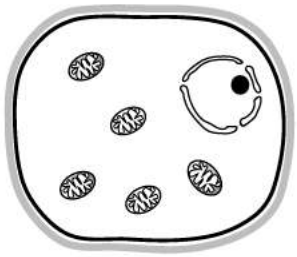


Image: Le Do/Shutterstock.com

A typical cell from section M



A typical cell from section K



Question 10 (1 MARK)

From this information, it can be concluded that

A cells in section K can only respire anaerobically.
B cells in section M can respire and photosynthesise.
C chlorophyll is present in cells from section M and K.
D cells in section M and K can convert light energy into glucose.

Adapted from VCAA 2017 Section A Q15

Question 11 (1 MARK)

Provided there are sufficient inputs, what prediction can be made about the rate of cellular respiration in cells from section M and K?

A Cells in section M would respire slower than cells in section K.

B Cells in section M would respire faster than cells in section K.

C Both cells types would respire at an equal rate.

D Only cells in section M could respire.

Question 12 (9 MARKS)

Animals can undergo two different types of cellular respiration.

a State the output/s of anaerobic cellular respiration in animals. (1 MARK)

Adapted from VCAA 2011 Exam 1 Section B Q7

b State the chemical equation for aerobic cellular respiration. (1 MARK)

c Plants can produce glucose using another chemical pathway.

i State both the simplified worded and simplified chemical equations of photosynthesis. (2 MARKS)

ii Plants contain the photosynthetic organelle chloroplasts, which share a number of similarities with mitochondria and prokaryotic cells. Identify two of these similarities. (2 MARKS)

d When an animal encounters a predator, it may choose to run away to escape. In doing so, its body quickly produces energy and its oxygen sources can be exhausted. When the body is low in oxygen, respiration can still occur and continue to release energy.

i Identify the type of respiration that occurs when the animal exhausts its oxygen supply. (1 MARK)

ii Identify two differences between the two respiration types in animals. (2 MARKS)

Question 13 (5 MARKS)

Methods to overcome mitochondrial diseases

Mitochondrial diseases occur when there is a problem in one of the 290 genes found in mitochondrial DNA (mtDNA), making the organelle dysfunctional. Symptoms of the disease may manifest at any age and can include poor growth, muscle weakness, problems with one or more organs, and neurological problems. Mitochondrial diseases are challenging for doctors to treat because we inherit our mtDNA from our mother. While some of her mitochondria may be functional, it is impossible for scientists to tell which egg cells contain these functional mitochondria. This means that if a mother has a mitochondrial disease, it is likely that she will pass the disorder onto her children.

Scientists have developed two approaches to prevent the inheritance of mitochondrial diseases. The first technique involves transferring the mother's nuclear DNA from one of her eggs into an enucleated donor egg with healthy mitochondria. Then, the eggs are fertilised with the father's sperm and developed into an embryo before selection and implantation in the mother's womb. The second approach first allows for the father's sperm to fertilise the mother's egg. The nucleus of the fertilised egg is then transferred to a healthy, enucleated donor egg, ending in implantation into the mother's womb. The first baby was born using these techniques in 2016.

a Identify and explain the difference between the two techniques of preventing the inheritance of mitochondrial diseases. (2 MARKS)

b These innovative techniques could have several consequences for potential parents looking at conceiving via these methods.

i Identify a potential benefit for parents of using donor mitochondrial DNA. (1 MARK)

ii Identify a potential concern parents may have about using donor mitochondrial DNA. (1 MARK)

c Some people consider these techniques 'unethical because babies born via this method have three parents'. Why are these babies said to have three parents? (1 MARK)

Key science skills

Question 14 (11 MARKS)

Yeast is a eukaryotic single-celled microorganism classified as a member of the fungi kingdom. Yeast are able to undergo aerobic and anaerobic cellular respiration. Two students, Brad and Riley, wanted to investigate aerobic respiration in yeast. They conducted an experiment where yeast cells were placed in an airtight container with a warm sugar solution, and left to sit for 15 minutes. The percentage levels of oxygen and carbon dioxide within the container were recorded. The results are summarised in the following table.

	Oxygen (%)	**Carbon dioxide (%)**
Initial percentage in container	22	2
Percentage in container after 10 minutes	18	8
Change in percentage	-4	+6

a Why was a sugar solution added to the yeast? (1 MARK)

b Why were the yeast placed in an airtight container? (2 MARKS)

c The concentration of both factors changed throughout the experiment.

i Explain the change in oxygen concentration. (2 MARKS)

ii Explain the change in carbon dioxide concentration. (2 MARKS)

d The students' teacher suggested they repeat their experiment and use more sophisticated measuring instruments.

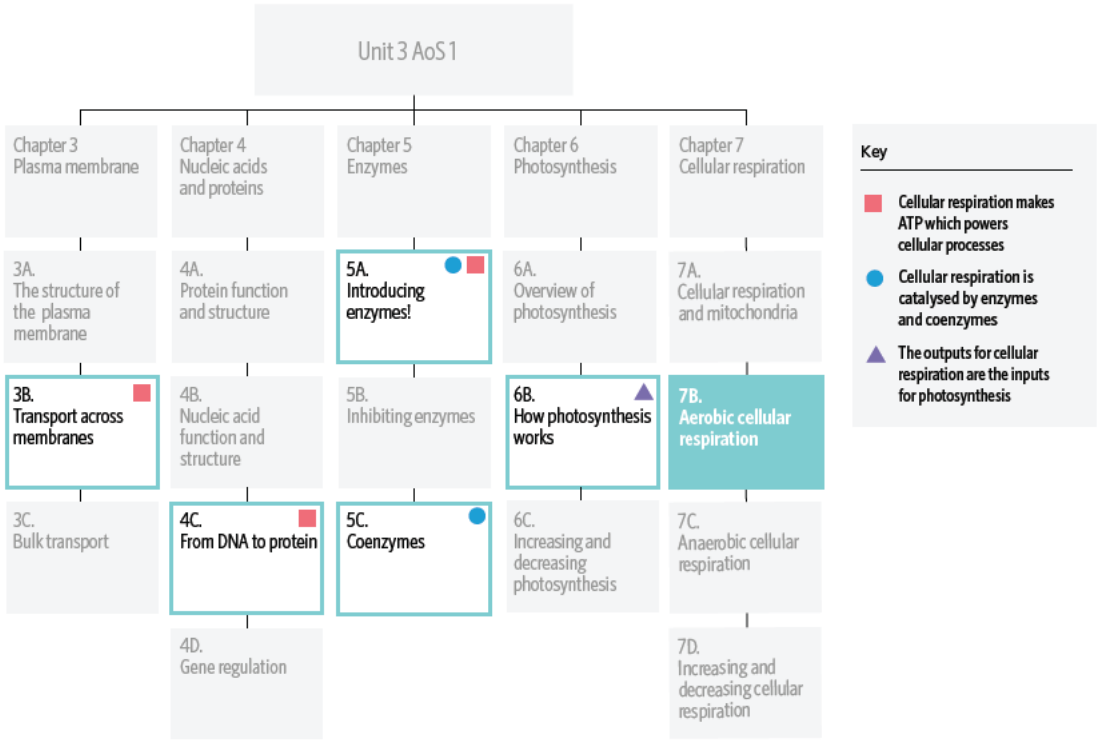
i How would repeating the experiment change the accuracy and precision of the students' results? (2 MARKS)

ii How would using more sophisticated measuring instruments change the accuracy and precision of the students' results? (2 MARKS)

Adapted from VCAA 2013 Section B Q1

7B AEROBIC CELLULAR RESPIRATION

Have you ever wondered exactly why humans breathe? And what makes oxygen so special? Time to find out.



In this lesson you will learn that there are three main stages in aerobic cellular respiration: glycolysis, the Krebs cycle, and the electron transport chain. In particular, for each of these three main stages, you need to know the location, inputs, and outputs.

Study design dot points

- the location of, and the inputs and outputs of, glycolysis including ATP yield (details of the biochemical pathway mechanisms are not required)
- the main inputs and outputs of the Krebs (citric acid) cycle and electron transport chain including ATP yield (details of the biochemical pathway mechanisms are not required)

Key knowledge units

Glycolysis	3.1.21.1
The Krebs cycle	3.1.23.1
The electron transport chain	3.1.23.2

Glycolysis 3.1.21.1

OVERVIEW

Glycolysis is the first of the three stages of aerobic respiration. It occurs in the cytosol and is where glucose breaks down into two pyruvate molecules, also creating two ATP and two NADH molecules in the process.

THEORY DETAILS

Purpose of glycolysis

Glycolysis is the first step in the whole process of aerobic respiration. A small amount of **ATP** is made in glycolysis, and this can be used to power cellular reactions. Importantly, the **pyruvate** and **NADH** will go on to help make even more ATP in the next two stages of aerobic respiration.

glycolysis the first stage of aerobic respiration in which glucose is split into two pyruvate molecules

ATP adenosine triphosphate, a high energy molecule that, when broken down, provides energy for cellular processes

pyruvate a three-carbon molecule which is formed from the splitting of glucose

NADH a coenzyme that is a proton (H^+) and electron carrier in cellular respiration

How glycolysis works

Table 1 The inputs and outputs of glycolysis

Glycolysis (location: cytosol)	
Inputs	**Outputs**
1 glucose ($C_6H_{12}O_6$)	2 pyruvate
2 ADP + P_i	2 ATP
2 NAD^+ + 2 H^+	2 NADH

Glycolysis occurs in the **cytosol** of the cell. During glycolysis, **glucose** (a six-carbon molecule) is broken down via 10 steps to form two pyruvate molecules (2 x three-carbon molecules).

When glucose is broken down into pyruvate, energy is released. This energy powers two key reactions:

- 2 ADP + 2 P_i → 2 ATP
  - The ATP is now free to power cellular reactions.
- 2 NAD^+ + 2 H^+ + 4 e^- → 2 NADH
  - The electrons (two per NADH) are often not written in this equation, but they are there.
  - The H^+ and electrons come from the breakdown of glucose.
  - The two NADH will be transported to the mitochondria, where each molecule will deliver protons and electrons to the **electron transport chain**, to help make more ATP.

The two pyruvate molecules will be transported to the mitochondria, where they will be broken down further in stage two of aerobic respiration: **the Krebs cycle**.

The Krebs cycle 3.1.23.1

OVERVIEW

The second stage of aerobic respiration is the Krebs cycle. It occurs in the matrix of mitochondria, and it produces four CO_2, two $FADH_2$, six NADH, and two ATP for every glucose molecule.

THEORY DETAILS

Purpose of the Krebs cycle

The purpose of the Krebs cycle is mostly to make lots of high-energy electron and proton carriers, NADH and **$FADH_2$**, which can be used in the electron transport chain. Small amounts of ATP are also produced.

The link reaction

To link glycolysis and the Krebs cycle, pyruvate is transported to the matrix of the mitochondria and converted into acetyl coenzyme A (**acetyl CoA**), a two-carbon molecule. The link reaction also releases carbon dioxide, a waste product that is exhaled, and makes NADH for the third stage of aerobic respiration.

How the Krebs cycle works

Table 2 The inputs and outputs of the Krebs cycle

The Krebs cycle (location: the matrix)	
Inputs	**Outputs**
2 acetyl CoA (derived from 2 pyruvate)	4 carbon dioxide (CO_2)
2 ADP + P_i	2 ATP
6 NAD^+ + 6 H^+	6 NADH
2 FAD + 4 H^+	2 $FADH_2$

The Krebs cycle is a series of eight reactions that break down acetyl CoA. You don't need to know any of the reactions for the exam, but you do need to know:

- By breaking down acetyl CoA, protons and high-energy electrons are released. These protons and electrons are loaded onto NAD^+ and FAD to generate high energy NADH and $FADH_2$.

Tip VCAA do not require you to remember the number of electron carriers used or produced in any cellular respiration reaction.

Figure 1 Summary of glycolysis, the first stage of aerobiccellular respiration

cytosol the aqueous fluid that surrounds the organelles inside the plasma membrane

glucose a six-carbon carbohydrate that comes from the food we eat

electron transport chain (ETC) the name for the third stage of respiration, it refers to a series of proteins embedded in the inner membrane of the mitochondria

the Krebs cycle the second stage of aerobic cellular respiration, where multiple reactions occur to create ATP and loaded NADH and $FADH_2$. Also known as **the citric acid** or **TCA cycle**

$FADH_2$ a proton and electron carrier created in the Krebs cycle

acetyl CoA the product of pyruvate oxidation that is an input into the Krebs cycle

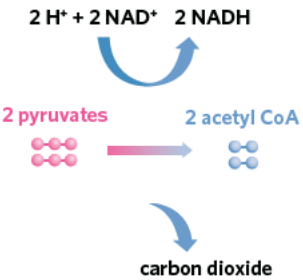


Figure 2 A summary of the link reaction

Tip VCE excludes the link reaction from exams and the study design, but in order to remember that acetyl CoA (not pyruvate) is an input for the Krebs cycle, you need to remember this small step.

- The Krebs cycle produces two ATP.
- The Krebs cycle produces two CO_2 molecules for every one acetyl CoA molecule, plus the one CO_2 molecule from the link reaction. This means a total of six CO_2 molecules are produced for every glucose molecule.

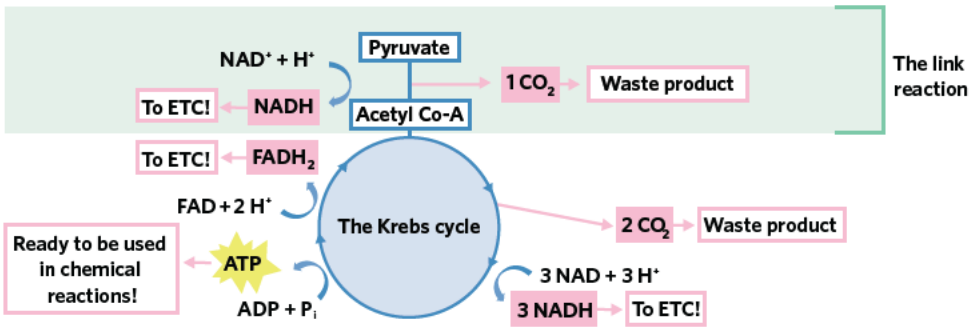


Figure 3 A summary of the Krebs cycle. Note that this occurs twice per glucose molecule, because 2 acetyl CoA molecules are made per glucose molecule.

Analogy

You can think of NADH and $FADH_2$ as waiters who run food and drinks at a restaurant. At the kitchen (glycolysis, the link reaction, and the Krebs cycle) they fill their trays up with food (high energy electrons and protons) then deliver it to tables (the electron transport chain). They also take empty plates (unloaded NAD^+ and FAD) back to the kitchen for reuse.

The electron transport chain 3.1.23.2

OVERVIEW

The electron transport chain, the third step of aerobic respiration, occurs on the inner membrane (or 'cristae') of the mitochondria. During this step, energy from electrons unloaded by NADH and $FADH_2$ generates a proton gradient that drives ATP production. ADP + P_i, NADH, $FADH_2$, and oxygen are inputs and 32 - 34 ATP, water, NAD^+, and FAD are the outputs.

THEORY DETAILS

Purpose of the electron transport chain

The electron transport chain is where the majority of ATP is produced in the process of aerobic respiration.

How the electron transport chain works

Table 3 The inputs and outputs of the electron transport chain

The electron transport chain (location: the cristae of the mitochondria)	
Inputs	**Outputs**
6 oxygen (O_2)	6 water (H_2O)
32 - 34 ADP + P_i	32 - 34 ATP
10 NADH	10 NAD^+ + 10 H^+
2 $FADH_2$	2 FAD + 4 H^+

For VCE Biology, the inputs, outputs, and the location of the electron transport chain are very important to know. Remembering them will be easier if you understand how the electron transport chain works. Here is a brief outline of the steps involved in making ATP at the electron transport chain:

1 NADH and $FADH_2$ unload electrons and protons at the first protein in the electron transport chain on the inner membrane of the mitochondria. The reactions NADH → $NAD^+ + H^+ + 2\ e^-$ and $FADH_2$ → FAD + 2 H^+ + 2 e^- take place.

2 The excited electrons (from NADH and $FADH_2$) power the active transport of protons from the mitochondrial matrix and into the narrow intermembrane space.

3 This leads to a build up of protons in the intermembrane space of the mitochondria. As this space is very narrow and small, the concentration quickly increases.

4 To move down their concentration gradient, they must travel through a protein channel - **ATPase**. As the protons travel through ATPase, they cause the enzyme to spin like a turbine. This kinetic energy powers the reaction ADP + P_i → ATP, which occurs in the matrix.

Tip VCAA will not assess you on these steps, they are here purely for a conceptual understanding. You only need to know the inputs, outputs, and location for each stage of aerobic respiration.

ATPase an enzyme in the inner mitochondrial membrane that uses the concentration gradient of H^+ to synthesise ATP from ADP and P_i

5 Large amounts of ATP are made this way, but there are many free protons and electrons building up in the matrix. Unbound protons and electrons can cause problems for cells in large concentrations - they can interfere with reactions, transport across membranes, and bonds. To prevent this from happening, oxygen binds with these protons and electrons to form water. Thus, one could say that the entire reason why humans breathe in oxygen is to mop up free protons and electrons at the end of the electron transport chain.

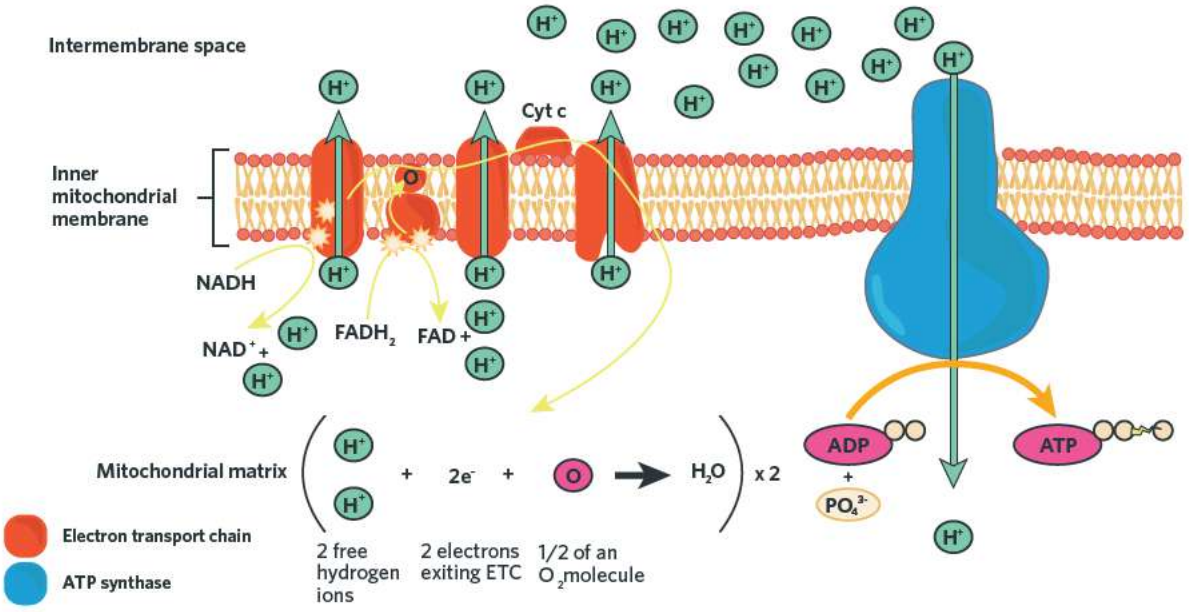


Figure 4 The electron transport chain

Case study

Occasionally, exam questions contain scenarios on poisons that inhibit enzymes in the electron transport chain. An example of this is cyanide, which irreversibly inhibits an enzyme called cytochrome c oxidase. It stops cytochrome c oxidase from being able to pass electrons along the electron transport chain, preventing an organism from being able to respire aerobically. The symptoms of cyanide poisoning are what you would expect of someone who does not have enough oxygen: dizziness, shortness of breath, fast heart rate, and eventually death.

Theory summary

Adding up the ATP molecules formed at each stage of aerobic respiration we find that for every molecule of glucose metabolised, 38 ATP molecules can be formed:

- two ATP from glycolysis
- two ATP from the Krebs cycle
- 32 - 34 ATP from the electron transport chain.

Note that a single glucose molecule could produce anywhere between 29 and 38 ATP. The process isn't perfect – there are losses in energy due to leaky membranes and inefficient reactions. 38 ATP is the total maximum yield.

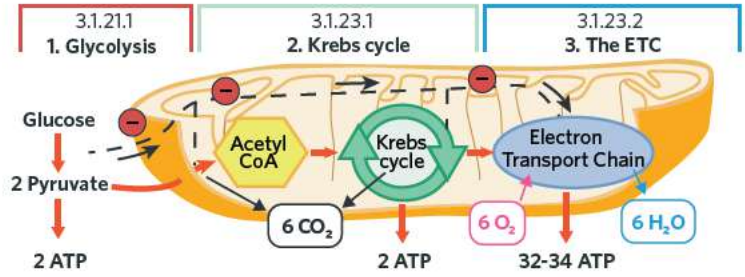


Figure 5 This diagram summarises the inputs and outputs of each stage of cellular aerobic respiration.

7B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ an organic three-carbon molecule involved in glycolysis

b _____ an uncharged electron carrier that is charged during glycolysis

c _____ the location in a cell where glycolysis takes place

d _____ the process where glucose is broken down into pyruvate

e _____ the location in a cell where pyruvate is converted to acetyl CoA

f _____ an organic two-carbon molecule involved in the Krebs cycle

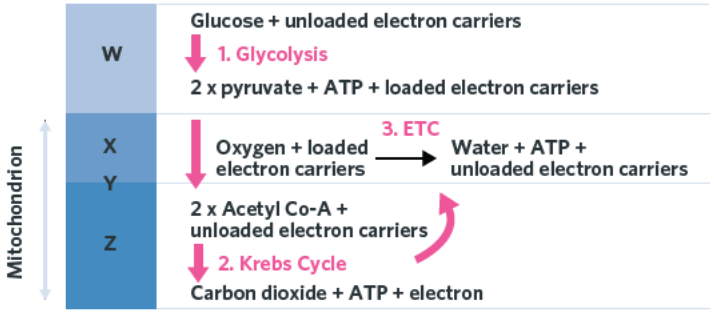
g _____ a charged coenzyme that carries two hydrogen ions

h _____ the location where NADH and $FADH_2$ are unloaded in the third stage of aerobic respiration

i _____ up to 38 of these molecules are produced per glucose molecule in aerobic respiration

Question 2

Which option correctly identifies the locations of the different stages in aerobic cellular respiration?



	W	X	Y	Z
A	intermembrane space	mitochondrial matrix	cristae	cytosol
B	cytosol	cristae	intermembrane space	mitochondrial matrix
C	mitochondrial matrix	intermembrane space	cristae	cytosol
D	cytosol	intermembrane space	cristae	mitochondrial matrix

Question 3

Which of the following options correctly lists the inputs of the reactions in aerobic cellular respiration?

	Glycolysis	Krebs cycle	Electron transport chain
A	glucose, ATP + P_i, NAD^+, H^+	acetyl CoA, NADH, FAD, ADP + P_i	O_2, NAD^+, $FADH_2$, ADP + P_i
B	glucose, ADP + P_i, NAD^+, H^+	acetyl CoA, CO_2, NAD^+, FAD, ADP + P_i	O_2, NADPH, $FADH_2$, ADP + P_i
C	glucose, ADP + P_i, NAD^+, H^+	acetyl CoA, NAD^+, FAD, ADP + P_i	O_2, NADH, $FADH_2$, ADP + P_i
D	glucose, ATP + P_i, NAD^+, H^+	acetyl CoA, NAD^+, FAD, ADP + P_i	O_2, NAD^+, FAD, H^+, ADP + P_i

Question 4

Which of the following options correctly lists the outputs of the reactions in aerobic cellular respiration?

	Glycolysis	Krebs cycle	Electron transport chain
A	pyruvate, ATP, NADH	NADH, $FADH_2$, CO_2, ATP	ATP, H_2O, NAD^+, FAD
B	glucose, ATP, NADH	NADH, $FADH_2$, CO_2, ATP	ATP, H_2O, NAD^+, FAD
C	pyruvate, ATP, NADH	NADH, $FADH_2$, CO_2, ATP	ATP, O_2
D	pyruvate, ADP, P_i, NADH	NADH, $FADH_2$, CO_2, ADP, P_i	ATP, H_2O, NAD^+, FAD

Question 5

The steps in aerobic cellular respiration are in the wrong order.

1 Energy is used to convert 2 ADP + P_i into 2 ATP molecules, and to bind protons (H^+) and electrons to NAD^+ to form NADH molecules.

2 The inputs of this stage are glucose, $NAD^+ + H^+$, and ADP + P_i.

3 In the next stage, energy is harvested in the form of high-energy electrons. NADH, $FADH_2$, and ATP are produced as a result, and carbon dioxide is a waste product.

4 Oxygen is used as the final electron and hydrogen ion acceptor, in a reaction which produces water.

5 Pyruvate (three carbon atoms) is converted to acetyl CoA (two carbon atoms), accompanied by the production of CO_2 (one carbon atom) and one NADH.

The correct order is

A 2, 5, 1, 3, 4

B 2, 5, 1, 4, 3

C 2, 1, 3, 5, 4

D 2, 1, 5, 3, 4

Exam-style questions

Within lesson

Question 6 (1 MARK)

Which of the following gives the inputs and outputs of the Krebs cycle in an animal cell?

	Inputs	Outputs
A	acetyl CoA, ATP, NAD^+, FAD	carbon dioxide, ADP, NADH, $FADH_2$, P_i
B	glucose, ADP, NAD^+, P_i	pyruvate, ATP, NADH
C	oxygen, ADP, $FADH_2$, NADH, P_i	water, ATP, FAD, NAD^+
D	acetyl CoA, ADP, NAD^+, FAD, P_i	carbon dioxide, ATP, NADH, $FADH_2$

Adapted from VCAA 2018 Section A Q9

Question 7 (1 MARK)

An animal cell culture was exposed to radioactively labelled oxygen. The cells were then monitored for three minutes. After this time, the radioactively labelled oxygen atoms would be present in the

A fatty acid tails in the inner membrane of the mitochondria.

B mitochondria as part of pyruvate molecules.

C water in the cytosol or in the matrix.
D atmosphere as carbon dioxide.

Question 8 (1 MARK)

During cellular respiration, fish use glucose

A in the glycolysis stage.
B to combine with carbon dioxide.
C to build up ATP molecules into ADP molecules.
D as the final acceptor of electrons and hydrogen ions.

Adapted from VCAA 2010 Exam 1 Section A Q18

Question 9 (1 MARK)

Rotenone is a chemical compound that is used as an insecticide and a piscicide (a substance that kills fish).

The rotenone molecule disrupts the electron transport chain in animal cells by interfering with one of the essential reactions within the electron transport chain.

After being exposed to rotenone

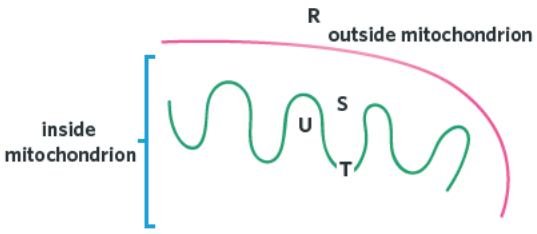
A glucose would accumulate in the cytosol.
B ATP would accumulate in the mitochondria.
C NAD^+ would accumulate in the mitochondria.
D NADH would accumulate in the mitochondria.

Adapted from VCAA 2015 Section A Q9

Multiple lessons

Question 10 (1 MARK)

The diagram shows a section through a part of a mitochondrion.



The structures depicted in the diagram are

A R – plasma membrane, S – outer membrane, T – inner membrane, U – intermembrane space.
B R – outer membrane, S – cytosol, T – cell membrane, U – cristae.
C R - cytosol, S - intermembrane space, T - cristae, U - matrix.
D R - cytosol, S - matrix, T - cristae, U - intermembrane space.

Adapted from VCAA 2018 Section A Q8

Question 11 (1 MARK)

ATP is a coenzyme.

Which one of the following is a correct statement about ATP?

A A large yield of ATP is produced in the electron transport chain.
B There is no ATP produced in the glycolysis stage of aerobic respiration.
C The Krebs cycle produces the greatest yield of ATP in aerobic respiration.
D ATP is responsible for carrying electrons and protons between reactions in cellular respiration.

Question 12 (1 MARK)

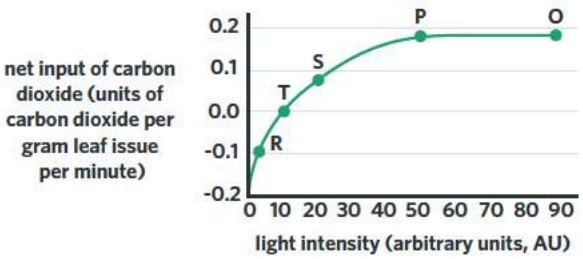
The process that produces the largest number of NADH molecules is

A translation.
B breakdown of glucose during glycolysis.
C the light-dependent reactions of photosynthesis.
D the electron transport chain in cellular respiration.

Adapted from VCAA 2012 Exam 1 Section A Q22

Question 13 (1 MARK)

The graph shows the net input of carbon dioxide in spinach leaves as light intensity is increased. Temperature is kept constant during the experiment.



Which one of the following conclusions can be made based on the graph?

A At point R photosynthesis is no longer occurring.

B Photosynthesis does not occur below a light intensity of 10 AU.

C At point S the level of light intensity for photosynthesis is optimal.

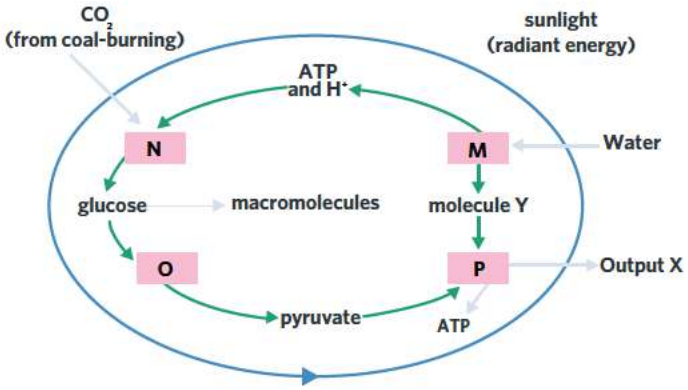
D At point T the rate of photosynthesis is equal to the rate of cellular respiration.

Adapted from VCAA Exam 2017 Section A Q13

Question 14 (5 MARKS)

Microalgae such as *Chlorella* can use greater amounts of carbon dioxide than land plants and they do not require prime soil, reliable rainfall, or a particular climate. *Chlorella* can be grown cheaply in existing or engineered ponds which are supplied with carbon dioxide from a coal-burning power station nearby.

The diagram represents a summary of the processes (labelled M, N, O, P) occurring in a *Chlorella* cell.



a Name output X and molecule Y (2 MARKS)

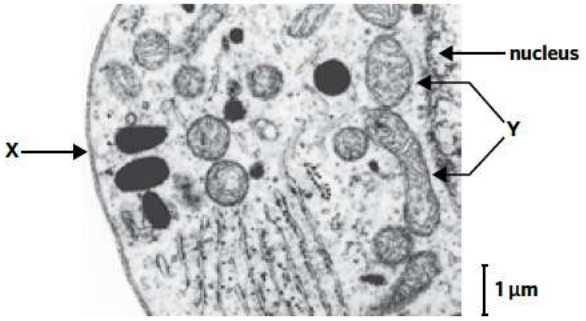
b With reference to the diagram, complete the following table. (3 MARKS)

Process	Name of process(es)	Site of process
M	Light-dependent reactions	
O		cytosol
P	Krebs cycle and electron transport chain	

Adapted from VCAA 2012 Exam 1 Section B Q8

Question 15 (5 MARKS)

The electron micrograph shows a portion of a cell.



a Name and describe the role of structure Y. (2 MARKS)

b Structure Y requires a supply of oxygen to undergo a metabolic reaction. Outline the process of how the oxygen molecules would enter the cell with reference to structure X. (2 MARKS)

c Researchers have discovered that cardiac muscle cells, found in the heart, contain a larger number of structure Y compared to other cells in the body. Suggest why cardiac muscle cells contain a large number of structure Y. (1 MARK)

Adapted from VCAA 2012 Exam 1 Section B Q1

Question 16 (8 MARKS)

Plants require ATP to complete many biochemical reactions.

a Identify the metabolic process that plants use to produce energy. (1 MARK)

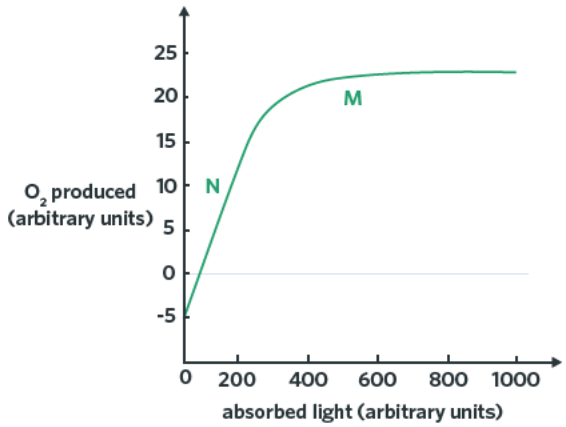
b State the worded equation for the aerobic production of energy. (1 MARK)

c In the presence of oxygen, the metabolic process to produce energy has three stages.

i Name and state the location for the first stage of this process. (1 MARK)

ii Name and state the location for the stage that requires oxygen as an input. (1 MARK)

d The graph shows the rate of oxygen exchange between a plant and its external environment as light intensity is altered. All other variables are kept constant throughout the experiment.



i With reference to metabolic processes, explain what is occurring when the oxygen produced is zero. (1 MARK)

ii Identify which metabolic pathway is dominant at point N. Justify your response. (2 MARKS)

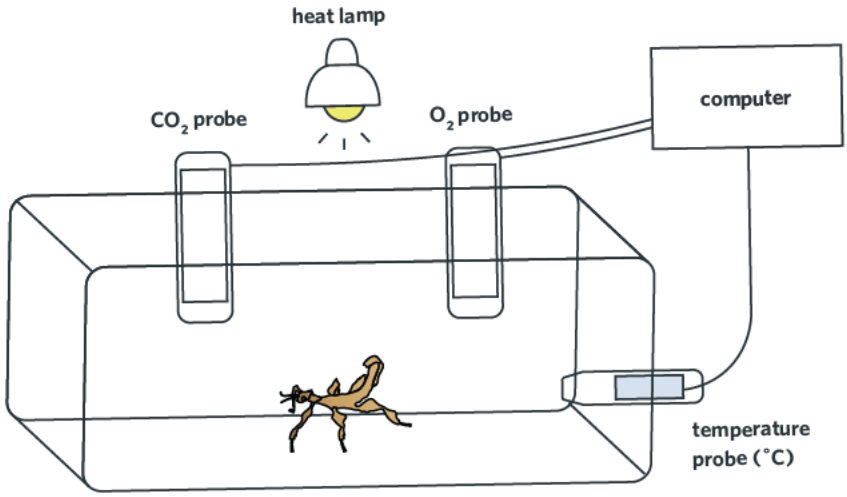
iii At point M, the graph begins to plateau. Explain why this occurs. (1 MARK)

Adapted from VCAA 2011 Exam 1 Section B Q7di

Key science skills

Question 17 (6 MARKS)

Duncan investigated how changes in environmental temperature affect oxygen and carbon dioxide levels in the air around a spiny stick insect. He used three digital probes linked to a computer, a closed animal chamber, and a heat lamp in the experimental set-up shown.



a Identify the independent and dependent variables. (2 MARKS)

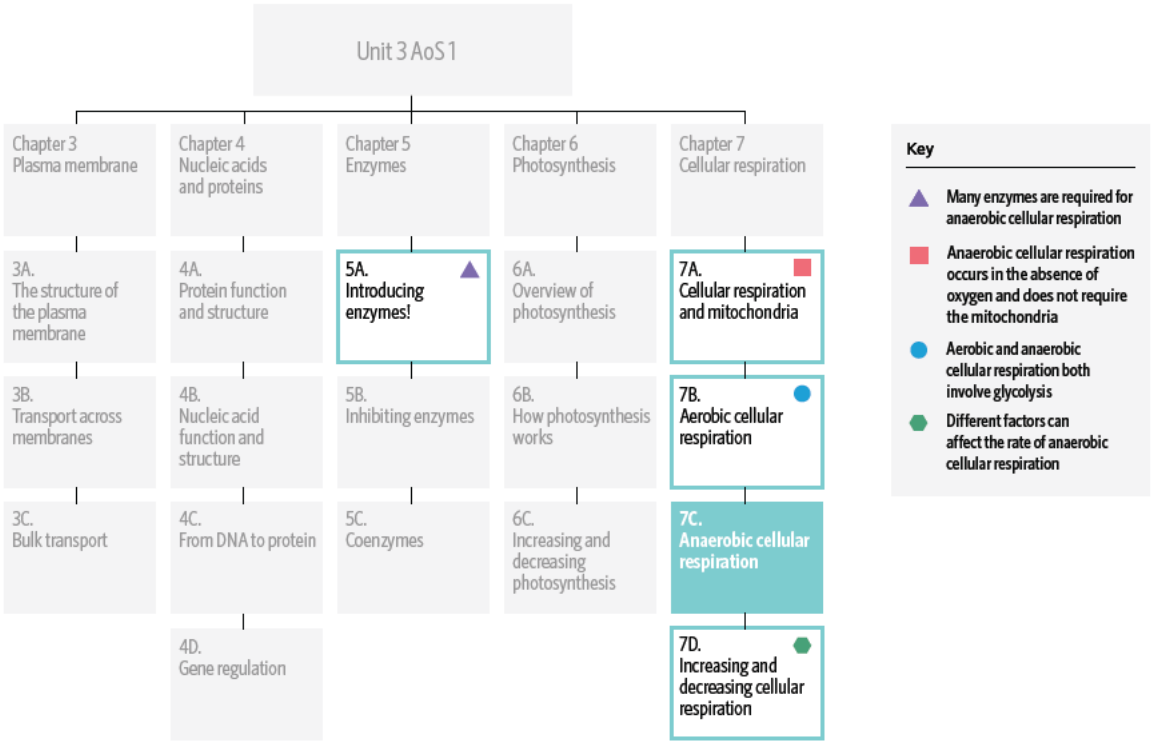
b With reference to the inputs and outputs of aerobic cellular respiration, explain why Duncan is measuring the levels of oxygen and carbon dioxide. (3 MARKS)

c Duncan tried the experiment again with a different temperature probe. He found that his results were different as the temperature probes produced results that were 2 °C higher. Identify what type of error this is. (1 MARK)

Adapted from VCAA 2017 Section B Q11

7C ANAEROBIC CELLULAR RESPIRATION

If humans anaerobically respired the same way as yeast, we'd get drunk every time we exercised.



In this lesson you will learn about anaerobic cellular respiration, a type of cellular respiration that occurs in the absence of oxygen. In particular, you will compare anaerobic cellular respiration in animals and yeast.

Study design dot point

- the location of anaerobic cellular respiration, its inputs, and the difference in outputs between animals and yeasts including ATP yield

Key knowledge units

How anaerobic cellular respiration works	3.1.24.1
Anaerobic cellular respiration in animals	3.1.24.2
Anaerobic cellular respiration in yeast and plants	3.1.24.3

How anaerobic cellular respiration works 3.1.24.1

OVERVIEW

Aerobic cellular respiration cannot occur without oxygen, whereas anaerobic cellular respiration occurs exclusively in oxygen-deprived conditions. Therefore, when oxygen availability is low, cells will rely on the process of anaerobic cellular respiration to make ATP.

lesson link In ***7B*** you covered the three steps of aerobic cellular respiration; glycolysis, the Krebs cycle, and the electron transport chain.

THEORY DETAILS

The final stage of aerobic respiration, the electron transport chain, requires oxygen to accept free protons and electrons to form water. In the absence of oxygen, the electron transport chain cannot be completed. Consequently, the loaded carriers NADH and $FADH_2$ cannot be converted into NAD^+ and FAD, which are required inputs for the Krebs cycle. Without these unloaded carriers, the Krebs cycle cannot begin. Therefore, no ATP is produced from the Krebs cycle and electron transport chain, and aerobic cellular respiration is stopped.

lesson link In ***5C*** you learned about the coenzymes NADH and ATP.

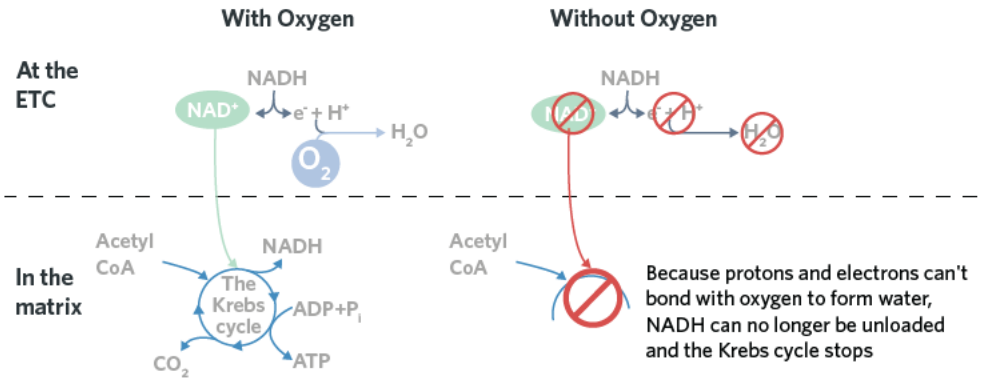


Figure 1 Effect on the ETC with and without oxygen present

Despite this, the cell still needs energy to survive. While it doesn't generate as much ATP as aerobic cellular respiration, living things can live off the energy from **anaerobic cellular respiration**, also known as fermentation.

As humans, we can respire both aerobically and anaerobically, however some small eukaryotes and bacteria only respire anaerobically. These organisms are known as obligate anaerobes.

Anaerobic cellular respiration works by ensuring glycolysis, which produces two ATP, can continue indefinitely. You should remember that glycolysis requires two NAD^+ and two ADP as inputs. Through this process, two pyruvate, two ATP, and two NADH are produced per glucose molecule. For glycolysis to start again, the cell must find a way to convert NADH back to NAD^+ without the use of oxygen. Animals and **yeast** have developed two different mechanisms to cycle NADH.

anaerobic cellular respiration cellular respiration that occurs in the absence of oxygen. It involves glycolysis, followed by further reactions that convert pyruvate into lactic acid, or ethanol and carbon dioxide. Also known as **fermentation**

yeast unicellular eukaryotic organisms from the kingdom Fungi

Tip Discussing why aerobic cellular respiration cannot progress in anaerobic conditions, as well as why anaerobic cellular respiration includes stages after glycolysis, helps us to better understand the processes of aerobic and anaerobic cellular respiration. However, it is unlikely that VCAA will expect you to discuss either process to this depth.

Anaerobic cellular respiration in animals 3.1.24.2

OVERVIEW

Anaerobic cellular respiration in animals produces ATP by converting glucose into lactic acid.

THEORY DETAILS

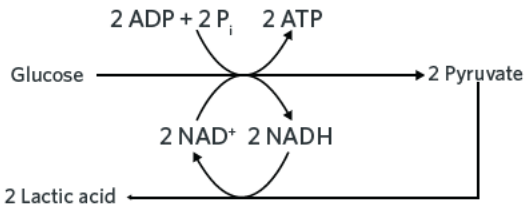


Figure 2 Lactic acid fermentation in animals

When oxygen is insufficient, such as when working at high intensities, animals undertake **lactic acid fermentation**. This process breaks down pyruvate into **lactic acid**, and cycles NADH back with NAD^+ for reuse in glycolysis.

Lactic acid cannot accumulate indefinitely, as it lowers the pH of our cells and our blood and can be toxic in high amounts. To deal with this, lactic acid is metabolised back into pyruvate when oxygen is present. The pyruvate can then be used for aerobic cellular respiration.

lactic acid fermentation anaerobic cellular respiration in animals that involves glucose being broken down into pyruvate during glycolysis, followed by a conversion into lactic acid

lactic acid the product of anaerobic cellular respiration in animals

Case study

You'll notice that your cells have been respiring anaerobically when you have that heavy feeling in your muscles after intense bursts of activity – this is an indication of the presence of lactic acid. Sprinters, for example, need to produce large amounts of ATP in a short span of time. Their muscle cells rapidly use up all the oxygen that is supplied to them. Once there is no oxygen left, the muscle cells rely on anaerobic cellular respiration to produce the ATP needed for powerful movements.

Anaerobic cellular respiration in yeast and plants 3.1.24.3

OVERVIEW

Anaerobic cellular respiration in yeast, bacteria, and plants produces ATP by converting glucose into ethanol and carbon dioxide.

THEORY DETAILS

Anaerobic cellular respiration in yeast, bacteria, and plants involves slightly different mechanisms to anaerobic cellular respiration in animal cells. In yeast, bacteria, and plants pyruvate is converted into **ethanol** and carbon dioxide. NAD^+ is also replenished in this process (Figure 3).

ethanol an alcohol that is produced along with carbon dioxide during anaerobic cellular respiration in yeast, bacteria, and plants

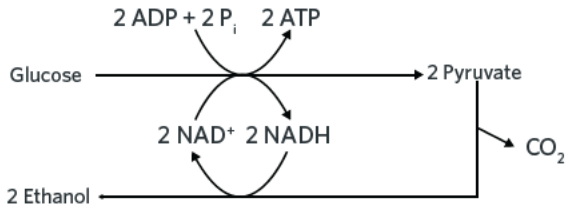


Figure 3 Fermentation in yeast, bacteria, and plants

Ethanol cannot be metabolised in yeast or plants. Instead, it diffuses out of cells, but can eventually accumulate to toxic levels.

Tip VCAA commonly test students on identifying the product of anaerobic cellular respiration given a particular cell type. For anaerobic cellular respiration in animal cells, VCAA will accept either lactic acid or lactate as the product. However, for yeast, bacteria, or plant cells, you must identify both ethanol and carbon dioxide as products.

Theory summary

It is useful for us to compare aerobic and anaerobic cellular respiration. Aerobic respiration is much more efficient at producing ATP from glucose, with around 36-38 ATP per glucose molecule. Anaerobic cellular respiration only produces 2 ATP per glucose molecule.

Conversely, anaerobic cellular respiration can produce ATP much faster than aerobic cellular respiration. This is because glycolysis occurs faster than either the Krebs cycle or the electron transport chain.

Some other key differences are listed in Table 1.

Tip VCAA commonly test students on differences between aerobic and anaerobic cellular respiration.

Table 1 Key differences between aerobic and anaerobic cellular respiration

	Aerobic	Anaerobic
Location	cytosol and mitochondria	cytosol only
Inputs	glucose and oxygen	glucose
Outputs	carbon dioxide and water	lactic acid (animals) or ethanol and carbon dioxide (yeast, bacteria, and plants)
Efficiency	36-38 ATP per glucose molecule	2 ATP per glucose molecule
Speed	slow	fast
Sustainability	can sustain indefinitely	cannot sustain indefinitely due to the build-up of lactic acid or ethanol which can be toxic

7C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ an alcohol that is produced during fermentation in bacteria
b _____ a unicellular eukaryotic fungi that can anaerobically respire to produce carbon dioxide
c _____ the product of fermentation in animal cells
d _____ cellular respiration that occurs in oxygen deprived environments
e _____ fermentation that occurs specifically in animal cells

Question 2

Which of the following options correctly identifies the products of anaerobic cellular respiration in animal and yeast cells?

	Animal	Yeast
A	lactic acid	ethanol, carbon dioxide
B	ethanol, carbon dioxide	lactic acid
C	lactic acid	ethanol
D	ethanol	lactic acid, carbon dioxide

Question 3

Which of the following options correctly compares the ATP yield of aerobic and anaerobic cellular respiration?

	Aerobic	Anaerobic
A	36 - 38 ATP	36 - 38 ATP
B	2 ATP	36 - 38 ATP
C	36 - 38 ATP	2 ATP
D	2 ATP	2 ATP

Question 4

Which of the following options correctly compares the location of aerobic and anaerobic cellular respiration?

	Aerobic	Anaerobic
A	Cytosol	Cytosol
B	Cytosol	Mitochondria
C	Cytosol and mitochondria	Chloroplast
D	Cytosol and mitochondria	Cytosol

Exam-style questions

Within lesson

Question 5 (1 MARK)

Consider the production of ATP molecules in a eukaryotic cell in the absence of oxygen.

The majority of ATP molecules are produced

A during glycolysis.
B in the Krebs cycle.
C in the electron transport chain.
D in the intermediate stage between glycolysis and the Krebs cycle.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q3

Question 6 (1 MARK)

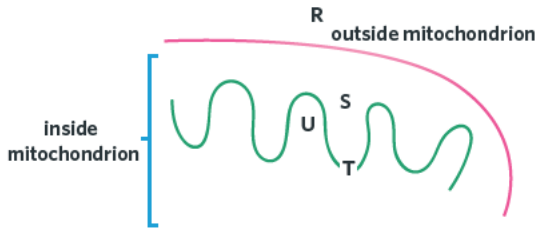
Which of the following is an output of anaerobic respiration in an animal cell?

A glucose
B pyruvate
C lactic acid
D carbon dioxide

Adapted from VCAA 2018 Section A Q9

Question 7 (1 MARK)

The diagram shows a section through part of a mitochondrion.



The ATP from anaerobic cellular respiration is produced at location

A R.
B S.
C T.
D U.

Adapted from VCAA 2018 Section A Q8

Question 8 (1 MARK)

During anaerobic cellular respiration in cells, glucose is broken down into pyruvate. Pyruvate is then converted into other products to regenerate NAD^+. Anaerobic cellular respiration occurs

A on the inner mitochondrial membrane and produces two ATP per glucose molecule.
B on the surface of the outer mitochondrial membrane.
C in the cytosol and cannot be sustained indefinitely.
D in the matrix of mitochondria.

Adapted from VCAA 2014 Section A Q7

Question 9 (1 MARK)

Which of the following is not true of glycolysis?

A It produces loaded carriers that can be unloaded in later stages of aerobic respiration.
B It is a common stage in both aerobic and anaerobic cellular respiration.
C It produces less ATP than the electron transport chain.
D Pyruvate is an input and lactic acid is an output.

Adapted from VCAA 2017 Sample Exam Section A Q13

Question 10 (1 MARK)

Which one of the following statements about anaerobic cellular respiration in plant cells is incorrect?

A Anaerobic cellular respiration in plants produces only ethanol.

B Anaerobic cellular respiration cannot be indefinitely sustained.

C The cytosol is the site of glycolysis and produces 2 ATP per glucose molecule.

D Anaerobic cellular respiration is less efficient than aerobic respiration as it produces fewer ATP per glucose molecule.

Multiple lessons

Question 11 (1 MARK)

The reaction ADP + P_i → ATP

A occurs in cellular respiration and not in photosynthesis.

B does not occur in plants when no oxygen is present.

C requires energy to occur.

D is irreversible.

Adapted from VCAA 2011 Exam 1 Section A Q20

Question 12 (1 MARK)

Aerobic and anaerobic cellular respiration both involve

A the loaded carriers NADH and $FADH_2$.

B the production of ADP from ATP and P_i.

C chemical reactions that occur in the cytosol.

D the use of a proton gradient during the electron transport chain.

Question 13 (1 MARK)

A student was asked to identify differences between the overall processes of aerobic and anaerobic cellular respiration in eukaryotic cells. The student prepared the table to outline the differences.

The only incorrect comparison listed by the student is

	Aerobic respiration	Anaerobic cellular respiration
A	more efficient	less efficient
B	faster	slower
C	involves glycolysis, the Krebs cycle, and the electron transport chain	involves glycolysis
D	can be sustained indefinitely	cannot be sustained indefinitely

Adapted from VCAA 2007 Exam 1 Section A Q7

Question 14 (7 MARKS)

The smoke produced during a house fire is usually more dangerous than the fire itself. Two of the many toxic chemicals in the smoke from a house fire are carbon monoxide and hydrogen cyanide. Carbon monoxide molecules bind to haemoglobin molecules in the blood, which reduces the blood's capacity to transport oxygen. This causes a significant reduction in oxygen supply to the cells of the body. Symptoms of carbon monoxide poisoning include dizziness, drowsiness, and nausea.

a Name and describe the process by which a cell produces ATP in the absence of oxygen, with reference to the product/s. (2 MARKS)

b Carbon monoxide poisoning can be treated by inhaling close to pure oxygen.

i State and explain carbon monoxide's mode of inhibition. (2 MARKS)

ii Name and describe the different stages of cellular respiration when cells are exposed to normal oxygen levels. (3 MARKS)

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q4

Key science skills

Question 15 (9 MARKS)

Kombucha tea has risen in popularity within the last decade, with increased levels of commercial and recreational brewing. The drink is often consumed for its supposed health benefits. These include claims for treating AIDS, aging, anorexia, cancer, and diabetes. However, there is yet to be concrete scientific evidence to support these claims.

Kombucha is a fermented drink that is made from sweetened tea and a symbiotic culture of bacteria and yeast (SCOBY). Part of the health claims come from probiotic bacteria that can be added in the culture during the brewing process.

During the brewing process, the yeast in the SCOBY is responsible for fermenting the glucose present within the tea.

a Name the product/s produced by yeast during the fermentation process. (1 MARK)

Adapted from VCAA 2016 Section B Q2b

b Explain the importance of fermentation in yeast cells. (1 MARK)

Adapted from VCAA 2016 Section B Q2a

c Give one similarity and one difference between aerobic cellular respiration and anaerobic cellular respiration. (2 MARKS)

d The SCOBY can contain several different species of bacteria. The culture almost always includes the particular bacterial strain, *Komagataeibacter xylinus. K. xylinus* can convert the product of yeast fermentation into acetic acid. This gives Kombucha the sour taste. A group of scientists hypothesised that *K. xylinus* is an obligate anaerobe, meaning that it can only live in an environment with little to no oxygen. They performed an experiment to test this hypothesis, and the experiment included the manipulation of oxygen content surrounding an agar plate.

i State the independent and dependent variables in this experiment. (2 MARKS)

Adapted from VCAA 2018 Section B Q11c

ii Assuming their hypothesis is proven correct, describe an environment in which this bacteria would thrive. (1 MARK)

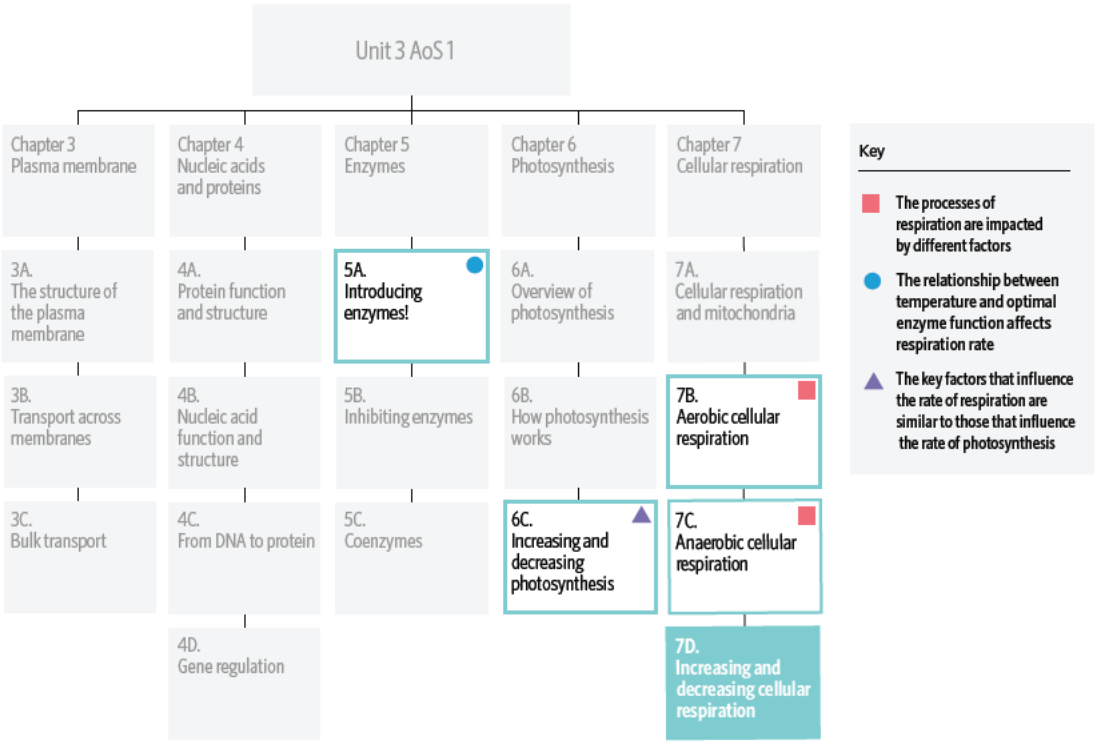
iii In the experiment, the samples were not labelled. What type of error is this? (1 MARK)

iv Describe the results that would support the hypothesis. (1 MARK)

Adapted from VCAA 2016 Section B Q2

7D INCREASING AND DECREASING CELLULAR RESPIRATION

Breaking down all the extra glucose we consume in the form of Woolies chocolate mud cakes can happen at different rates as factors change.



In this lesson you will learn that the availability of glucose, the concentration of oxygen, and the environmental temperature all affect the rate of cellular respiration.

Study design dot point

- factors that affect the rate of cellular respiration, including temperature, glucose availability, and oxygen concentration

Key knowledge units

Effect of glucose availability on cellular respiration	3.1.25.1
Effect of oxygen concentration on aerobic cellular respiration	3.1.25.2
Effect of temperature on cellular respiration	3.1.25.3

Effect of glucose availability on cellular respiration 3.1.25.1

OVERVIEW

Eat your breakfast, kids. Having more breakfast means more glucose is consumed, and there is more raw material available for cellular respiration. Increasing glucose availability increases the rate of cellular respiration until the maximum rate of cellular respiration is reached.

THEORY DETAILS

The availability of glucose impacts the rate at which plants and animals can undergo respiration. When looking at the simplified equations for aerobic and anaerobic respiration this makes perfect sense as glucose is the key input in both respiration pathways.

lesson link Just like photosynthesis in ***lesson 6C***, the rate of the cellular respiration processes are impacted by several key factors.

aerobic respiration

glucose + oxygen ⟶ carbon dioxide + water + energy

anaerobic respiration (in animals)

glucose ⟶ lactic acid + energy

Figure 1 The simplified respiration equations in humans show why glucose availability influences respiration rate.

lesson link Enzymes and enzyme-catalysed reactions are covered in ***lesson 5A.***

Glucose is used in the first stage of respiration, glycolysis, meaning that its concentration determines the rate at which glycolysis can proceed. Furthermore, as every subsequent reaction in respiration is dependent on the completion of glycolysis, the availability of glucose dictates the rate of respiration as a whole. Also, because glucose is the input in both aerobic and aerobic respiration, its availability impacts the rate of both of these processes. The more glucose is present, the faster a cell can produce **ATP** through cellular respiration.

Assuming oxygen is unlimited, increasing glucose will increase respiration rate until a maximum level is reached. Similar to photosynthesis, this maximum is reached when the enzymes within the cells are operating at their maximum capacity.

ATP adenosine triphosphate, a high energy molecule that, when broken down, provides energy for cellular processes

electron transport chain (ETC) the name of the third stage of respiration, it refers to a series of proteins embedded in the inner membrane of the mitochondria

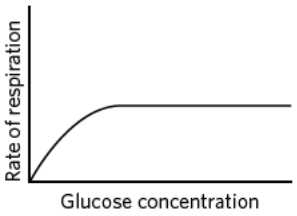


Figure 2 With unlimited oxygen, respiration rate increases with glucose to a point.

Tip In the past, VCAA have not tested the rate of respiration in graph-based questions like they have for photosynthesis. However, you are required to know how both photosynthesis and respiration impact each other.

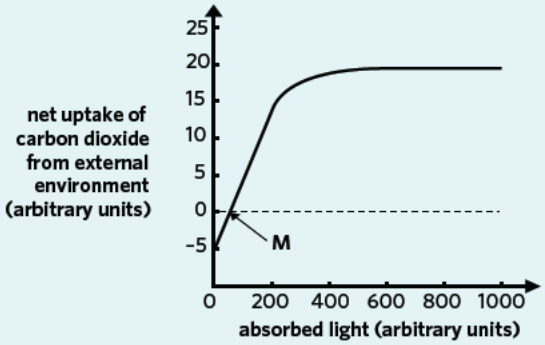


Figure 3 An excerpt from the VCE Biology 2017 Sample Exam

Take, for example, this question from VCE Biology 2017 Sample Exam Section A Q14. The questions relating to this graph ask when photosynthesis is occurring, about the rate of photosynthesis at point M, and why the graph plateaus. However, this question involves cellular respiration too, as you can see that the y-axis measures 'net uptake of carbon dioxide'.

The graph shows that increasing light absorption increases CO_2 uptake due to photosynthesis until about 300 AU. At point M there is no net uptake of CO_2; however, this does not mean that photosynthesis is not occurring. If the rate of CO_2 production (from respiration) is equal to the rate of CO_2 consumption (from photosynthesis), then the net uptake of CO_2 is zero. Above point M, the photosynthesis rate is greater than respiration, and below point M the respiration rate is greater than the photosynthesis rate.

Effect of oxygen concentration on aerobic cellular respiration 3.1.25.2

OVERVIEW

Increasing oxygen concentration increases the rate of aerobic respiration, as it is an input in the reaction.

THEORY DETAILS

Aerobic respiration requires a constant supply of oxygen for the **electron transport chain** to function. Therefore, the level of oxygen present affects the rate of aerobic cellular respiration. Oxygen is not an input to anaerobic respiration, however, and therefore the amount of oxygen only influences aerobic respiration.

As oxygen levels rise, the aerobic respiration rate increases. Therefore, more oxygen results in faster ATP production. At a certain point, assuming unlimited glucose, adding more oxygen does not increase the rate of respiration, as the enzymes involved in the process are working at their maximum.

When oxygen is in short supply, cells may instead undergo anaerobic respiration. This allows them to acquire a quick supply of ATP, but at a lower efficiency compared to aerobic respiration.

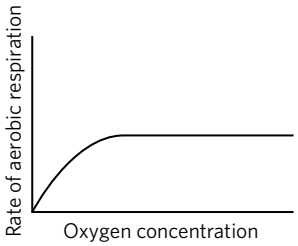


Figure 4 With unlimited glucose, aerobic respiration rate increases with oxygen up to a point.

Effect of temperature on cellular respiration 3.1.25.3

OVERVIEW

Given that enzymes are essential to cellular respiration, temperature has a large effect on respiration rate.

THEORY DETAILS

The temperature of an organism impacts the rate of cellular respiration. As you learned in previous lessons, enzymes catalyse many of the steps in both aerobic and anaerobic respiration processes. Enzymes have an **optimal** temperature for functioning. At the optimal, the enzyme-catalysed reactions occur at the greatest rate. As a result of this, respiration rate and ATP production are greatest when the temperature aligns with the enzyme's optimal temperature.

optimal the point at which, for a given condition (e.g. temperature), the maximum function of an enzyme occurs

denature to irreversibly change a protein's tertiary structure

Below the optimal temperature, respiration rate is slower as individual molecules have lower kinetic energy causing fewer collisions between the enzyme and substrate. Above the optimal, enzymes begin to **denature** and respiration rate drops significantly due to the loss of enzyme function.

The temperature range within which an organism can respire is different for each kind of organism. However, every organism's peak respiration rate and ATP production occurs when the temperature matches their enzyme's optimal temperature.

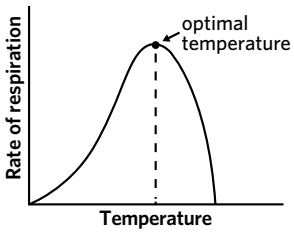


Figure 5 The effect of temperature on cellular respiration rate

Theory summary

The rate of cellular respiration is greatest when both the glucose and oxygen levels are unlimited, and the temperature matches the enzyme's optimal temperature.

Table 1 Summary of factors impacting cellular respiration rate

	Glucose availability	Oxygen concentration	Temperature
Type of cellular respiration affected	Both aerobic and anaerobic respiration	Aerobic respiration	Both aerobic and anaerobic respiration
Increasing the factor	More glucose → increased respiration rate. This increase is limited by enzyme availability	More oxygen → increased respiration rate. This increase is limited by enzyme availability	Respiration rate is highest at the optimal temperature of the enzymes involved in respiration. Above the optimal, enzymes may denature
Decreasing the factor	Less glucose → decreased respiration rate	Less oxygen → decreased aerobic respiration rate. Cell may still undergo anaerobic respiration	Decreases rate when below optimal due to fewer enzyme-substrate collisions.

7D QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the temperature where the most enzyme-catalysed reactions occur

b _____ molecule produced in glycolysis and the ETC that stores a large amount of energy

c _____ an irreversible change in an enzyme's active site caused by extremely high temperatures

d _____ the stage in aerobic respiration that is dependent on oxygen molecules

Question 2

Which of the following are all true regarding the rate of cellular respiration?

A	Typically increases as glucose increases	Aerobic respiration rate is dependent on oxygen concentration	Anaerobic respiration rate generally decreases as oxygen concentration increases	Eventually reaches a maximum rate with increasing amounts of glucose and unlimited oxygen
B	Typically increases as glucose increases	Aerobic respiration rate is dependent on carbon dioxide concentration	Anaerobic respiration rate generally decreases as oxygen concentration increases	Eventually reaches a maximum rate with increasing amounts of glucose and unlimited oxygen
C	Typically decreases as glucose increases	Aerobic respiration rate is dependent on carbon dioxide concentration	Anaerobic respiration rate generally increases as oxygen concentration increases	A maximum rate can never be reached
D	Typically increases as glucose increases	Aerobic respiration rate is dependent on oxygen concentration	Anaerobic respiration rate generally increases as oxygen concentration increases	Eventually reaches a maximum rate with increasing amounts of glucose and unlimited oxygen

Question 3

Fill in the blanks in the following sentences.

The rate of aerobic respiration is dependent on glucose availability, oxygen concentration, and _____**I**____. Without a large supply of _____**II**____, a cell may undergo anaerobic respiration instead. The key input in both respiration types is _____**III**____, which is broken down to create energy in the form of _____**IV**____.

	I	**II**	**III**	**IV**
A	temperature	oxygen	glucose	water
B	temperature	carbon dioxide	water	ADP
C	temperature	oxygen	glucose	ATP
D	carbon dioxide concentration	oxygen	water	glucose

Question 4

Which of the following are all true regarding temperature and cellular respiration rate?

A	Only affects aerobic respiration rate	Below the optimal temperature, rate increases as temperature increases	Above the optimal temperature, rate decreases as temperature increases	The optimal temperature for respiration rate is twice the enzymes' optimal temperature
B	Affects both aerobic and anaerobic respiration rate	Below the optimal temperature, rate increases as temperature increases	Above the optimal temperature, rate increases as temperature increases	The optimal temperature for respiration rate aligns with the enzymes' optimal temperature
C	Only affects aerobic respiration rate	Below the optimal temperature, rate decreases as temperature increases	Above the optimal temperature, rate increases as temperature increases	The optimal temperature for respiration rate is half the enzymes' optimal temperature
D	Affects both aerobic and anaerobic respiration rate	Below the optimal temperature, rate increases as temperature increases	Above the optimal temperature, rate decreases as temperature increases	The optimal temperature for respiration rate aligns with the enzymes' optimal temperature

Question 5

Classify each of the following statements about respiration rate as either relating to temperature, glucose availability, or oxygen concentration. NOTE: each statement can be classified into multiple groups.

1 influences aerobic respiration rate

2 can be seen in both respiration equations

3 an increase can denature enzymes

4 is an input in anaerobic respiration

5 a continued increase can result in a maximum respiration rate being reached

6 is key to the ETC functioning in respiration

7 directly influences anaerobic respiration rate

8 a decrease in this factor typically decreases aerobic respiration rate

9 is an input in aerobic respiration

	Temperature	Glucose	O_2
A	1, 3, 7, 8	1, 2, 4, 5, 7, 8, 9	1, 5, 6, 8, 9
B	1, 3, 5, 7, 8	1, 2, 4, 6, 7, 9	2, 5, 6, 9
C	1, 3, 7, 8	1, 2, 4, 5, 7, 9	1, 5, 7, 8, 9
D	1, 3, 5, 7	1, 2, 3, 4, 6, 8, 9	1, 2, 5, 6, 7

Exam-style questions

Within lesson

Question 6 (1 MARK)

Muscle cells in the heart contract and relax more rapidly during exercise and require a constant supply of energy. Heart muscle cells can increase their rate of cellular respiration by

A increasing carbon dioxide supply.

B increasing oxygen concentration.

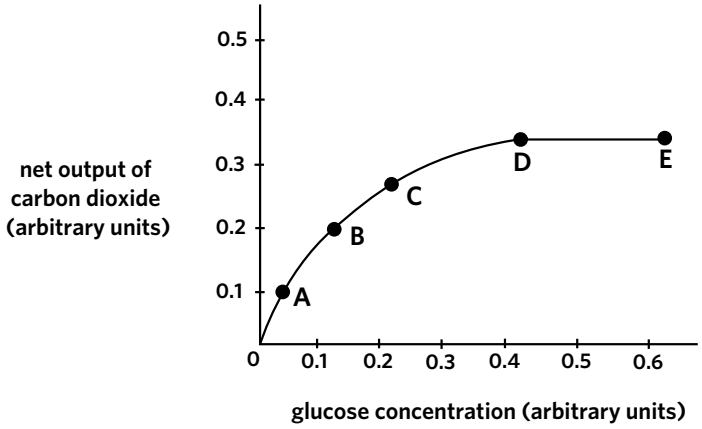
C increasing water concentration.

D increasing pH above 7.2.

Adapted from VCAA 2014 Section B Q3c

Use the following information to answer Questions 7 and 8.

The graph shows the net output of carbon dioxide from yeast as glucose concentration is increased. Temperature is kept constant during the experiment.



Question 7 (1 MARK)

Which one of the following conclusions can be made based on the graph?

A At point E, cellular respiration is no longer occurring.

B The optimal level of glucose concentration is 0.3 arbitrary units.

C At point A, the amount of carbon dioxide output is half of maximum.

D Below 0.2 arbitrary units of glucose concentration, enzymes involved in cellular respiration are not saturated.

Adapted from VCAA 2017 Section A Q13

Question 8 (1 MARK)

The rate of carbon dioxide output remains constant between points D and E. This may be because

A there is another metabolic reaction that uses up the carbon dioxide produced.

B the concentration of carbon dioxide increases the rate of cellular respiration.

C glucose competitively inhibits enzymes involved in the Krebs cycle.

D the enzymes involved in cellular respiration are saturated.

Adapted from VCAA 2017 Section A Q14

Question 9 (1 MARK)

A group of students noticed bubbles forming on the submerged leaves of an aquatic plant growing in a tank. The bubbles seen on the leaves were the result of a gas formed within the cells of the leaves. The aquarium was in the dark the entire time.

The rate of formation of these bubbles could be increased by

A increasing the amount of dissolved glucose in the tank.

B decreasing the number of leaves in the tank.

C increasing the amount of water in the tank.

D cooling the tank to approximately 4°C.

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q1a

Multiple lessons

Question 10 (1 MARK)

An increase in the environmental glucose level increases the rate of cellular respiration. The rate of cellular respiration increases because

A the rate of glycolysis reactions in the matrix of mitochondria increases.

B the rate of the light-independent reactions in the stroma increases with the increase in CO_2 level.

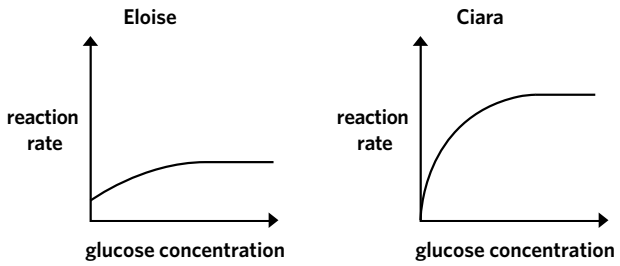
C water, a product of cellular respiration, is removed more easily due to the hypertonic environment.

D more glucose molecules collide with the enzymes that break it down, increasing the rate at which glycolysis can occur.

Adapted from VCAA 2014 Section A Q8

Use the following information to answer Questions 11 and 12.

Eloise and Ciara set up an experiment to measure the rate of anaerobic respiration. Yeast cells were cultured and suspended in solution in sealed tubes to limit oxygen availability. The cells were then exposed to different glucose concentrations and the rate of respiration was measured. Eloise was given strain A yeast and Ciara was given strain B yeast. The results obtained by both students are shown.



Question 11 (1 MARK)

Which of the following could the students have measured to quantify the reaction rate?

A ethanol production

B water consumption

C lactic acid production

D oxygen gas production

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q5bi

Question 12 (1 MARK)

Which of the following could explain the difference in the results of the students?

A Strain B only respires aerobically, whereas strain A respires both aerobically and anaerobically.

B Strain A yeast had fewer mitochondria in each cell compared to strain B.

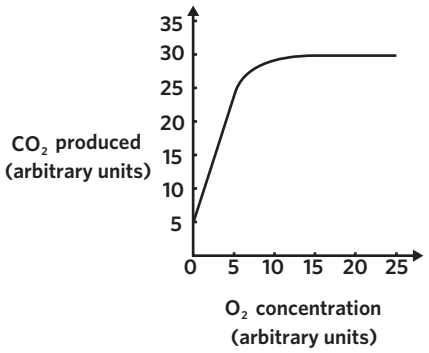
C Eloise had a lower number of yeast cells in her suspension.

D Ciara conducted her experiment at a lower temperature.

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q5biii

Question 13 (7 MARKS)

The graph shows the rate of carbon dioxide exchange between a plant root system and its external environment as oxygen level is altered. All other variables are kept constant throughout the experiment.



a Danny suggested that aerobic respiration is still occurring when there is no environmental O_2 because the CO_2 produced is greater than zero. Evaluate Danny's statement and justify your response. (2 MARKS)

b Describe the consequence for plant root cells if they are deprived of O_2 for an extended period of time. (2 MARKS)

c A plateau is seen on the graph.

i Explain why the graph line becomes nearly horizontal from about 15 arbitrary units of oxygen concentration. (1 MARK)

ii Describe the variable(s) that, when altered, could raise the value of the plateau on the graph. (2 MARKS)

Key science skills

Question 14 (11 MARKS)

Yeast is a single-celled microscopic fungus that uses sucrose as a food source by breaking it down into glucose. An experiment was carried out by four separate groups of students to investigate the cellular respiration rate of four similar species of yeast. Four groups were set up, each with a different species of yeast cells in a container, and a 0.1 M sucrose solution was added to each. The containers were sealed in such a way as to prevent air from entering. The percentages of oxygen and ethanol in the containers were recorded over a one-hour period. The experiment was carried out at a room temperature of 26 °C, which is close to yeast's optimal temperature (30 °C). The results for each group and the mean are shown in the following table.

Group	Percentage of oxygen		Percentage of ethanol	
	At the start of the experiment	At the end of the experiment	At the start of the experiment	At the end of the experiment
1	21	18	0	4
2	8	17	0	5
3	22	19	0	3
4	21	18	0	4
Mean for all groups	18	18	0	4

a State the dependent and independent variables. (2 MARKS)

b Consider the data provided.

i Which type of cellular respiration is being measured by the change in the percentage of oxygen in the container? (1 MARK)

ii Name and describe the process occurring in the yeast that produces ethanol. (2 MARKS)

c Another student carried out the same experiment at a temperature of 60 °C instead. Describe and explain the expected change in percentage of ethanol. (2 MARKS)

d Consider the design of the experiment to investigate cellular respiration.

i A student misread the first value in Group 2. Name the type of error that has occurred in Group 2. (1 MARK)

ii Outline how this error impacts the class results. (1 MARK)

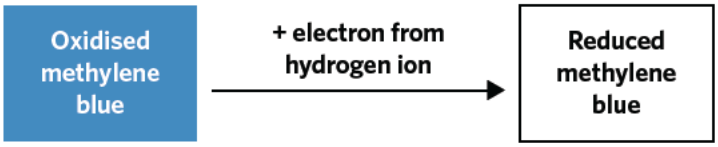
iii Identify and explain a factor other than sucrose availability that could be changed in the original experiment to decrease the rate of both aerobic and anaerobic cellular respiration. (2 MARKS)

Adapted from VCAA 2017 Sample Exam Section B Q1

ACTIVITY

Cellular respiration and temperature

This practical asks you to apply what you have learnt about cellular respiration by examining the effect of temperature on the rate of cellular respiration in yeast. Yeast cells can use glucose as a fuel source for cellular respiration. In the presence of oxygen, yeast aerobically respire to produce carbon dioxide and water. In the absence of oxygen, yeast respire anaerobically to produce ethanol and carbon dioxide. In the process of cellular respiration, carrier molecules such as NAD^+ and FAD accept protons and electrons. In this experiment, you will be using methylene blue as a carrier molecule. When methylene blue accepts protons and electrons, it turns from blue to colourless.



Materials

- Yeast culture 200 g/L
- Glucose solution 10 g/L
- Methylene blue indicator
- Distilled water

Apparatus

- 7 boiling tubes
- Boiling tube rack
- Permanent marker
- 5x Waterbaths: 30°C, 40°C, 50°C, 60°C, and 70°C. If thermostatically controlled baths are not available, use a Bunsen burner, tripod, thermometer, and beaker setup.
- 1x ice bath: 5°C
- Thermometers
- 7 test tubes
- Test tube rack
- Plastic pipette/dropper
- Timer/stopwatch
- Stirring rod

Procedure

1. Label the seven boiling tubes – U, V, W, X, Y, Z, and A.
2. Add 10 mL of glucose solution to each boiling tube.
3. Add 1 mL of methylene blue solution to tubes U-Z.
4. Add 1 mL of distilled water to tube A.
5. Label seven test tubes – 1, 2, 3, 4, 5, 6, and 7.
6. Stir the yeast culture solution. Add 1 mL of yeast culture solution to all seven test tubes.
7. Stand tubes U, A, 1, and 7 in the waterbath at 30°C for five minutes. Repeat for:
   - **a** Tubes V and 2 in the ice bath at 5°C
   - **b** Tubes W and 3 in the waterbath at 40°C
   - **c** Tubes X and 4 in the waterbath at 50°C
   - **d** Tubes Y and 5 in the waterbath at 60°C
   - **e** Tubes Z and 6 in the waterbath at 70°C

It is important that steps 8 to 11 are completed quickly for more accurate results.

8. Pour the contents of test tube 1 into boiling tube U. Repeat for:
   - **a** Test tube 2 and boiling tube V
   - **b** Test tube 3 and boiling tube W
   - **c** Test tube 4 and boiling tube X

d Test tube 5 and boiling tube Y

e Test tube 6 and boiling tube Z

f Test tube 7 and boiling tube A

9 Immediately stir the contents of each tube three times. Rinse stirring rod between each tube. Immediately start the timer.

10 Inspect the colour of the liquid in the tubes. Do not disturb the tubes. Ignore the blue ring that may form at the top of the liquid.

11 Record the time it takes for the liquid in each boiling tube to reach the same colour as the liquid in boiling tube A. Stop the timer at 30 minutes and note if any tubes have not changed colour.

12 Repeat the experiment three times and calculate the average results for each temperature treatment.

Questions

1 Construct a graph of temperature (x axis) against the recorded time until colourless values (y axis).

2 What is the optimal temperature for cellular respiration in yeast? Explain by referring to your results.

3 Describe and use theory to explain the results below optimal temperature. Refer to specific tubes in your answer.

4 Describe and use theory to explain the results above optimal temperature. Refer to specific tubes in your answer.

5 Explain the purpose of boiling tube A.

6 Why is methylene blue used as an indicator of respiration rate? Refer to specific stage/s of cellular respiration in your response.

7 Identify areas of potential error in this experiment.

8 Discuss improvements that could be made to the experiment.

CHAPTER SUMMARY

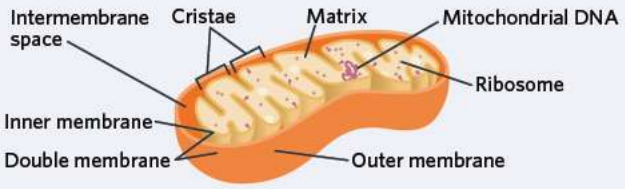
<table>
<tr><th></th><th>Aerobic respiration</th><th>Anaerobic respiration</th></tr>
<tr><td>Equation</td><td>Glucose + Oxygen → Carbon dioxide + Water + Energy
$C_6H_{12}O_6$ $6\ O_2$ $6\ CO_2$ $6\ H_2O$ 36-38 ATP</td><td>Glucose → Lactic acid + Energy
$C_6H_{12}O_6$ $2\ C_3H_6O_3$ 2 ATP
(in animals)

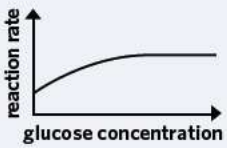
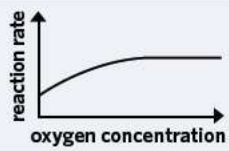
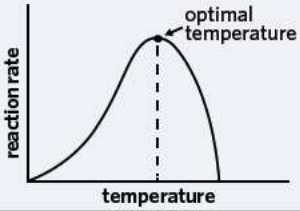
Glucose → Ethanol + Carbon dioxide + Energy
$C_6H_{12}O_6$ $2\ C_2H_5OH$ $2\ CO_2$ 2 ATP
(in plants and yeast)</td></tr>
<tr><td>Efficiency</td><td>36 – 38 ATP per glucose molecule</td><td>2 ATP per glucose molecule</td></tr>
<tr><td>Locations</td><td>Mitochondria and cytosol</td><td>Cytosol</td></tr>
<tr><td>Stages</td><td>1. Glycolysis – cytosol
In: Glucose; $2\ ADP + P_i$ | Out: 2 pyruvate; 2 ATP
2. Krebs cycle – mitochondrial matrix
In: 2 acetyl CoA (from pyruvate); $2\ ADP + P_i$ | Out: $6\ CO_2$; 2 ATP
3. Electron transport chain – mitochondrial cristae
In: $6\ O_2$; $32 – 34\ ADP + P_i$ | Out: $6\ H_2O$; 32 – 34 ATP</td><td>1. Glycolysis – cytosol
In: Glucose; $2\ ADP + P_i$ | Out: 2 pyruvate; 2 ATP
2. Further reactions – cytosol
In: Pyruvate | Out: Lactic acid (animals) OR Ethanol and CO_2 (plants and yeast)</td></tr>
</table>

Endosymbiosis of mitochondria

Evidence that supports the endosymbiotic theory in mitochondria:

- Presence of **circular DNA** (mtDNA)
- Replicate via **binary fission**
- Have their own **ribosomes**
- Can produce their own proteins
- Contain transport proteins called porins
- Have a **double membrane**



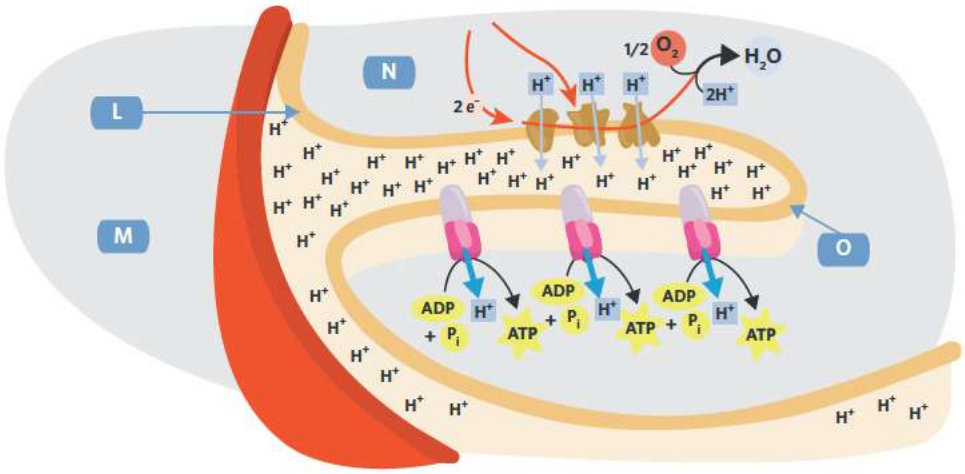
	Type of respiration affected	Trend	Graph of factor against reaction rate
Glucose availability	Both aerobic and anaerobic respiration	Respiration rates increase with glucose up to a point	
Oxygen concentration	Aerobic respiration	Aerobic respiration increases with oxygen up to a point. When limited, aerobic respiration may occur instead	
Temperature	Both aerobic and anaerobic respiration	Respiration rates are highest when aligned with the optimal temperature of the cells' enzymes	

CHAPTER REVIEW QUESTIONS

SECTION A (15 MARKS)

Question 1 (1 MARK)

The diagram shows a cross-section of a mitochondrion. The sites of each stage of aerobic cellular respiration have been labelled.



The sites of the stages in aerobic respiration are

A L - glycolysis; O - Krebs cycle; N - electron transport chain

B M - glycolysis; L - Krebs cycle; N - electron transport chain

C N - glycolysis; M - Krebs cycle; O - electron transport chain

D M - glycolysis; N - Krebs cycle; O - electron transport chain

Adapted from VCAA 2018 Section A Q8

Question 2 (1 MARK)

An animal cell culture was exposed to radioactively labelled carbon atoms through glucose molecules. The cells were then monitored for three minutes.

After this time, the radioactively labelled carbon atoms would be present in which cellular molecule?

A CO_2

B ATP

C H_2O

D NADH

Adapted from VCAA 2017 Section A Q11

Question 3 (1 MARK)

Which of the following gives the inputs and outputs of glycolysis in a plant cell?

	Inputs	Outputs
A	ADP, P_i, NAD^+, glucose	ATP, NADH, pyruvate
B	ADP, P_i, NAD^+, glucose	ATP, NADH, ethanol, carbon dioxide
C	ADP, P_i, NADH, water, glucose	ATP, NAD^+, H^+, oxygen
D	$NADP^+$, H^+, ADP, P_i, glucose	ATP, NADPH, pyruvate

Adapted from VCAA 2018 Section A Q9

Question 4 (1 MARK)

The graph shows the growth rate of four different strains of bacteria when exposed to varying concentrations of atmospheric oxygen.

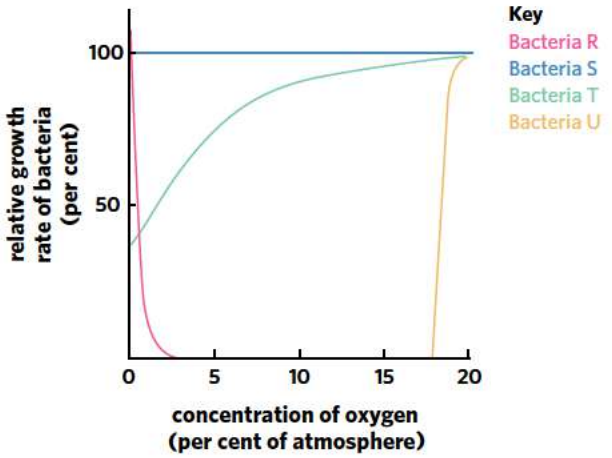
Based on your knowledge and the information in the graph, which one of the following statements is true?

A Bacteria R are able to carry out both aerobic and anaerobic respiration.

B Bacteria T are only able to carry out anaerobic respiration.

C Bacteria U are only able to carry out aerobic respiration.

D Bacteria S can photosynthesise.



Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q5

Question 5 (1 MARK)

Evidence for the bacterial origin of mitochondria is supported by observations that both mitochondria and bacteria

A do not contain ribosomes.

B reproduce and divide by mitosis.

C have a single circular chromosome.

D store plasmids in their outer membrane.

Adapted from VCAA 2017 Section A Q12

Use the following information to answer Questions 6 and 7.

The following is a three-dimensional diagram of a mitochondrion found in eukaryotic cells.

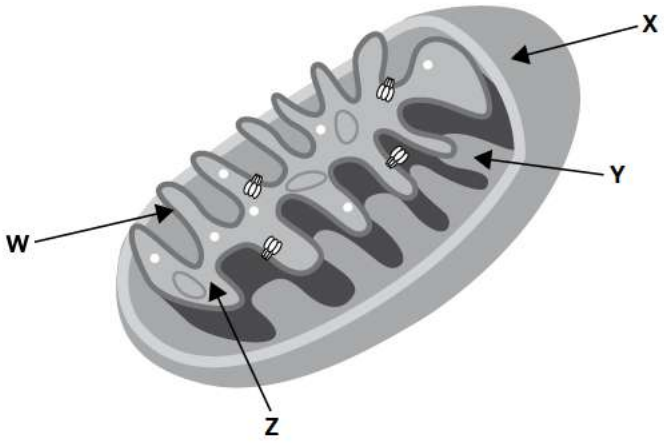


Image: Alila Medical Media/Shutterstock.com

Question 6 (1 MARK)

Which of the following structures represents the cristae?

A X

B Y

C W

D Z

Adapted from VCAA 2017 Section A Q9

Question 7 (1 MARK)

At structure Y

A NAD^+ is converted into NADH.

B there is a high concentration of protons.

C the majority of ATP is produced in the cell.

D pyruvate is broken down, releasing carbon dioxide.

Adapted from VCAA 2017 Section A Q10

Question 8 (1 MARK)

Cellular respiration is influenced by a number of different environmental factors. A factor that would increase the rate of cellular respiration would be

A an increase in water availability.

B an increase in glucose concentration.

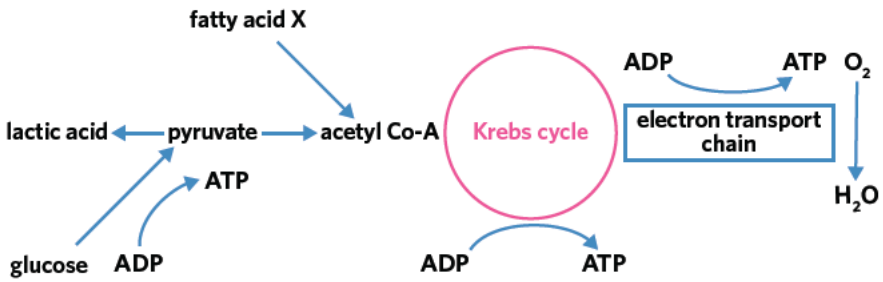
C a reduction in environmental oxygen levels.

D a decrease in the environmental temperature.

Question 9 (1 MARK)

If there is insufficient glucose for cellular respiration, fatty acids can be changed to acetyl CoA. Each fatty acid X molecule produces eight molecules of acetyl CoA.

The following diagram summarises the pathways for the breakdown of fatty acid X and glucose. The number of molecules produced in each step is not shown.



Using your knowledge of cellular respiration and referring to the information provided, which one of the following conclusions can be made?

A Lactic acid is a product of aerobic cellular respiration.

B Fatty acid X is not converted into pyruvate molecules.

C The breakdown of glucose into pyruvate produces one ATP molecule.

D A single glucose molecule produces more ATP than a molecule of fatty acid X.

Adapted from VCAA 2014 Section A Q12

Use the following information to answer Questions 10 and 11.

In the laboratory, scientists can isolate animal cells in a test tube. These cells can be burst by submerging them in a hypertonic solution, and their cellular organelles can be extracted. Suspensions of cytosol, mitochondria, and other organelles can be collected. In one experiment, a suspension of mitochondria only was collected using this method and was oxygenated. Different substances were added to the suspension and the change in oxygen concentration was recorded.

Question 10 (1 MARK)

Which of the following substances would result in a decrease in oxygen concentration?

A ATP

B Glucose

C Pyruvate

D None of the above

Adapted from VCAA 2016 Section B Q4

Question 11 (1 MARK)

In another experiment, which suspension would have the greatest increase in lactic acid?

A Suspension of cytosol and mitochondria

B Suspension of mitochondria

C Suspension of cytosol only

D None of the above

Adapted from VCAA 2016 Section B Q4

Question 12 (1 MARK)

In a laboratory, mammal cells were incubated in an anaerobic environment and supplied with glucose containing radioactive carbon atoms. After four hours, an analysis of the chemicals in and around the mammal cells was undertaken. Which one of the following molecules would contain the radioactive carbon atoms after four hours?

A Water

B Ethanol

C Lactic acid

D Carbon dioxide

Adapted from VCAA 2016 Section A Q10

Question 13 (1 MARK)

Which one of the following is not an output of the Krebs cycle?

A ATP

B $FADH_2$

C NADPH

D Carbon dioxide

Adapted from VCAA 2017 Sample Exam Section A Q12

Question 14 (1 MARK)

Which one of the following is true of the electron transport chain?

A It is involved in both aerobic and anaerobic respiration.

B It requires oxygen, NADPH, and $FADH_2$ as inputs.

C It produces more ATP than glycolysis.

D It occurs in the cytosol of the cell.

Adapted from VCAA 2017 Sample Exam Section A Q13

Question 15 (1 MARK)

The electromicrograph provided shows a portion of a cell.

In organelle X

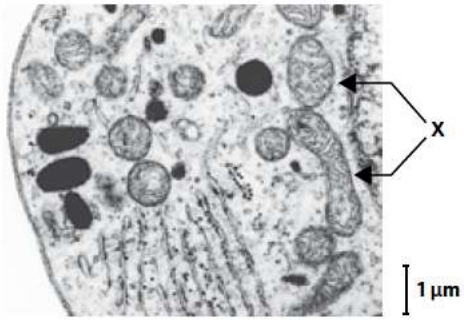
A the cycling of NADPH occurs.

B lactic acid or ethanol is produced.

C the Krebs cycle occurs on the cristae.

D a proton gradient is coupled with ATP production.

Adapted from VCAA 2017 Sample Exam Section A Q11



SECTION B (25 MARKS)

Question 16 (6 MARKS)

At high altitudes, the air gets 'thinner'. This means that the concentration of gases like oxygen is reduced and less oxygen is available for the lungs. This causes a significant reduction in oxygen supplied to the cells of the body.

a Identify a metabolic process that requires oxygen as an input to produce large amounts of energy. (1 MARK)

b With reference to the lack of oxygen, suggest how the pH of human cells may change at high altitudes. (2 MARKS)

c Ethan moved house and now lives at a higher altitude. In the process of relocating, he dug up one of his saplings and transplanted it into his new garden. Ethan noticed that the plant did not grow as well as it had at lower altitudes, and eventually it began to die. Explain how lower oxygen levels may have contributed to the sapling's unsuccessful transplantation. (3 MARKS)

Question 17 (6 MARKS)

Plant materials containing starch and other polysaccharides are broken down during digestion to produce glucose. Glucose can then be used by mammal cells during anaerobic respiration.

a Why is anaerobic respiration important for mammal cells? (1 MARK)

Adapted from VCAA 2016 Section B Q2a

b What is/are the product/s of anaerobic respiration in mammal cells? (1 MARK)

Adapted from VCAA 2016 Section B Q2b

c Temperature is a factor that affects the rate of cellular respiration. Describe and explain the relationship between temperature and respiration rate. (2 MARKS)

d State one similarity and one difference between aerobic and anaerobic cellular respiration. (2 MARKS)

Adapted from VCAA 2005 Exam 1 Section B Q3d

Question 18 (7 MARKS)

Oxygen is required for the process of aerobic cellular respiration.

a The three stages of this process are listed in the table. Complete the table by naming the missing inputs and outputs of each stage of cellular respiration when normal oxygen levels are available. (3 MARKS)

Stage	Location	Inputs	Outputs
Glycolysis		2 ADP + P_i $NAD^+ + H^+$	2 ATP Pyruvate NADH
	Matrix	2 ADP + P_i $NAD^+ + H^+$ Acetyl CoA FAD + 2 H^+	2 ATP NADH $FADH_2$
Electron transport chain	Cristae	$FADH_2$ 32-34 ADP + P_i NADH	FAD + 2 H^+ 32-34 ATP $NAD^+ + H^+$

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q4a

b Cytochrome c oxidase is an essential enzyme in the electron transport chain. It is the last enzyme in the electron transport chain, and catalyses the transfer of electrons to oxygen. Hydrogen cyanide is a non-competitive inhibitor of this enzyme.

i Outline the effect on the structure of the active site when hydrogen cyanide binds to the enzyme. (2 MARKS)

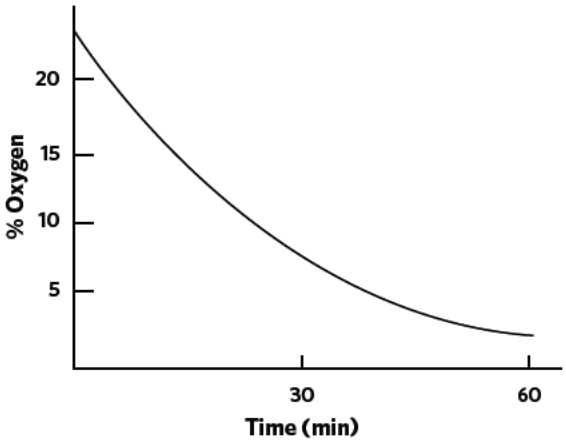
ii Justify how this inhibitor could be lethal. (2 MARKS)

VCAA 2017 Northern Hemisphere Exam Section B Q4

Question 19 (6 MARKS)

Yeast is a single-celled, microscopic fungus that can use sucrose as a food source. An experiment was carried out to investigate cellular respiration by a particular species of yeast. Yeast cells were placed in a container and a sucrose solution was added. An airtight lid was placed on the container. The percentages of oxygen and ethanol in the container were recorded over a one-hour period. The experiment was carried out at room temperature.

The change in oxygen percentage within the container is shown in the graph.



a State where ethanol is produced in a yeast cell. (1 MARK)

b Predict whether the ethanol concentration inside the airtight container would change within the time the experiment was carried out. Explain the reasoning behind your prediction. (2 MARKS)

Adapted from VCAA 2013 Exam 1 Section B Q1a

c The percentage of carbon dioxide was also monitored during the experiment. It was noted that there was virtually no carbon dioxide in the container at the start of the experiment. Redraw the curve for oxygen concentration in your own workbook. Then, draw the expected change in carbon dioxide concentration on the same set of axes. (2 MARKS)

Adapted from VCAA 2013 Section B Q1

d State the stage of aerobic cellular respiration where carbon dioxide is produced and identify where in the yeast cell this stage occurs. (1 MARK)

UNIT 3

AOS2

How do cells communicate?

In this area of study students focus on how cells receive specific signals that elicit a particular response. Students apply the stimulus-response model to the cell in terms of the types of signals, the position of receptors, and the transduction of the information across the cell to an effector that then initiates a response. Students examine unique molecules called antigens and how they elicit an immune response, the nature of immunity, and the role of vaccinations in providing immunity. They explain how malfunctions in signalling pathways cause various disorders in the human population and how new technologies assist in managing such disorders.

Outcome 2

On completion of this unit the student should be able to apply a stimulus-response model to explain how cells communicate with each other, outline immune responses to invading pathogens, distinguish between the different ways that immunity may be acquired, and explain how malfunctions of the immune system cause disease.

Image: Billion Photos/Shutterstock.com

UNIT 3 AOS 2, CHAPTER 8

Cell signals

08

8A The stimulus-response model

8B Living things communicate using chemicals

8C Signal transduction

8D Apoptosis

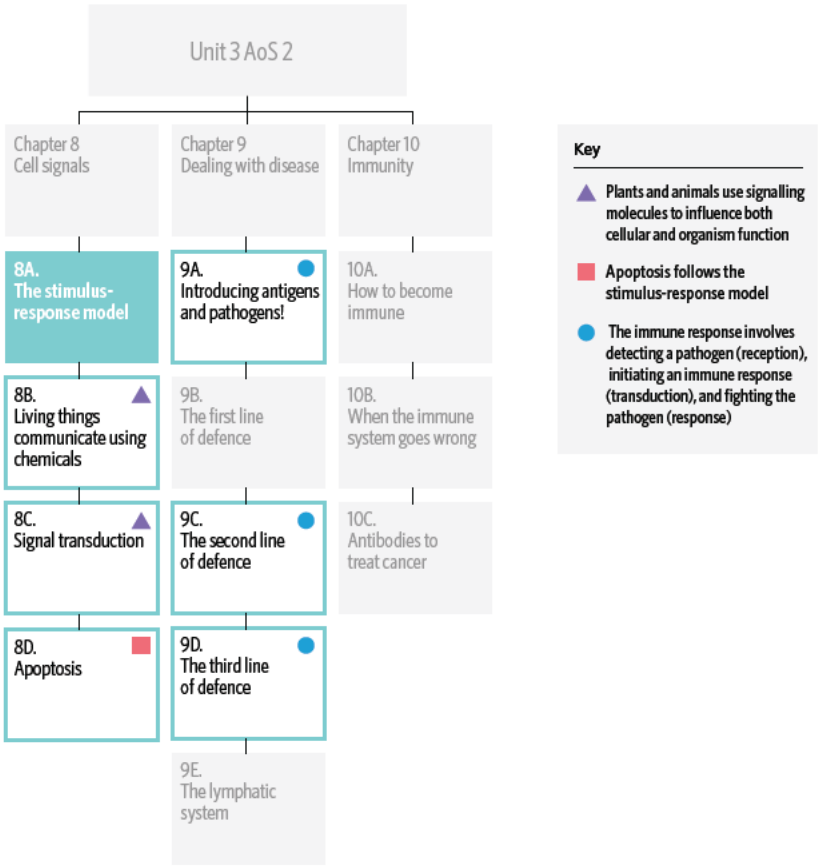
Key knowledge

- the stimulus-response model when applied to the cell in terms of signal transduction as a three-step process involving reception, transduction, and cellular response
- the sources and mode of transmission of various signalling molecules to their target cell, including plant and animal hormones, neurotransmitters, cytokines, and pheromones
- difference in signal transduction for hydrophilic and hydrophobic signals in terms of the position of receptors (on the membrane and in the cytosol) and initiation of transduction (details of specific chemicals, names of second messengers, G protein pathways, reaction mechanisms, or cascade reactions are not required)
- apoptosis as a natural, regulatory process of programmed cell death, initiated after a cell receives a signal from inside (mitochondrial pathway) or from outside (death receptor pathway) the cell resulting in the removal of cells that are no longer needed or that may be a threat to an organism, mediated by enzymes (caspases) that cleave specific proteins in the cytoplasm or nucleus (details of specific cytoplasmic or nuclear proteins are not required)
- malfunctions in apoptosis that result in deviant cell behaviour leading to diseases including cancer

Image: Dr Ajay Kumar Singh/Shutterstock.com

8A THE STIMULUS-RESPONSE MODEL

When you hear a loud noise, you turn towards it. When light hits your pupil, your pupil shrinks. When a muscle cell recognises an insulin molecule, it transports glucose into the cell. These reactions all follow the stimulus-response model.



In this lesson you will learn the key steps in the stimulus-response model.
The stimulus-response model outlines how changes in the internal and external environment can influence organism function.

Study design dot point

- the stimulus-response model when applied to the cell in terms of signal transduction as a three-step process involving reception, transduction, and cellular response

Key knowledge unit	
Reception, transduction, and response	3.2.2.1

Reception, transduction, and response 3.2.2.1

OVERVIEW

The stimulus-response model can be simplified into three steps: 1. Reception, 2. Transduction, and 3. Response.

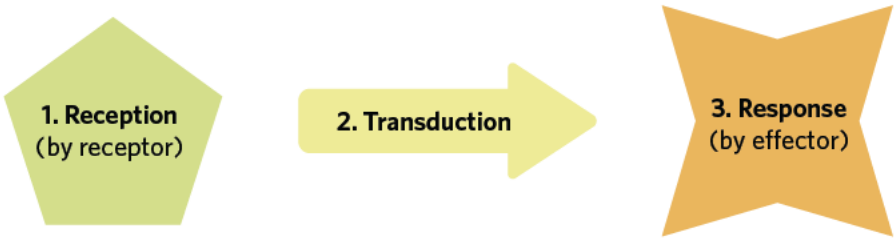


Figure 1 The stimulus-response model

THEORY DETAILS

What is a stimulus?

Our internal and external environments are constantly changing. When the change in either of these environments is large enough to cause a **response** in individual cells or an organ, this change is considered a **stimulus**. Different stimuli include a change in an environmental condition such as temperature or light, or the presence of a **signalling molecule.**

Case study

Our senses and the world around us

Our brain receives signals created after the detection of certain stimuli by receptors. The detection of these signals allows us to interpret the world in the form of senses. Most people know the big five senses, but some researchers have suggested that we have up to 21 senses! Each sense is involved in the interpretation of and response to different intracellular and extracellular stimuli. Our sense of sight deciphers light that intercepts our retinas, our sense of hearing translates the pressure waves hitting our eardrums into sound, and our sense of proprioception tells us where our limbs are even if you aren't looking at them.

Other animals have different sets of senses than us. Sharks and platypus detect electrical signals in water using specialised electroreceptors and some birds and bees can detect and navigate by the Earth's magnetic field.

response the action of a cell, organ, or organism caused by a signal

stimulus (pl. stimuli) an event or molecule that can initiate a response

signalling molecule a molecule which can interact with and initiate a response in a target cell

reception the detection of a signal due to a change in the internal or external environment

stimulus-response model a model that describes how a system responds to a stimulus via the three-step process of reception, transduction, and response

receptor a structure that detects a signal, usually a protein

signal transduction the series of events that occur after the reception of a signal which results in the generation of a response

1. Reception

Reception is the first stage of the **stimulus-response model**, and is characterised by the detection of a stimulus. **Receptors** are often membrane-bound or cytoplasmic proteins that can detect a change in the environment or the presence of a signalling molecule. In many cases a whole cell can act as a receptor, such as a sensory neuron that responds to a change in temperature (these temperature-sensing neurons are known as thermoreceptors). Other examples of receptors include nociceptors (pain receptors), baroreceptors (pressure receptors), chemoreceptors (detect particular chemicals), and photoreceptors (light receptors). A receptor's reaction to a stimulus can generate a mechanical, electrical, or chemical signal. The generation of this signal falls under the second stage of the stimulus-response model: **transduction**.

lesson link VCAA assesses five main groups of signalling molecules. Each of these signalling molecule types will be discussed in ***8B***.

2. Transduction

Transduction is the second stage of the stimulus-response model, and refers to the transmission of a signal during cellular signalling. The transduction stage of the stimulus-response model follows the detection of a stimulus and includes everything up to the final response of a cell or organ. While this sounds simple the actual changes to a signal during signal transduction can be complex and vary between each stimulus-response pathway. For instance:

- In a nervous system signalling pathway, electrical signals are generated after the stimulation of receptor neuron. This signal is carried to the central nervous system via a series of other neurons, causing the signal to change from electrical → chemical → electrical many times. Eventually, a response is produced, such as the movement of muscles or 'thought'.
- In an endocrine signalling pathway, signalling molecules are produced in a cell and usually released into the blood. These signalling molecules can travel throughout the body.
- In the *lac* operon signalling pathway, high lactose presence leads to a cascade of signal transduction (conversion into allolactose, binding to the repressor which releases the operator, RNA polymerase can bind and transcription can proceed) so that the enzymes that enable lactose digestion are produced.

Transduction can involve sending a signal between organisms, across the body, to a neighbouring cell, or back to the original receptor cell.

lesson link Signalling molecules can be hydrophilic or hydrophobic. Hydrophilic signalling molecules bind to transmembrane receptors and hydrophobic signalling molecules bind to cytoplasmic receptors. These two types of signalling molecules will be covered in greater detail, and explained in the context of the stimulus-response model in ***8C***.

3. Response

The response is the third and final stage of the stimulus-response model. The response is any change in the function of a target cell, organ, or organism after stimulation from an initial signal.

For instance, increased or decreased protein production, the release of chemicals, changes to solute concentrations, and the movement of a cell or organism are all common responses in the stimulus-response pathway. The response will require the action of some structure, which is known as the **effector**. For instance, if the response is opening up a protein channel to allow ions into a cell, the effector is the protein channel itself as it opens up. If the response is the movement of a leg, the effector would be the muscle cells within the leg contracting to cause movement.

effector a molecule or organ that responds to a signal and produces a response

Theory summary

The stimulus-response model has three steps: reception, transduction, and response.

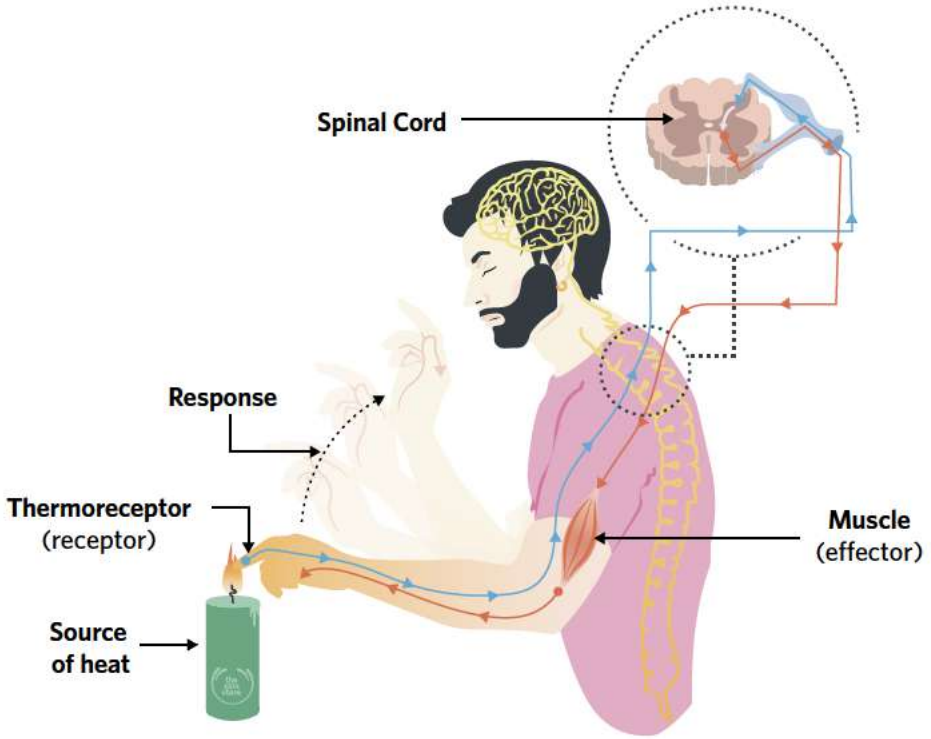


Figure 2 When touching something hot, thermoreceptors detect heat and generate an electrical signal. This signal is sent via neurons to the central nervous system, then to muscle cells which initiate the response of removing our hand.

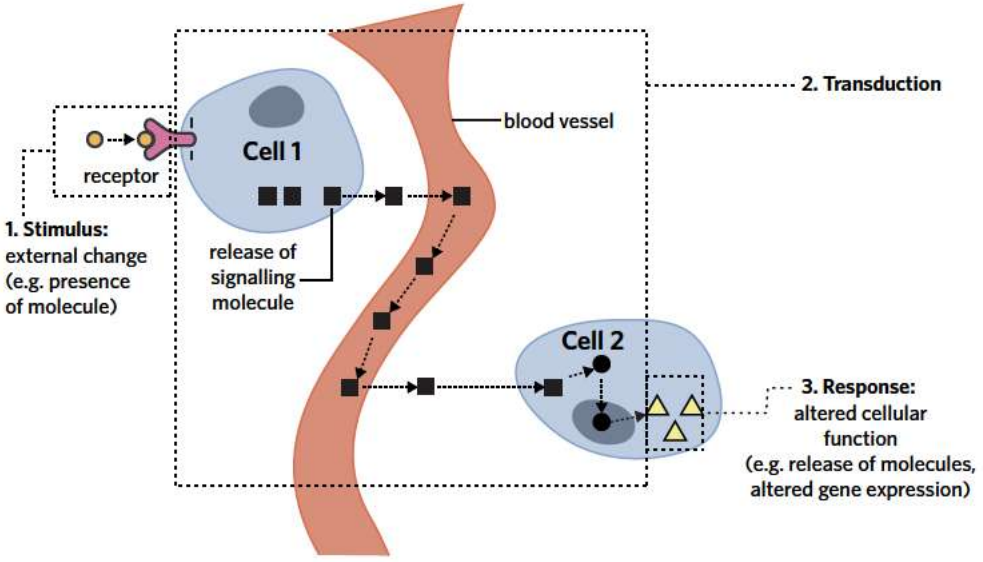


Figure 3 A stimulus detected by one cell can cause a response in another cell by releasing signalling molecules.

8A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ these molecules can be produced in one cell but initiate a reaction in another cell

b _____ an environmental factor that is detected by receptors

c _____ the functional change of a cell, organ, or organism due to a stimulus

d _____ detects a change in the internal or external environment

e _____ the first step of the stimulus-response model

f _____ the series of events leading up to the response after the initial detection of a signal

Question 2

What is the function of the receptor in signal transduction?

A produce the response of a cell

B detect an environmental change

C initiate the third stage in the stimulus-response model

D carry a signal between a transmembrane protein and DNA

Question 3

Which of the following would not be considered a response?

A an increase in gene expression

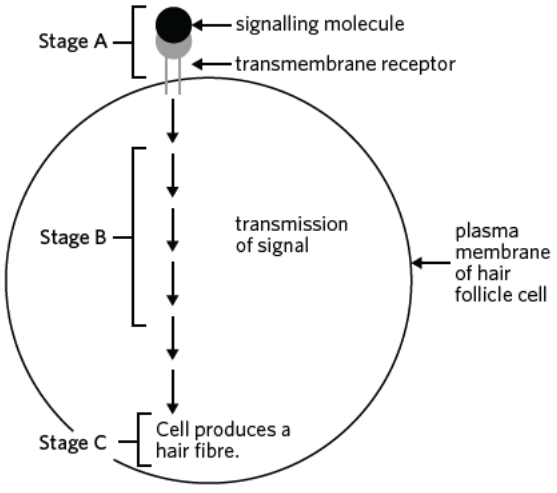
B a decrease in the cellular respiration rate

C the movement of a bacterium toward a food source

D the detection of an extracellular signalling molecule

Question 4

Which of the following options correctly describes the three steps of the stimulus-response model in the diagram?



	Stage A	Stage B	Stage C
A	Reception	Transduction	Response
B	Transduction	Reception	Response
C	Reception	Response	Transduction
D	Stimulus	Transduction	Reception

Exam-style questions

Within lesson

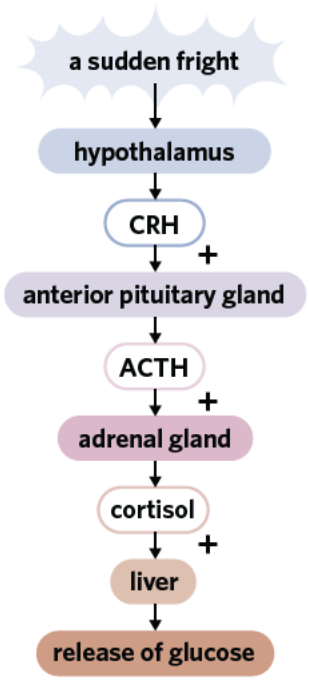
Question 5 (1 MARK)

When considering the stimulus-response model, all receptors are

A proteins.
B molecules that initiate changes in target cells.
C cells that detect changes in solute concentrations.
D structures that detect changes in either the internal or external environment.

Use the following information to answer Questions 6 and 7.

The anterior pituitary gland, located in the brain, absorbs the signalling molecules that are transported in the blood. The anterior pituitary gland itself secretes a signalling molecule that targets the adrenal glands that are located on top of the kidneys. A pathway is shown.



Key

CRH	cortico-releasing signalling molecule
ACTH	adrenocorticotropic signalling molecule
cortisol	signalling molecule derived from cholesterol
+	stimulation

Question 6 (1 MARK)

In the pathway shown, the

A anterior pituitary gland is stimulated by ACTH.
B hypothalamus reacts to the release of glucose.
C cortisol signalling molecule is likely synthesised within the adrenal gland.
D stimulus would not be a change in either the intracellular or extracellular environment.

Question 7 (1 MARK)

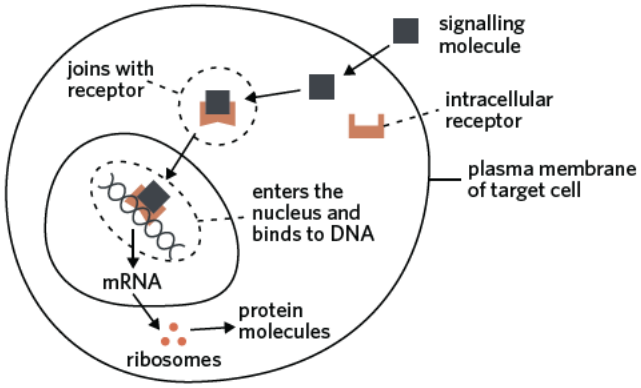
According to the stimulus-response model, the response would most likely be

A the release of glucose into the bloodstream.
B CRH being released by the hypothalamus.
C the person becoming less scared.
D a sudden fright.

Adapted from VCAA 2011 Exam 1 Section B Q6b

Question 8 (1 MARK)

Consider the following diagram of a signalling molecule interacting with a target cell.



The signalling molecule alters cellular function in the target cell.

Which of the following is a correct statement when considering the interaction between the signalling molecule and the target cell?

A The production of protein molecules is the response of the target cell.

B The signalling molecule requires a transmembrane protein to enter the cell.

C The signalling molecule-receptor complex synthesises an RNA molecule from a template DNA strand.

D The signalling molecule interacting with the plasma membrane represents the first stage of the stimulus-response model.

Adapted from VCAA 2018 Section A Q19

Question 9 (1 MARK)

Consider the interaction between the source cell and cell X.

In the interaction the signalling molecule

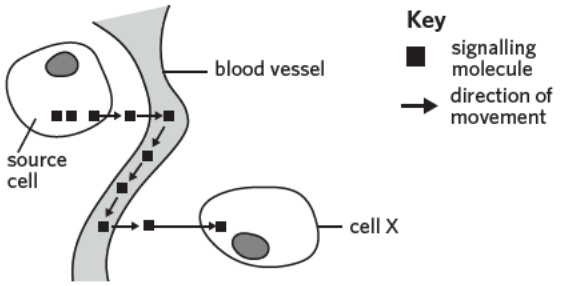
A is produced by the source cell.

B is a segment of mRNA.

C is a red blood cell.

D is hydrophilic.

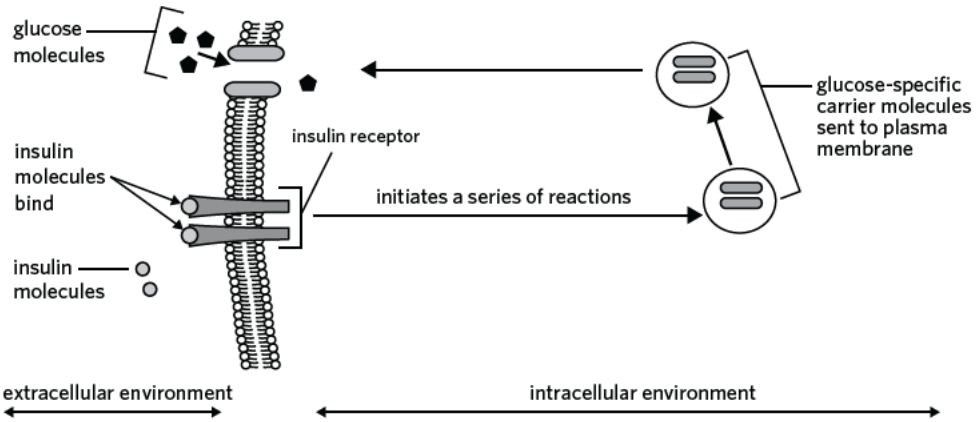
Adapted from VCAA 2018 Section A Q18



Multiple lessons

Question 10 (1 MARK)

The diagram shows a summary of the steps in an insulin signalling pathway that results in increased glucose uptake.



A scientist studied the insulin signalling pathways of two female patients, Eleni and Shani. Eleni's pathway is the same as that shown in the diagram. The scientist discovered that the gene that encodes the insulin receptor in Shani has been altered. Insulin molecules cannot bind to Shani's insulin receptors.

From this information, it would be correct to conclude that

A the response is the production of insulin.

B glucose enters the cell by facilitated diffusion.

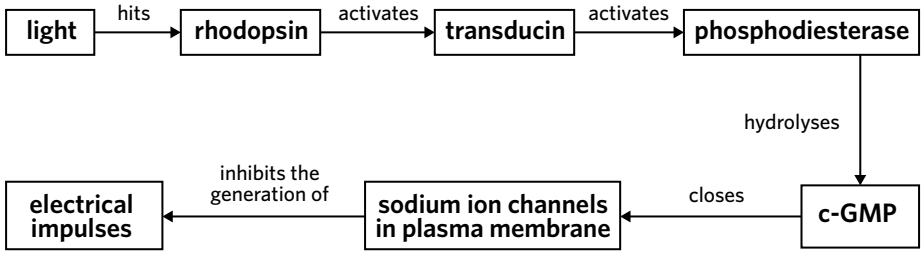
C Eleni would have a greater insulin concentration within the cell than Shani.

D the presence of glucose activates receptors on the cell surface, initiating transduction.

Adapted from VCAA 2017 Section A Q17

Question 11 (5 MARKS)

The flow chart summarises a sequence of events occurring inside a rod cell in the retina of the eye of a human named Jordan.



This sequence of events may be described by the stimulus-response model.

a Explain why light is regarded as a stimulus in this system. (1 MARK)

Adapted from VCAA 2012 Exam 1 Section B Q6bi

b In a game of basketball, one of Jordan's teammates passed the ball. Light was reflected off the ball and intercepted by Jordan's retina. Following this, Jordan's arms moved to catch the ball.

What is the response in this stimulus-response system? (1 MARK)

c Later that night, Jordan notices that his night vision is significantly worse than usual, and rushes to a doctor immediately. The doctor explains that after leaving a bowl of chicken and rice on the bench all day and then eating it, he is now suffering from a bacterial infection. This particular bacterial strain produces a molecule that competitively inhibits the enzyme phosphodiesterase, preventing the normal function of the enzyme and Jordan's regular ability to see in the dark.

i Describe how this molecule might prevent the normal function of phosphodiesterase. (2 MARKS)

ii Explain the effect this would have on electrical impulses in Jordan's rod cells. (1 MARK)

Question 12 (11 MARKS)

E. coli bacteria are able to rely on both glucose and lactose as an energy source for cellular respiration. They preferentially use glucose in cellular respiration but in certain situations may rely on lactose instead.

The *lacI* gene codes for the *lac* repressor protein, which is synthesised and produced by the ribosomes of the cell. Once produced, the *lac* repressor protein binds to a specific region of DNA and prevents the transcription of the *lac* operon.

However, when levels of lactose are high, some lactose is converted into allolactose via an enzyme-linked reaction. Allolactose binds to and deactivates the *lac* repressor protein, allowing gene expression of the *lac* operon to proceed. Once gene expression is complete, the pre-mRNA molecule undergoes splicing and is exported from the nucleus.

a Describe an environment that would result in *E. coli* bacteria primarily using lactose as an energy source. (1 MARK)

b Outline the steps of translation in the synthesis of the *lac* repressor protein. (3 MARKS)

Adapted from VCAA 2018 Section B Q1a

c How does allolactose inhibit the function of the *lac* repressor protein? (1 MARK)

d Name and describe the location of the sequence of DNA to which the *lac* repressor protein binds. (2 MARKS)

e The *lac* operon encodes for the production of three genes involved in the digestion of the lactose molecule, encoded by the regions *lacZ*, *lacY*, and *lacA*. Are the three regions *lacZ*, *lacY*, and *lacA* considered structural or regulatory genes? Justify your answer. (2 MARKS)

f Identify the stimuli and corresponding response for the stimulus-response model which involves the expression of the *lac* operon. (2 MARKS)

Adapted from VCAA 2017 Section A Q2

Key science skills

Question 13 (7 MARKS)

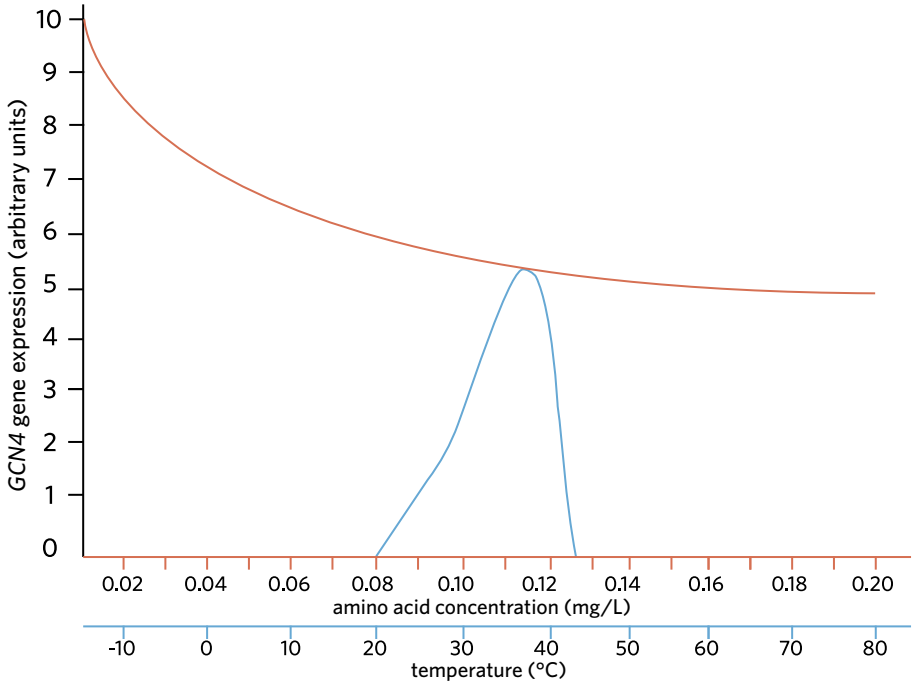
A group of scientists are attempting to uncover the factors which are involved in the regulation of the gene *GCN4*. Previous research has indicated that the *GCN4* gene is involved in the production of many of the amino acids that can be synthesised by yeast.

The scientists' experimental procedure involved growing *Saccharomyces cerevisiae* (yeast) on a number of separate nutrient agar plates. Using proper scientific technique, the scientists spread a yeast solution on 20 identical nutrient agar plates. They labelled the first 10 agar plates A1 through 10 and the remaining agar plates B1 through 10.

On plate A1, the scientists added an amino acid broth so that the average concentration of amino acids in the plate was equal to 0.02 mg/L. The scientists increased the concentration of amino acids by 0.02 mg/L in each of the following plates A2 through 10, so that plate A10 had an average amino acid concentration of 0.2 mg/L.

The scientists placed plate B1 in a box with an average temperature of -10°C. The scientists then incrementally increased the environmental temperature by 10°C for each of the remaining plates B2 through B10, so that plate B10 was in an environment of 80°C.

Each nutrient agar plate was cultured in their respective environments for 48 hours, after which the average *GCN4* gene expression was recorded for each plate. All non-manipulated environmental variables remained constant between experiments at their environmental optimum. The results of the experiment are shown in the graph.



a The scientists considered many different variables in their experimental design.

i Identify the independent and dependent variables in the experiment. (1 MARK)

Adapted from VCAA 2018 Section B Q11c

ii Identify each of these variables as either a stimulus or a response according to the stimulus-response model. (1 MARK)

b Upon inspection of their data, scientists were able to determine that many factors influenced *GCN4* gene expression. In particular, they noted the relationship between *GCN4* gene expression and the concentration of amino acids.

i Using the graph, describe how the concentration of amino acids may influence *GCN4* gene expression. (1 MARK)

ii What does this suggest about the relationship between amino acid concentration and *GCN4* gene expression? (1 MARK)

c When expressed, the GCN4 protein can bind to many DNA sequences, helping to initiate transcription. Is the *GCN4* gene a structural or regulatory gene? Justify your response. (1 MARK)

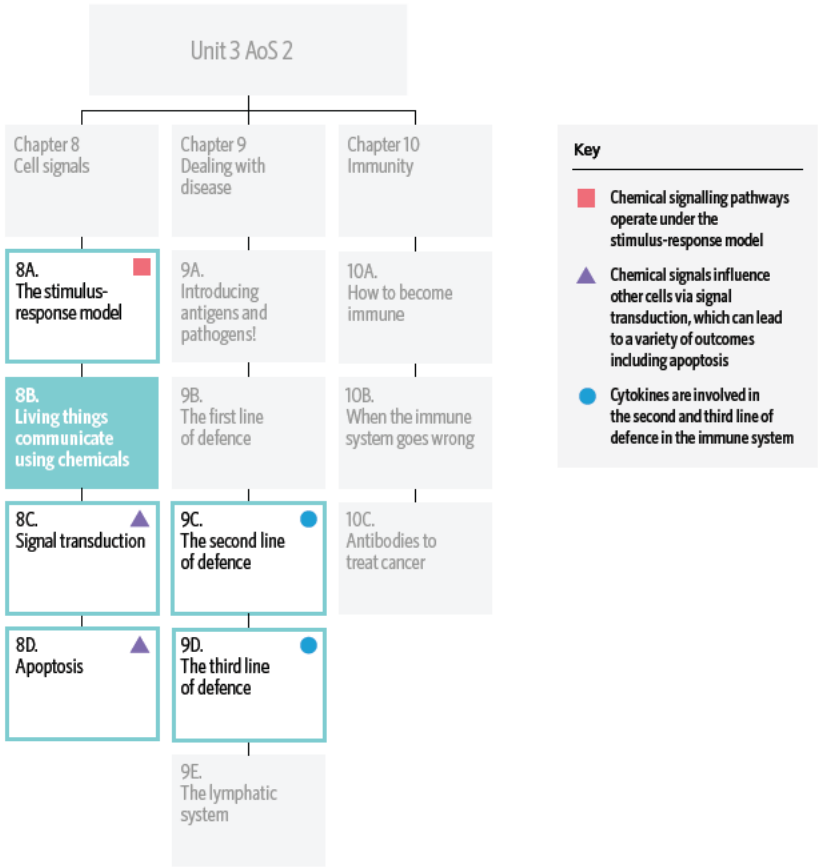
Adapted from VCAA 2018 Section B Q6a

d The scientists were criticised for poor experimental design and unreliable results. Suggest how the scientists could have increased the reliability of their results. (1 MARK)

e Other than influencing *GCN4* gene expression, explain how a shortage of amino acids may affect cellular function. (1 MARK)

8B LIVING THINGS COMMUNICATE USING CHEMICALS

Ever wondered why dogs sniff other dogs' pee, why plants bend towards sunlight, or why your heart beats faster when you're scared? The answer is chemical signals.



In this lesson you will learn about the major types of chemical signalling molecules that communicate between cells in both plants and animals.

Study design dot point

- the sources and mode of transmission of various signalling molecules to their target cell, including plant and animal hormones, neurotransmitters, cytokines, and pheromones

Key knowledge units

Introduction to chemical signalling molecules	3.2.1.1
Animal hormones	3.2.1.2
Plant hormones	3.2.1.3
Pheromones	3.2.1.4
Neurotransmitters	3.2.1.5
Cytokines	3.2.1.6

Introduction to chemical signalling molecules 3.2.1.1

OVERVIEW

Cells use chemicals called signalling molecules to communicate with other cells.

THEORY DETAILS

In multicellular eukaryotes, distant cells must communicate with one another. Communication allows for a single cell that detects a change in the environment to initiate a myriad of responses in cells throughout the body. This is where specialised chemicals called **signalling molecules** come into play.

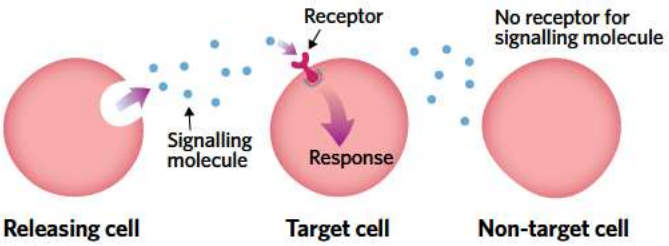


Figure 1 Chemical signals initiate responses in target cells.

A cell can release chemical signalling molecules, which bind to specific receptors complementary in shape to the molecule, and initiate a response within a target cell (Figure 1). When binding to a cell receptor, chemical signalling molecules are the stimulus in the stimulus-response model of a cell covered in lesson 8A. If a cell does not have the specialised receptor for the signalling molecule, it will not respond.

The transmission of signalling molecules from one cell to another can occur over short or long distances in the body. Chemical signalling can be broken up into three different modes of transmission (Figure 2):

- **Autocrine signalling** – when signalling molecules act on and initiate a response in the same cell that released them
- **Paracrine signalling** – when signalling molecules act on cells neighbouring the source cell
- **Endocrine signalling** – when signalling molecules are transported in the blood to act on cells far away from the source cell.

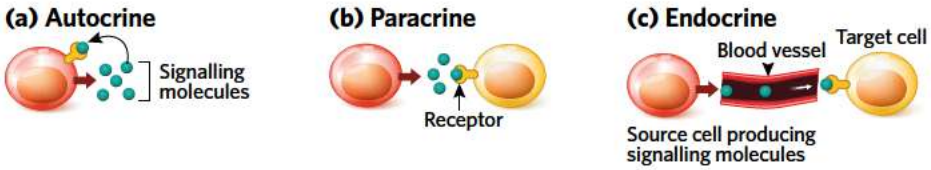


Image: Designua/Shutterstock.com

Figure 2 Following release, signalling molecules can act **(a)** on the original cell (autocrine signalling), **(b)** on a neighbouring cell (paracrine signalling) and **(c)** throughout the body in circulation (endocrine signalling).

There are a variety of chemical signalling molecules found in plants and animals. In VCE biology, you are required to know about: **hormones** in both animals and plants, **pheromones**, **neurotransmitters**, and **cytokines**.

Animal hormones 3.2.1.2

OVERVIEW

Hormones are one of the main types of chemical signalling molecules. In animals, hormones are produced and released by glands, perform a variety of functions, and can act on nearby cells or be transported throughout the body in the bloodstream.

THEORY DETAILS

Hormones are integral to the growth and development of animals. Right now there are 50 million individual hormone molecules inside you causing all kinds of cellular responses.

In animals, hormones are synthesised by **glands** of the **endocrine system** before being transported around the body. The system is made up of many ductless glands (Figure 3) that secrete hormones directly into the bloodstream. These hormones are then transmitted in the blood to target cells.

signalling molecule a molecule which can interact with and initiate a response in a target cell

autocrine signalling when a cell releases a signalling molecule that acts on itself

paracrine signalling when a cell releases a signalling molecule that acts on a neighbouring target cell

endocrine signalling when a cell releases a signalling molecule into the blood to act on a distant target cell

hormone a signalling molecule released from endocrine glands that regulates the growth or activity of target cells

pheromone chemicals that are excreted by one organism and produce a response in another organism

neurotransmitter a signalling molecule that is produced and released by neurons and travels across a synapse

cytokine a signalling protein released by cells (typically in the immune system) that has an effect on other cells

gland a group of cells that secrete chemical substances for use in the body or to be discharged into the surroundings

endocrine system the collection of glands in animals responsible for producing hormones that can be transported in the bloodstream

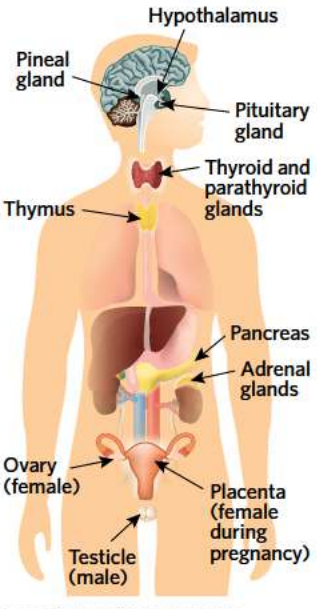


Image: Designua/Shutterstock.com

Figure 3 The endocrine system in humans

When hormones are transported by the blood, it is known as endocrine signalling. However, they can also act locally on neighbouring cells (paracrine signalling) or on the cell that released them (autocrine signalling).

Types of animal hormones

Hormones have an extremely wide range of functions in animals. They can be classified into three main types, outlined in Table 1.

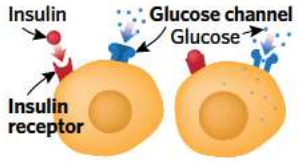


Image: gritsalak karalak/Shutterstock.com

Figure 4 The hormone insulin stimulates glucose uptake.

Table 1 The three types of animal hormones and common examples in humans

Type of hormone	Lipid-based hormones		Peptide and protein hormones		Amino-acid derived hormones	
Description	Lipid-based hormones are derived from fatty acids or cholesterol. When derived from cholesterol they are known as steroid hormones		Peptide hormones consist of short chains of amino acids, whereas protein hormones are longer polypeptides		Small hormones derived from the amino acids tyrosine or tryptophan. Distinguished from peptide/protein hormones by differences in functioning	
Examples	Testosterone	Oestrogen (estrogen)	Insulin (peptide) (Figure 4)	Growth hormone (GH) protein	Adrenaline (epinephrine)	Thyroxine
Origin of example	Adrenal glands and testes	Ovaries, adrenal glands, and testes	Pancreas	Anterior pituitary gland	Adrenal glands	Hypothalamus
Example target cells	Male reproductive tissues	Female reproductive tissues	Many cells	Bone and muscle	Many cells	Many cells
Example response	Sexual development, increased muscle, body hair growth, and plays a small role in female development	Sexual development, breast development, regulation of the menstrual cycle, and plays a role in male sexual function	Regulates blood glucose levels	Promoting protein synthesis and growth	Increases heart rate and blood pressure, increases respiratory rate, causes muscle contractions	Regulates the rate of cellular metabolism

In VCE biology you are not required to memorise specific hormone examples, or the glands of the endocrine system. However, you are required to know the three types of animal hormones, that these hormones are secreted by ductless glands of the endocrine system, and that they may act locally or may be transmitted by the bloodstream to distant organs.

Tip It is important to note that one hormone can cause different responses in different target cells, as different target cells can express different receptor proteins which trigger different signalling pathways (see responses for adrenaline in Table 1).

Plant hormones 3.2.1.3

OVERVIEW

Hormones found in plants are created by a variety of cells. They exist in many forms, five of which you are required to know about for VCE biology.

THEORY DETAILS

Plants also use hormones to communicate between their cells. Unlike animals, plants do not have an endocrine system or specialised glands. Instead, every plant cell is capable of producing a wide range of hormones which can be transmitted around the plant. The five main types of plant hormones are summarised in Table 2.

Table 2 The five types of plant hormones

Type of hormone	Main source	Transmission around plant	Effect
Auxins (Figure 5)	Shoot tip, root tip, seeds	From cell to cell, usually moving to the dark side of the plant	Redistributed to cells on the dark side of a plant. Stimulates cell growth and elongation, causing the shoot tip to grow towards light (phototropism). Gravity will cause auxin to accumulate in the bottom of roots, causing the roots to grow downwards (geotropism)
Cytokinins	Branches, roots, and developing fruit	In xylem	Cell division, lateral branch growth

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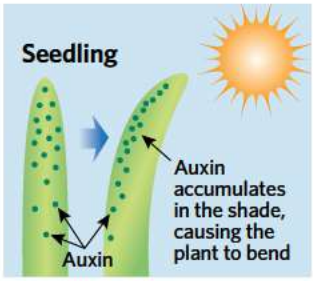


Figure 5 The plant hormone auxin is responsible for phototropism.

Memory device To remember the five types of plant hormones you could remember that to be protected and safe, plants can be placed in **A CAGE**.

Abscisic acid	Chloroplasts of leaves, roots	In xylem and phloem	Seed and bud dormancy, drought tolerance, germination
Gibberellins	Roots and shoots, growing leaves, seeds	Typically used in the cell that made it	Growth accelerator
Ethylene (or ethene)	Ripening fruits, plant body	Diffusion into the atmosphere as it is a gas	Regulation of fruit ripening, dropping of fruits and leaves

Pheromones 3.2.1.4

OVERVIEW

Pheromones are chemical signalling molecules produced in an organism that are transmitted through the air and detected by cells in a separate organism, usually of the same species.

THEORY DETAILS

Pheromones are signalling molecules that are released by an organism into the external environment, and can be detected by another organism. This differs from hormones and other signalling molecules which are responsible for communication between cells within an organism.

Pheromone chemical signals are typically detected by the olfactory (smell) receptors within the nose. Pheromones influence the behaviour and physiology of the receiving individual. The receiving individual is usually a member of the same species as the signalling organism.

Pheromones allow insects such as ants or bees to run their highly structured communities, enable dogs to mark their territories, cue fish to release eggs and semen, and are involved in attracting a mate in many animal species. For example, female moths will release a pheromone into the air when they are ready to breed. Male moths detect this pheromone stimulus and seek out the female, and then the pair breed. The extent to which humans communicate between one another via pheromones is hotly debated.

Case study

Do human pheromones exist?

Bees, wasps, ants, mice, cats, dogs, elephants, and many other animals communicate via pheromones. The human olfactory (smell) system was once thought of as having no role in communication between individuals. However, several studies suggest that human social interactions are influenced by chemicals acting as pheromones, even if they aren't detected consciously. Examples of potential pheromone signalling in humans include:

- Fragrance companies claim that human pheromones exist, especially pheromones relating to sexual attraction. These 'human sex pheromones' are said to play a large role in attraction to potential mates, and by buying certain fragrances you can become more attractive.
- It has been proposed that women living in close proximity can have their menstrual cycles align due to the presence of human pheromones.
- Studies have concluded that infants can recognise their mothers by olfactory clues alone, and it is suggested this is because of pheromones. Some have even gone as far as to say that mothers have the ability to recognise their newborn child by only their smell.

Image: New Africa/Shutterstock.com

Figure 6 There have been claims that fragrances increase attraction by simulating 'human sex hormones'.

Despite these theories, as of now no study has lead to the isolation and chemical identification of human pheromones, although some molecules have been shown to have pheromone-like properties.

Claims of the existence of human sex pheromones have been refuted by researchers due to a lack of evidence and the use of small sample sizes in studies arguing for their existence. A study that proposed pheromones led to menstrual synchrony has been heavily scrutinised for a lack of experimental validity. It seems that, as far as science is currently aware, human pheromones do not exist.

Case study

Pheromone traps

The sex pheromones of insects can be isolated and utilised by humans to construct 'pheromone traps'. Pheromone traps typically contain sex hormones from female insects, which are detected by male insects who are attracted to the scent of the pheromones, and are caught in the trap. The traps are often installed around crops or other areas of interest and can be designed to capture insects for monitoring purposes, or to destroy pests.

Neurotransmitters 3.2.1.5

OVERVIEW

Neurotransmitters are cell signalling molecules that are synthesised and released by neurons. They then diffuse across a synapse to reach their target cell.

THEORY DETAILS

Neurotransmitters are signalling molecules produced and secreted by **neurons** (Figure 7). Neurons are highly specialised cells that use electrical signals to trigger the release of neurotransmitters, allowing for rapid transmission of messages around an animal. Neurotransmitters are released in three steps:

1 The neuron is excited by a stimulus

2 An electric current passes along the neuron

3 This leads to the production and release of neurotransmitters.

neuron a specialised cell that transmits electrical impulses in the nervous system

synapse the junction between a neuron and a target cell where neurotransmitters cross

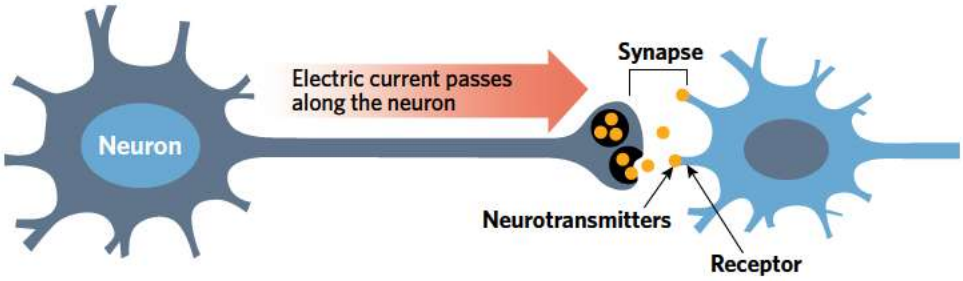


Figure 7 Neurotransmitters travel from a neuron and across the synapse.

Neurotransmitters act via paracrine signalling so, after release via exocytosis, they diffuse across a small gap before reaching complementary receptors on a target cell (Figure 8). If the target cell is another neuron, this gap is known as a **synapse**. If the target cell is a muscle cell, the gap is called a neuromuscular junction. Depending on the target cell, neurotransmitter reception leads to a variety of responses:

- If the cell is a neuron, it can lead to a chain of neurons producing electrical impulses, releasing neurotransmitters, and stimulating the next neuron.
- If the cell is a muscle cell, it may cause muscle contraction.
- If the cell is part of a gland, it may cause hormone release.

Examples of neurotransmitters include serotonin (which contributes to mood, sleep, and feelings of happiness) and dopamine (which plays a role in reward-motivated behaviour).

Tip Although they are not mentioned on the study design, another group of signalling molecules known as neurohormones have appeared in previous exams. Some neurons (known as neurosecretory cells) can produce signalling molecules that are transported in the blood. Because of this, the signalling molecules are called neurohormones as they are produced and released like neurotransmitters, but transmitted like hormones.

Tip The term synapse is often used interchangeably with the term synaptic gap. Technically, the synapse refers to the junction between a neuron and a target cell that is the site of neurotransmitter release and reception whilst the synaptic gap refers to the space between the neuron and target cell. In the past, VCAA have used both synapse and synaptic gap when referring to the area that neurotransmitters travel across.

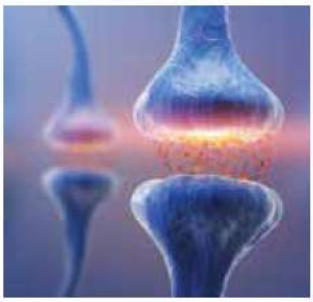


Image: KateStudio/Shutterstock.com

Figure 8 Three dimensional renderings of neurotransmitters travelling across a synapse

Cytokines 3.2.1.6

OVERVIEW

Cytokines are chemical signals typically released by cells of the immune system that communicate with a variety of cell types throughout the body.

lesson link Cytokines are heavily involved in communication between cells in the body's second (***lesson 9C***) and third (***lesson 9D***) lines of defence.

THEORY DETAILS

Cytokines are signalling proteins that are involved in communication between many different cells, however in VCE biology you will focus on their function as part of the immune system. Specialised cells of the body's immune system release certain cytokines that bind to and guide other immune cells to a site of infection or injury. Cytokines cause a number of different responses, and are typically transmitted via autocrine or paracrine signalling. Some cytokines are involved in regulating inflammation and other responses to infection (Figure 9).

Image: kckate16/Shutterstock.com

Figure 9 Some cytokines signal for cells of the immune system to cause inflammation at a site of injury.

Cytokines differ from hormones as all cytokines are protein-based, they are made by a variety of cells rather than specialised glands, and they circulate in lower concentrations than hormones.

Theory summary

Cells communicate with one another by releasing signalling molecules which bind to a receptor and cause a response in a target cell. The types of chemical signalling molecules are summarised in Table 3.

Table 3 A summary of the five main types of chemical signalling molecules

Signalling molecule	Key points	Sources	Mode of transmission
Animal hormones	Three types: • Steroid • Peptide/protein • Amino-acid derived Have many different functions and responses, and can act locally or be transported by the bloodstream	Glands of the endocrine system including the adrenal glands, pituitary gland, and testes/ovaries	Endocrine (in the blood), paracrine, or autocrine signalling
Plant hormones	Five types: • Auxin – phototropism & geotropism • Cytokinins – cell division • Abscisic acid – seed dormancy • Gibberellins – growth accelerator • Ethylene – ripening, dropping of leaves	Majority of plant cells can make many different hormones	Variety, including cell to cell contact, and in xylem and phloem
Pheromones	Released by one organism and cause a response when received by another individual, typically of the same species	Seen in many insects and vertebrates such as cats and dogs.	Airborne, typically received by olfactory system
Neurotransmitters	Released by neurons and travel across a synapse in the nervous system	Neurons	Paracrine signalling across synapse
Cytokines	Involved in communication within the immune system	Cells of the immune system	Typically autocrine or paracrine signalling

8B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ signalling molecules that are released and cause responses in other organisms

b _____ the general name for a molecule that can interact with a cellular receptor and initiate a response in the cell

c _____ a group of signalling molecules involved in the body's immune response

d _____ signalling molecules that are heavily involved in growth and development such as puberty in humans

e _____ signalling molecules released by cells of the nervous system

Question 2

Which of the following are all true of animal hormones?

A	Fall into three types – lipid-based, peptide, and amino-acid derived	Can transmit in an autocrine, paracrine, or endocrine fashion	Are produced by glands of the endocrine system	Examples include insulin, oestrogen, and adrenaline
B	Fall into three types – amino acid-derived, pheromone, and peptide	Can transmit in an autocrine, paracrine, or endocrine fashion	Are produced by neurons of the nervous system	Examples include pheromones, cytokines, and ethylene
C	Fall into three types – lipid-based, peptide, and amino-acid derived	Can only transmit in an endocrine fashion	Are excreted from the organism's body	Examples include insulin, gibberellins, and pheromones
D	Fall into three types – lipid-based, peptide, and amino-acid derived	Can transmit in an autocrine, paracrine, or endocrine fashion	Are produced by glands of the endocrine system	Examples include auxin, oestrogen, and adrenaline

Question 3

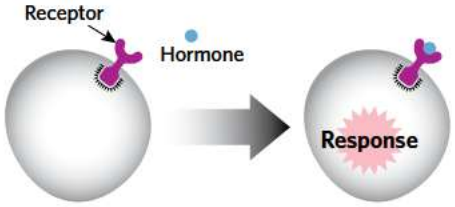
Fill in the blanks in the following sentences.

_____**I**_____ are chemical signalling molecules released by neurons that travel across a gap known as a synapse. They always function within an organism, whereas _____**II**_____ are released by one organism and received by another. Hormones are found in both plants and animals. Plant hormones include _____**III**_____, auxin, and _____**IV**_____.

	I	**II**	**III**	**IV**
A	Neurotransmitters	pheromones	cytokines	ethylene
B	Neurotransmitters	hormones	abscisic acid	gibberellins
C	Neurotransmitters	pheromones	ethylene	abscisic acid
D	Cytokines	hormones	adrenaline	gibberellins

Question 4

A hormone is transported from the pituitary gland through the bloodstream to reach a target cell.



What type of transmission is this an example of?

A autocrine signalling

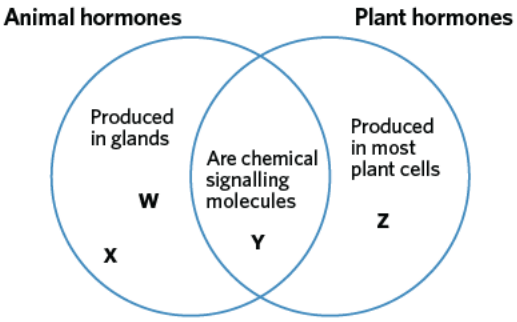
B paracrine signalling

C endocrine signalling

D environmental signalling

Question 5

Look at the Venn diagram comparing animal and plant hormones. Which of the following is correct?



	W	X	Y	Z
A	Can be transported in the bloodstream	An example is adrenaline	A subset of the group are pheromones	An example is cytokinin
B	An example is adrenaline	Fall into three main types	A subset of the group are pheromones	Can be transported in the bloodstream
C	Fall into three main types	An example is ethylene	Can act locally or can be transported around the organism	An example is abscisic acid
D	Can be transported in the bloodstream	An example is testosterone	Can act locally or can be transported around the organism	An example is gibberellin

Exam-style questions

Within lesson

Question 6 (1 MARK)

Cytokines are an example of a signalling molecule.

Cytokines

A are involved in the body's second line of defence in the immune system.

B are a type of steroid used to transmit chemical signals around the body.

C cross a synaptic gap when transmitting a signal.

D only transmit via an autocrine pathway.

Adapted from VCAA 2017 Section A Q20

Question 7 (1 MARK)

The European honey bee (*Apis mellifera*) is a eusocial flying insect that lives in communities where a Queen bee dictates the functioning of the hive. The Queen bee releases chemicals into the environment that cause reactions in other individuals of the hive.

These chemicals are called

A cytokines.

B hormones.

C pheromones.

D neurotransmitters.

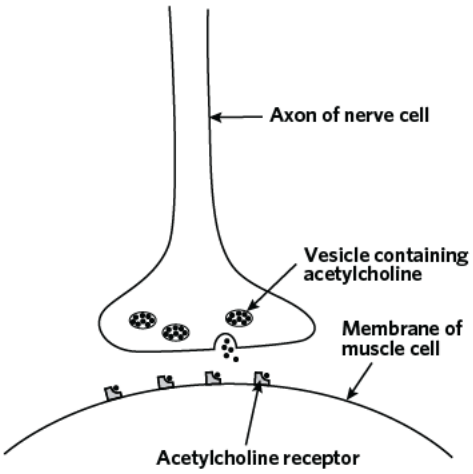
Adapted from VCAA 2013 Section A Q13

Question 8 (1 MARK)

Myasthenia gravis is a disease where the transmission of a nerve impulse is affected.

In myasthenia gravis, communication between a nerve and a muscle across a neuromuscular junction is disrupted. The muscle cannot contract when this communication is disrupted.

The diagram shows a neuromuscular junction, and the release of a type of neurotransmitter called acetylcholine. Reception of acetylcholine increases muscle activity.



Blocking the acetylcholine receptors will

A increase muscle activity as the acetylcholine receptor is stimulated by the blocking molecule.

B decrease muscle activity as the acetylcholine cannot stimulate the acetylcholine receptor.

C decrease muscle activity as the acetylcholine will never be released from the nerve.

D increase muscle activity as the acetylcholine stimulates the acetylcholine receptor.

Adapted from VCAA 2017 Section A Q21

Question 9 (1 MARK)

Which one of the following is false in regards to chemical signalling molecules?

A They can transmit signals via autocrine, endocrine, and paracrine systems.

B Some can be transported through body fluids such as in the bloodstream.

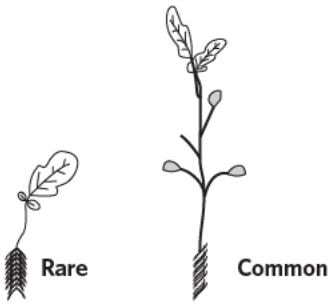
C Both plants and animals communicate via chemical signals.

D They always produce the same response in target cells.

Adapted from VCAA 2015 Section A Q13

Question 10 (1 MARK)

There are two different forms of a common vegetable crop. When both forms are grown for two weeks, the following growth pattern is seen.



The rare form of the vegetable crop is more likely to

A produce more gibberellins than the common form.

B produce less cytokinin than the common form.

C be able to bend towards a source of light.

D release a large number of pheromones.

Adapted from VCAA 2011 Exam 1 Section A Q15

Question 11 (1 MARK)

Hormones are an example of a signalling molecule.

Hormones

A always transmit via an endocrine pathway.

B are released only from cells of the immune system.

C can transmit via an autocrine, paracrine, or endocrine pathway.

D elicit strong responses in another organism when released from the body.

Adapted from VCAA 2017 Section A Q20

Question 12 (1 MARK)

When female ants are ready to copulate, they release a chemical that attracts male ants.

This chemical is a

A neurohormone.

B pheromone.

C hormone.

D cytokine.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q8

Question 13 (1 MARK)

A person is about to be mugged in the street. Inside their body, the chemical signalling molecule epinephrine (adrenaline) is released from the adrenal gland upon feeling threatened causing their heart to beat faster.

Which of the following correctly identifies which group of molecule epinephrine belongs to and an example of its effect?

A pheromone, decreases heart rate
B pheromone, increases heart rate
C hormone, decreases heart rate
D hormone, increases heart rate

Adapted from VCAA 2013 Section B Q3a

Use the following information to answer Questions 14 and 15.

A comparison between aspects of the nervous system and the endocrine system are given in the table.

	Nervous system	Endocrine system
Speed	Faster	Slower
Found in humans?	Yes	Yes
Found in plants?	No	No
Signalling molecule	**W**	**X**

Question 14 (1 MARK)

Which of the following correctly identifies W?

A cytokine
B hormone
C pheromone
D neurotransmitter

Question 15 (1 MARK)

Which of the following correctly identifies X?

A cytokine
B hormone
C pheromone
D neurotransmitter

Adapted from VCAA 2012 Exam 1 Section B Q6c

Multiple lessons

Question 16 (7 MARKS)

Phototropism is the growth of a plant in response to a light stimulus. It is caused by the gathering of a chemical on the dark side of a plant.

a Name the plant hormone responsible for phototropism. (1 MARK)

Adapted from VCAA 2011 Exam 1 Section B Q3a

b Plants contain five major types of hormones. Identify another type of hormone in plants and briefly describe its function. (2 MARKS)

c Bending towards the light is beneficial for plants as it allows them to rearrange their chloroplasts in the leaves to maximise photosynthesis, promoting growth.

State the simplified chemical equation for photosynthesis. (1 MARK)

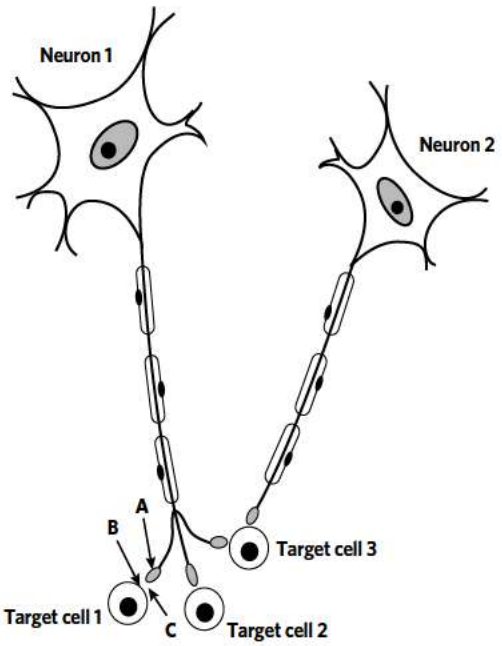
d Animals are also capable of producing their own hormones.

i What is the name of the system that produces hormones in humans? (1 MARK)

ii Hormones can affect cells near their point of secretion, or cells much further away in the body. Explain how some hormones can affect cells far away from their point of secretion. (2 MARKS)

Question 17 (7 MARKS)

The diagram shows two neurons that are capable of interacting with three target cells. Both neurons are excitatory neurons meaning that they stimulate their target cells.



a Identify the type of chemical signalling molecule released by neurons. (1 MARK)

b Neighbouring neurons can pass signals along the nervous system by communicating between cells. Under the stimulus-response model, the response of an intermediate neuron in a chain of neurons is the generation of an electrical current leading to the production and release of neurotransmitters. What is the stimulus that leads to the response of the intermediate neuron? (1 MARK)

c Which label on the diagram represents a synaptic gap? (1 MARK)

d Referring to labels A, B, and C, briefly describe how a neuron can cause an effect on a target cell. (2 MARKS)

Adapted from VCAA 2015 Section B Q2aii

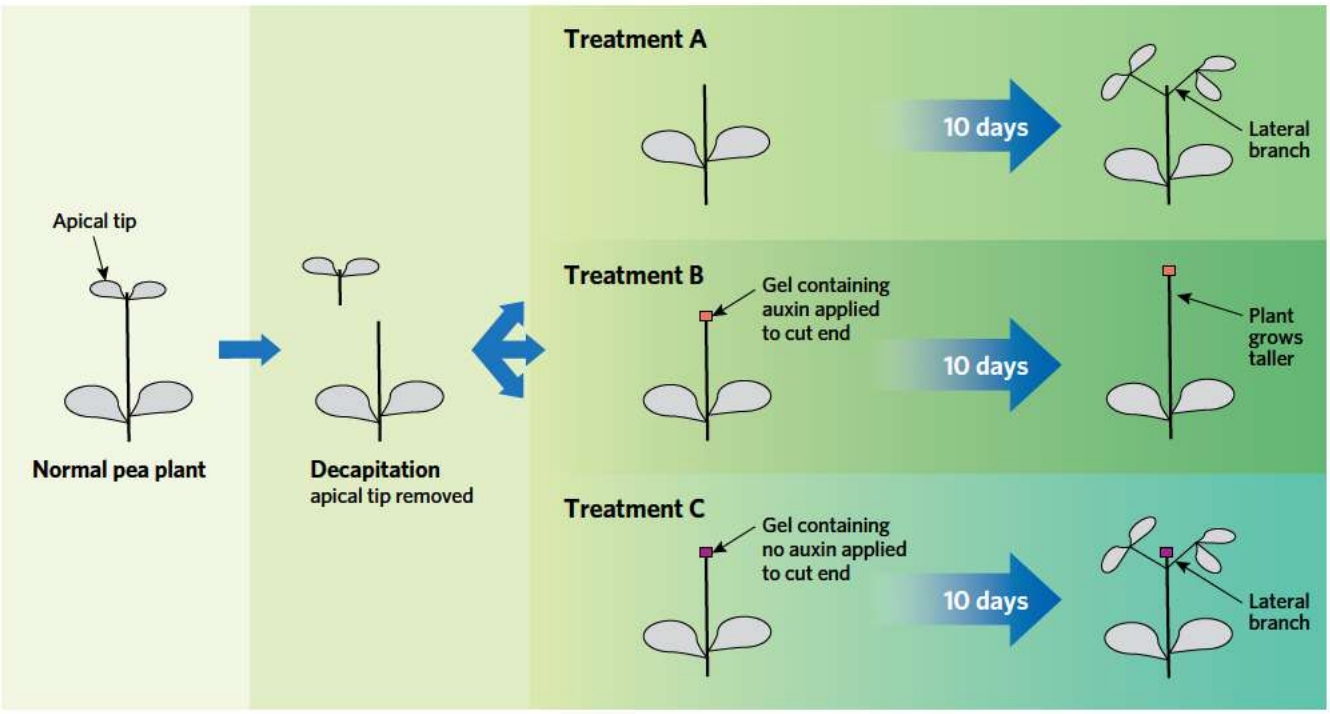
e Which of the three target cells undergoes a response more frequently? Justify your response. (2 MARKS)

Adapted from VCAA 2013 Section A Q9

Key science skills

Question 18 (5 MARKS)

Auxin is one of the five major hormones found in plants. Auxin encourages the growth of a plant's shoot, and is produced in the tip of the shoot. Jessie wanted to test the effect of auxin in the apical tip of a pea plant. She believed that auxin would inhibit lateral branch growth. The following experiment was set up in which three pea plants underwent decapitation (apical tip removed) before receiving separate treatments. Results of each treatment after 10 days are shown.



a What was Jessie's hypothesis? (1 MARK)

b Why were the pea plants decapitated? (1 MARK)

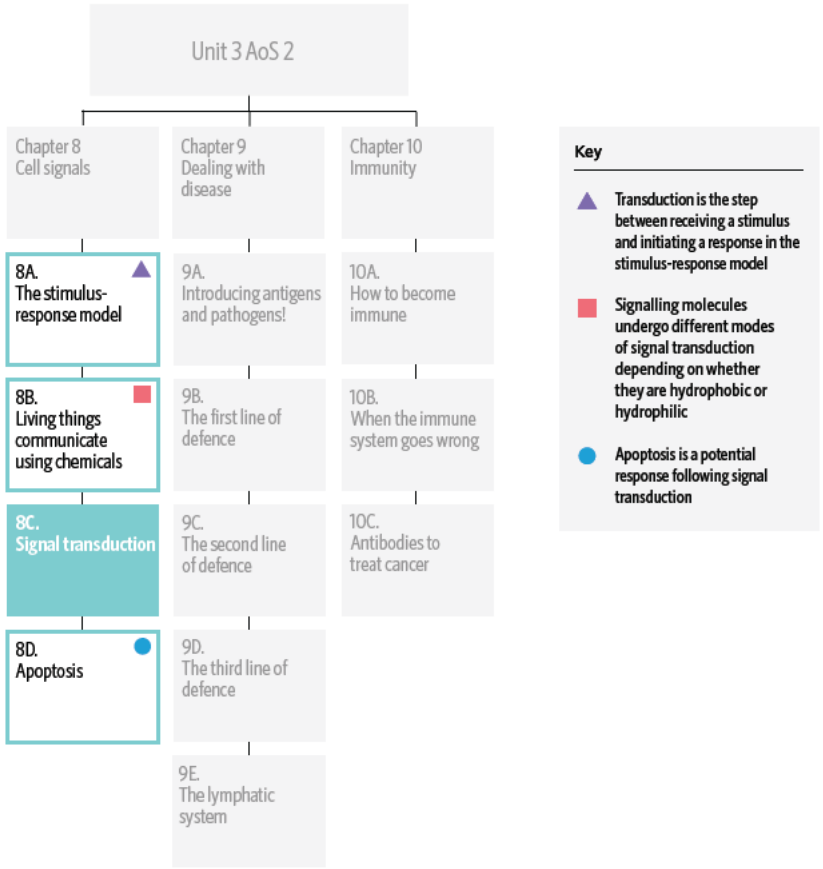
c Treatment A was a control for the experiment as it contained no gel on the cut end. What was the purpose of Treatment C? (1 MARK)

d Do the results support Jessie's hypothesis? Justify your response. (2 MARKS)

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q9

8C SIGNAL TRANSDUCTION

If a chemical signalling molecule is a risky text, signal transduction is that painfully long period where the text travels to, and is received by, your crush, before they initiate a response.



In this lesson you will learn that following a stimulus, there are two pathways for signal transduction of a molecule that lead to a cellular response. The pathway taken depends on whether the signalling molecule is hydrophobic or hydrophilic.

Study design dot point

- difference in signal transduction for hydrophilic and hydrophobic signals in terms of the position of receptors (on the membrane and in the cytosol) and initiation of transduction (details of specific chemicals, names of second messengers, G protein pathways, reaction mechanisms, or cascade reactions are not required)

Key knowledge units

Hydrophobic signalling molecules diffuse through the membrane	3.2.3.1
Hydrophilic signalling molecules need secondary messengers	3.2.3.2

Hydrophobic signalling molecules diffuse through the membrane 3.2.3.1

OVERVIEW

Hydrophobic signalling molecules are able to passively cross the plasma membrane and bind to intracellular receptors, initiating a response in the target cell.

THEORY DETAILS

Signal transduction is the stage in the **stimulus-response model** that bridges the gap between receiving a stimulus and responding. Signal transduction on a cellular level involves transmitting a signal in the form of a **signalling molecule**, eventually leading to a cellular response (Figure 1). This often involves converting the signal (e.g. from an electrical signal to a chemical signal).

signal transduction the series of events that occur after the reception of a signal which results in the generation of a response

stimulus-response model a model that describes how a system responds to a stimulus via the three-step process of reception, transduction, and response

signalling molecule a molecule which can interact with and initiate a response in a target cell

Once a signal reaches the target cell, signal transduction occurs in two distinct pathways depending on the nature of the signalling molecule:

- **Hydrophobic** (typically nonpolar) signalling molecules cross the **plasma membrane** and bind to intracellular receptors.
- **Hydrophilic** (typically polar) signalling molecules cannot cross the plasma membrane and instead bind to transmembrane receptors exposed to the extracellular space.

In this first part of the lesson, you will focus on signal transduction of hydrophobic signalling molecules. In the next section, you will look at hydrophilic signalling molecules.

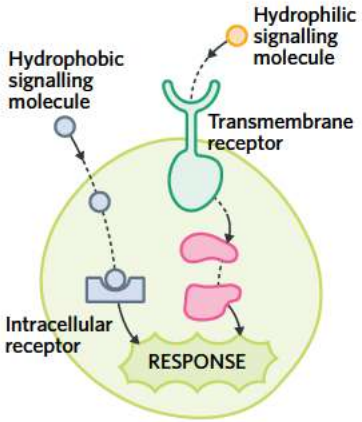


Figure 1 Signal transduction of a hydrophobic signalling molecule (left) and a hydrophilic signalling molecule (right)

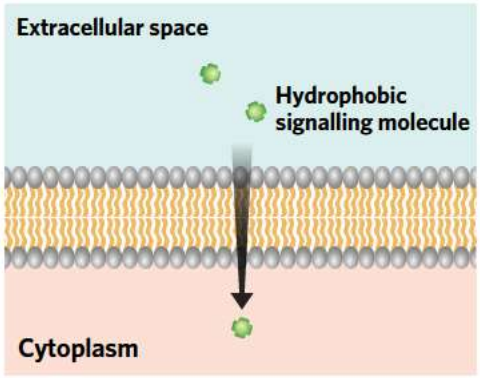


Figure 2 Hydrophobic signalling molecules can cross the plasma membrane by simple diffusion.

The majority of the plasma membrane is composed of nonpolar fatty acids. Because of this, hydrophobic signalling molecules can freely diffuse across the plasma membrane of a target cell (Figure 2). Hydrophobic signalling molecules bind to intracellular receptors (forming a molecule-receptor complex) in the cytosol or in the nucleus. Only cells that have the specific intracellular receptor for a given signalling molecule will respond to its stimulus. To initiate a response in a cell, there are two common modes of action for hydrophobic signalling molecules after binding to receptors:

1 The molecule-receptor complex travels to the DNA and binds to regulatory regions to amplify or repress gene expression. In this case, the signalling molecule acts as a transcription factor.

2 The molecule-receptor complex may repress or activate enzymes in the cell.

Steroid **hormones** like testosterone and oestrogen are types of hydrophobic signalling molecule because they are lipid-based (and lipophilic) (Figure 3). One target of oestrogen is endometrial cells, which are located in the uterus and help produce and maintain the uterine lining. Being hydrophobic, oestrogen passively crosses the membrane of endometrial cells and leads to the activation of genes that are necessary for normal uterine lining development. The process is complex and involves many molecules, however, it demonstrates how a signalling molecule can influence the function of a cell by influencing gene expression.

hydrophobic having a tendency to repel from and be insoluble in water

plasma membrane the phospholipid bilayer and embedded proteins which separate the intracellular environment from the extracellular environment

hydrophilic having a tendency to be attracted to and dissolve in water

hormone a signalling molecule released from endocrine glands that regulates the growth or activity of target cells

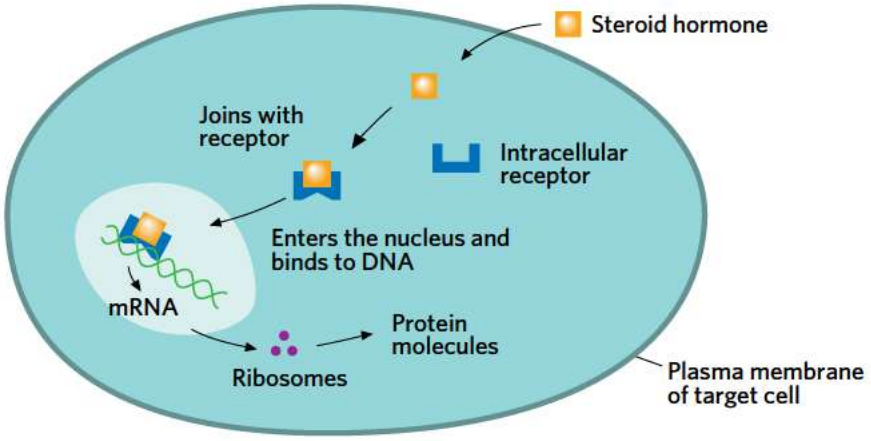


Figure 3 Steroid hormones bind to intracellular receptors before initiating a response

Hydrophilic signalling molecules need secondary messengers 3.2.3.2

OVERVIEW

Hydrophilic signalling molecules cannot readily cross the plasma membrane, so they bind to transmembrane receptors and rely on secondary messengers to pass the signal through a transduction cascade to bring about a cellular response.

THEORY DETAILS

Hydrophilic molecules are typically polar and are therefore unable to diffuse across the plasma membrane in the way hydrophobic signalling molecules can. Because of this, the receptors for hydrophilic signalling molecules are **transmembrane proteins** embedded in the plasma membrane. Each type of receptor has a binding site that is complementary to a particular signalling molecule, so only cells that have the specialised receptor can respond to the signal. Hydrophilic signalling molecules include protein-based hormones, most amino-acid derived hormones, **neurotransmitters**, and **cytokines**.

Because the receptors span the plasma membrane, when a signalling molecule binds to the receptors outside of the cell, this can cause a change within the cell (Figure 4). The change is typically a conformational change of the transmembrane protein, which results in the activation of molecules within the cell.

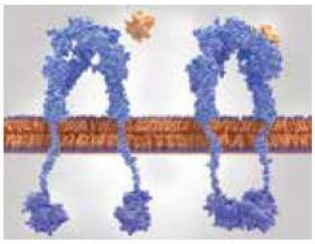


Image: Juan Gaertner/Shutterstock.com

Figure 4 The transmembrane receptor of a hydrophilic signalling molecule (insulin) undergoing a change of configuration upon binding

transmembrane protein an integral protein that spans from the intracellular to the extracellular side of the plasma membrane

neurotransmitter a signalling molecule that is produced and released by neurons and travels across a synapse

cytokine a signalling protein released by cells (typically in the immune system) that has an effect on other cells

second messenger a group of small molecules that relay a signal from a transmembrane receptor during signal transduction. Also known as **secondary messengers**

signal amplification a process during signal transduction whereby a single signal carried by a molecule is converted into many signals carried by many molecules

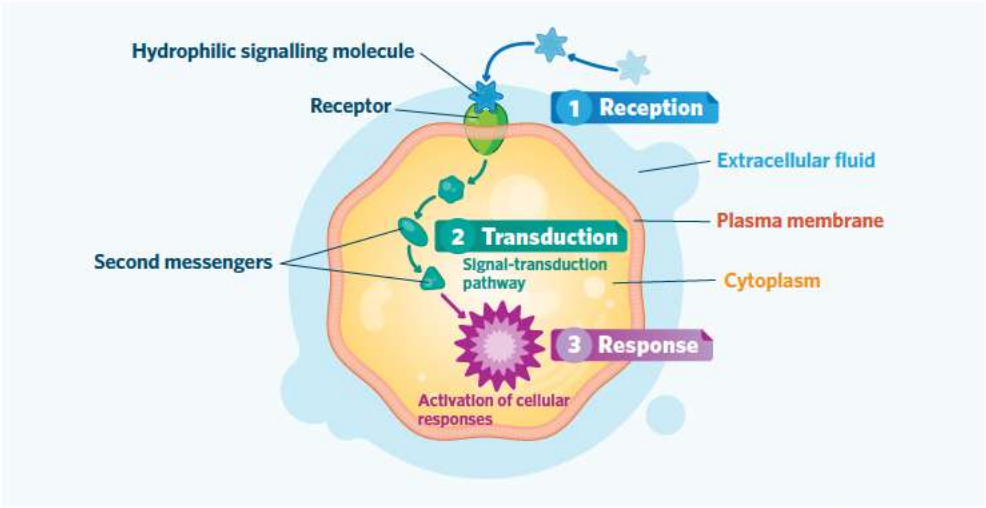


Image: VectorMine/Shutterstock.com

Figure 5 Steps involved in the transduction of a hydrophilic signalling molecule

Once bound to the receptor, the signal carried by the signalling molecule outside of the cell must be relayed to its destination within the cell. This requires several intermediary molecules called **second messengers** and other membrane proteins. Second messengers are usually hydrophilic and function in a sequence, one after another. There are typically many second messengers involved in transmitting a signal from the plasma membrane to the cytosol or nucleus.

When one signal results in the activation of many secondary messengers simultaneously, it is known as **signal amplification** (Figure 6). The amplification of a signal is important as it allows for one signalling molecule to generate a response involving hundreds to millions of molecules.

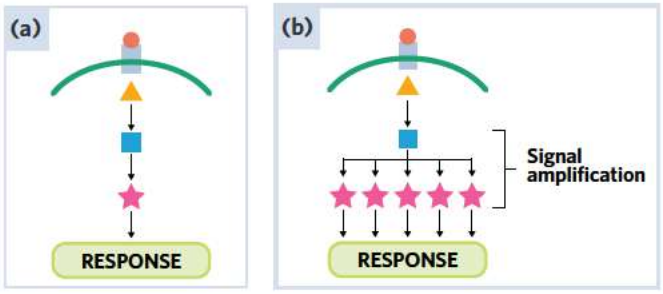


Figure 6 Secondary messengers carry a signal from a transmembrane receptor **(a)** without and **(b)** with signal amplification.

The process of a hydrophilic signalling molecule binding to a receptor, activating a second messenger, which activates another second messenger, and so on until a response is generated, is known as a **transduction cascade**.

transduction cascade the relaying of a signal from a transmembrane receptor to the cytosol or nucleus, involving many second messengers and proteins

In summary, the steps involved in signal transduction of a hydrophilic signalling molecule are:

1. A signalling molecule binds to a specific transmembrane receptor and causes the receptor to undergo a conformational change
2. Second messengers are activated within the cell, leading to a transduction cascade and signal amplification
3. Second messengers deliver the signal to the destination within the cell, causing a cellular response.

Like hydrophobic signalling molecules, hydrophilic signalling molecules often elicit a response relating to gene expression or enzyme activation, or the control of protein channels. An example of the mode of action of the protein-based hormone adrenaline is seen in Figure 7. Here, adrenaline binds to a transmembrane receptor, which activates a second messenger (GTP), which in turn activates cAMP via adenylate cyclase. cAMP activation leads to amplification of the signal, as multiple enzymes are then activated.

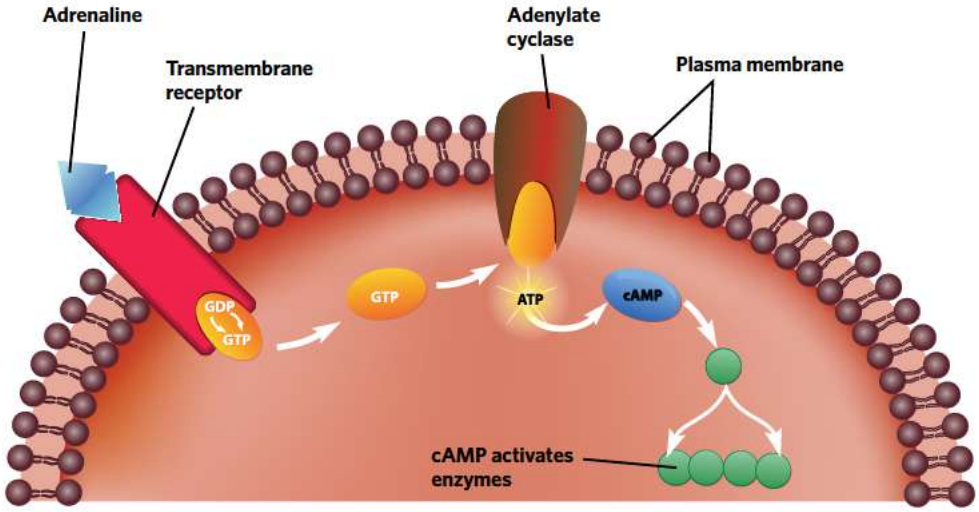


Image: Designua/Shutterstock.com

Figure 7 The first steps of a cascade, initiated by the signalling molecule adrenaline

Case study

MAPK pathway in cancer

The MAP kinase pathway is an important signal transduction pathway in cells that regulates cell growth, proliferation, and differentiation, and plays a key role in the development of cancers.

A stimulus of this pathway is the hydrophilic signalling molecule EGF which binds to the transmembrane protein EGFR. The intracellular domain of EGFR undergoes a conformational change which leads to a complex signalling cascade involving proteins such as RAS, RAF, MEK, and ERK. ERK travels into the nucleus and activates transcription factors (e.g. Myc, Ets, and Fos) which in turn activate hundreds of genes related to cell growth and proliferation. The simple binding of EGF to EGFR can result in changes in the expression of hundreds of genes through the MAPK pathway.

Cancer cells often develop mutations in proteins in the MAPK pathway. For example, around 50% of melanomas contain a mutation in the RAF protein causing it to be constantly expressed, even without activation by EGFR. Constant activation of the target genes in the pathway results in uncontrollable cell growth and proliferation that are characteristic of cancer cells. Many drugs developed to target cancer cells actually target these mutated proteins in the MAPK pathway in order to prevent this overactivation, an example being Vemurafenib which inhibits a mutant form of the RAF protein.

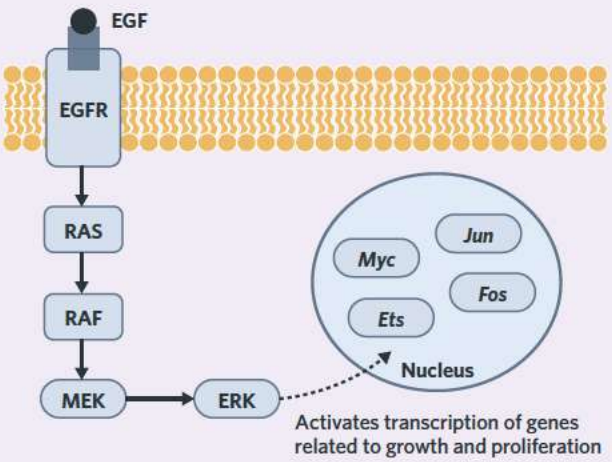


Figure 8 Simplified diagram of the MAPK pathway. There are actually more molecules involved in this signalling cascade in the cytoplasm, not to mention the hundreds of proteins that can inhibit and activate various molecules in this pathway.

Theory summary

Signal transduction encompasses the steps between a cell receiving a stimulus and responding to it. Signal transduction occurs in two major pathways, depending on the nature of the signalling molecule, as summarised in Table 1.

Tip In VCE biology, you are not required to remember specific molecules or pathways such as in Figure 7 or Figure 8. You are, however, required to know the general characteristics of hydrophobic and hydrophilic-initiated signal transduction pathways.

Table 1 Summary of signal transduction of hydrophobic and hydrophilic signalling molecules

	Hydrophobic signalling molecules	Hydrophilic signalling molecules
Nature	Lipophilic, typically nonpolar	Lipophobic, typically polar
Receptor location	Cytosol or nucleus	In the plasma membrane
Mode of action	• Can passively cross the plasma membrane • Bind to intracellular receptors in the cytosol or nucleus • Causes a cellular response, often related to gene expression or enzyme inhibition/activation	• Cannot cross the plasma membrane • Bind to transmembrane receptors, triggering changes in the receptor and within the cell • Second messengers and proteins relay the signal (often with amplification) in a cascade to the cytosol or nucleus • Causes a cellular response, often related to gene expression or enzyme inhibition/activation, or protein channel function
Examples	Steroid-based hormones (e.g. testosterone, cortisol, oestrogen)	Protein-based hormones (e.g. insulin), amino-acid derived hormones (e.g. adrenaline), neurotransmitters (e.g. acetylcholine), cytokines

8C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ describes molecules that are attracted to water and cannot diffuse across the plasma membrane

b _____ small molecules that relay a message received at a transmembrane receptor

c _____ production of multiple signals from one original signal

d _____ a receptor that spans the membrane

e _____ describes molecules that are repelled by water and easily diffuse across the plasma membrane

f _____ the events occurring between receiving and responding to a stimulus in a cell

Question 2

Which of the following are all true of hydrophobic signalling molecules?

A	can diffuse across the plasma membrane	bind to intracellular receptors in the cytosol or nucleus	are water-fearing	are lipid-loving
B	cannot freely diffuse across the plasma membrane	bind to intracellular receptors in the nucleus only	are water-loving	are lipid-fearing
C	can diffuse across the plasma membrane	bind to intracellular receptors in the cytosol or nucleus	are water-loving	are lipid-fearing
D	can diffuse across the plasma membrane	bind to intracellular receptors in the nucleus only	are water-fearing	are lipid-loving

Question 3

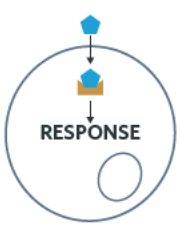
What can be said about the nature of this signalling molecule?

A it is hydrophilic

B it is hydrophobic

C it is amphipathic

D it is neither hydrophilic or hydrophobic



Question 4

The following steps of the signal transduction of a hydrophilic signalling molecule are in the wrong order.

1 The hydrophilic signalling molecule arrives at a target cell

2 The signal cascades between second messengers and undergoes amplification

3 A cellular response occurs

4 The transmembrane receptor activates a second messenger within the cell

5 The amplified signals of the second messengers arrive at an intracellular receptor

6 The transmembrane receptor undergoes a configuration change

7 The hydrophilic signalling molecule binds to the transmembrane receptor

The correct order is:

A 1, 7, 2, 4, 6, 5, 3

B 1, 7, 4, 6, 5, 2, 3

C 1, 7, 4, 6, 2, 5, 3

D 1, 7, 6, 4, 2, 5, 3

Question 5

Classify each of the following statements as either relating to hydrophobic signalling molecules, or hydrophilic signalling molecules. NOTE: some statements may be classified into multiple groups.

I Are lipophilic

II Bind to the extracellular portion of transmembrane proteins

III Are typically polar

IV Can signal for changes in gene expression

V Examples include amino-acid derived hormones and cytokines

VI Can cross the plasma membrane via diffusion

VII Are the stimulus in a stimulus-response model

VIII Require second messengers to transmit the signal

IX Are insoluble in water

	Hydrophobic signalling molecules	Hydrophilic signalling molecules
A	I, III, IV, V, VI, VII	II, IV, VII, VIII, IX
B	I, IV, VI, VII, IX	II, III, IV, V, VII, VIII
C	I, IV, VII, VIII, IX	II, III, IV, V, VI, VII
D	I, III, IV, VI, VII, IX	II, IV, V, VII, VIII

Exam-style questions

Within lesson

Question 6 (1 MARK)

Receptors for the hormone angiotensin are found on the exterior of cells in the adrenal glands, arteries, and fat tissues.

What does this suggest about the nature of angiotensin?

A it is nonpolar

B it is lipophilic

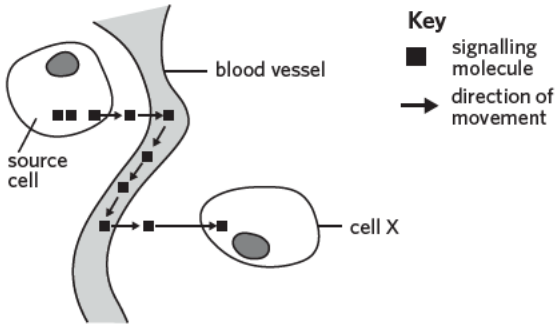
C it is hydrophilic

D it is steroid-based

Adapted from VCAA 2013 Section B Q3b

Question 7 (1 MARK)

Consider the interaction between the source cell and cell X.



The signalling molecule is

A nonpolar.

B lipophobic.

C hydrophilic.

D protein-based.

Adapted from VCAA 2018 Section A Q18

Question 8 (1 MARK)

When a hydrophobic signalling molecule reaches a target cell, which sequence of steps occurs?

A binding to a glycolipid on cell surface, transduction, response

B binding to a cytoplasmic receptor molecule, transduction, response

C binding to a protein receptor on cell surface, transduction, response

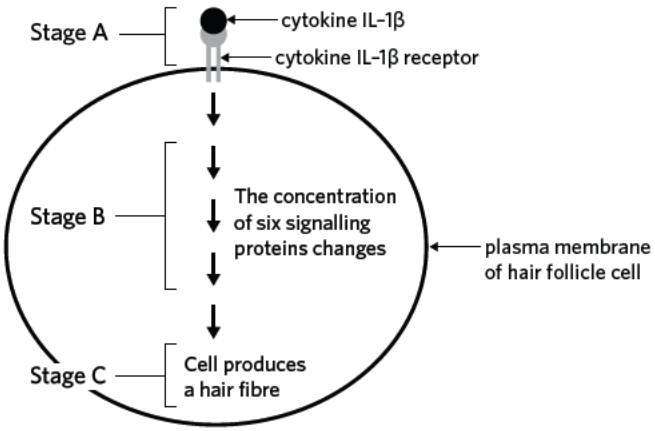
D binding to a plasma membrane protein channel, transduction, response

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q7

Use the following information to answer Questions 9 and 10.

Cytokines play an important role in signalling either the destruction or survival of hair follicle cells in rats. One type in particular, cytokine IL-1β, has a significant effect on hair follicles. Scientists found that six different signalling proteins within the cytoplasm changed in concentration in the presence of cytokine IL-1β.

A simplified cytokine IL-1β cell signalling pathway found in a hair follicle cell is shown.



Question 9 (1 MARK)

Which stage/s represents the stimulus of the model?

A Stage A

B Stage B

C Stage C

D Stages A & B

Question 10 (1 MARK)

The six signalling proteins within the cell changed concentrations in a chain of events. At times, multiple proteins acted as second messengers simultaneously, resulting in multiple molecules carrying a signal.

A statement consistent with the information is that

A Stage B involves a cascade of signals where the signal was amplified.

B Stage B involves a cascade of signals but no signal amplification occurred.

C Stage B does not involve a signal cascade and the signal was not amplified.

D Stage B does not involve a signal cascade but signal amplification occurred.

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q6c

Question 11 (6 MARKS)

A group of scientists are currently studying the molecular mechanisms that cause the sensation of pain. It has been discovered that many different receptors and signalling molecules are involved. The group identified three new specific pain receptors (GPLR4-2, X9, and K2P4) and the nature of the signalling molecules they interact with are shown in the table. K2P4 appears to be a breakthrough discovery as it can interact with multiple kinds of signalling molecules.

Complete the table by suggesting the cellular location of the three receptors (either plasma membrane or inside the cell). Justify your answers.

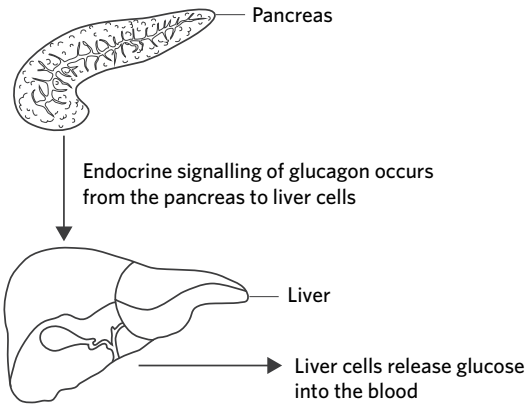
Name of pain receptor	Chemical nature of signalling molecule	Receptor location	Justification
GPLR4-2	Protein-based, hydrophilic		
X9	Lipid-based, hydrophobic		
K2P4	Both protein-based hydrophilic molecules AND lipid-based hydrophobic molecules		

Adapted from VCAA 2015 Section B Q2b

Multiple lessons

Use the following information to answer Questions 12–14.

After exercise, low levels of blood glucose can result in the release of glucagon from the pancreas. One site of glucagon activity is liver cells, where it causes a process called glycogenolysis to occur. In this process, stored glycogen is broken down and glucose is released into the bloodstream.



Question 12 (1 MARK)

Glucagon is made in the endocrine system.

Glucagon is a

A neurohormone.

B pheromone.

C hormone.

D cytokine.

Question 13 (1 MARK)

How is glucagon transported from the pancreas to liver cells?

A in the bloodstream
B transported from cell to cell
C diffusion into the environment
D along neurons of the nervous system

Question 14 (1 MARK)

Glucagon is unable to cross the plasma membrane of liver cells. Which of the following is true of glucagon?

A it is lipophilic
B it is hydrophobic
C it is steroid-based
D it is protein-based

Adapted from VCAA 2014 Section B Q3

Question 15 (1 MARK)

A small percentage of humans are born with malfunctioning protein channels in their plasma membranes.

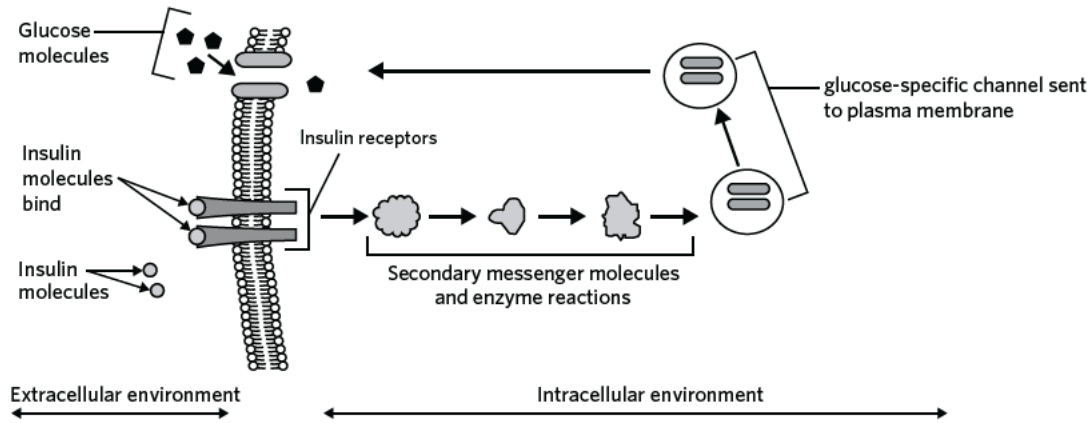
Which one of the following molecules will be difficult to transport across plasma membranes with malfunctioning protein channels?

A cholesterol
B carbon dioxide
C potassium ions
D steroid-based hormones

Adapted from VCAA 2017 Sample Exam Section A Q4

Question 16 (8 MARKS)

The diagram shows a summary of the steps in an insulin signalling pathway that results in increased glucose uptake. Insulin is produced in the pancreas, a part of the endocrine system.



a What type of chemical signalling molecule is insulin? (1 MARK)

b Insulin receptors are found on the plasma membrane.
What can be said about the chemical nature of insulin? (1 MARK)

c There are higher levels of glucose outside of the cell, yet a channel is required for glucose to enter the cell.
- **i** Why is glucose unable to freely enter the cell? (1 MARK)
- **ii** Identify the mode of transport of glucose entering the cell and state if the expenditure of energy is required. (2 MARKS)
- **iii** Does this transport of glucose occur down or against the concentration gradient? (1 MARK)

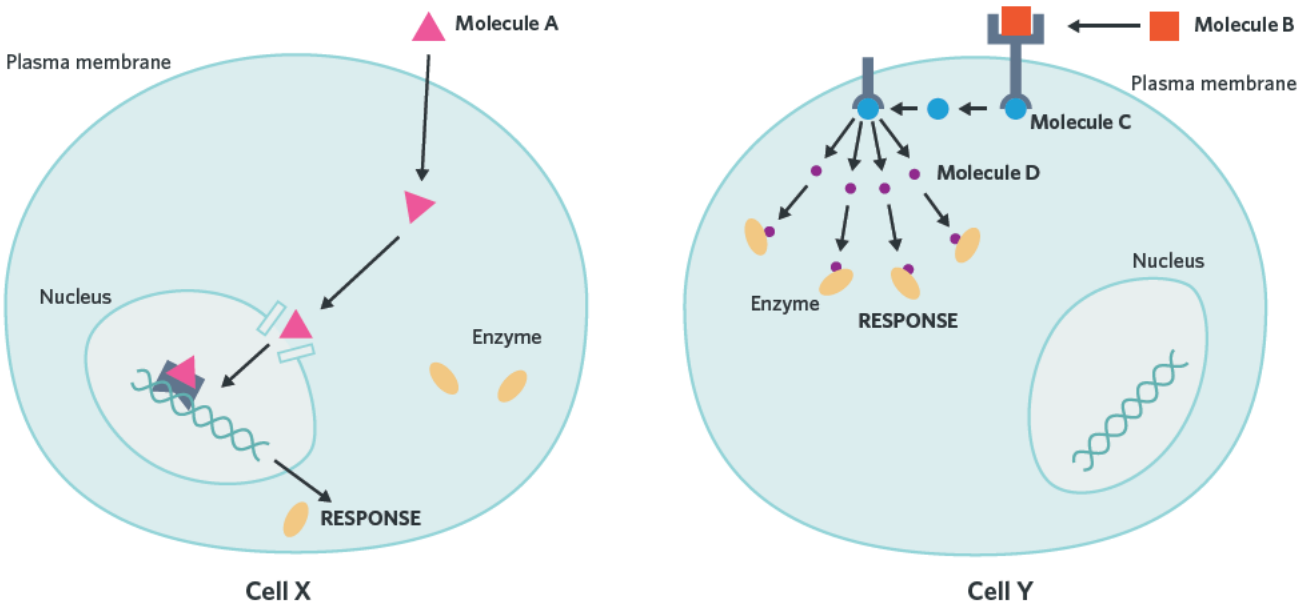
d Describe how an insulin molecule can act on a muscle cell, when it is produced in the pancreas. (2 MARKS)

Adapted from VCAA 2017 Section A Q17

Key science skills

Question 17 (8 MARKS)

Two students, Akmed and Ling, were experimenting on the mode of action of two signalling molecules, A and B. They researched the two signalling molecules and found diagrams of their pathways as shown.



a In which cell/s are second messengers involved in the signalling pathway? (1 MARK)

b In which cell/s does signal amplification occur? Justify your response. (2 MARKS)

c Outline the steps involved in the signalling pathway for Cell Y. (3 MARKS)

d The two signalling molecules, A and B, were isolated in the lab and investigated. Following the investigation, the students collated their results into the following table.

	Molecule A	**Molecule B**
Hydrophilic or hydrophobic	hydrophobic	hydrophilic
Type of signalling molecule	hormone	hormone
Type of hormone	steroid-based	protein-based
Polarity		

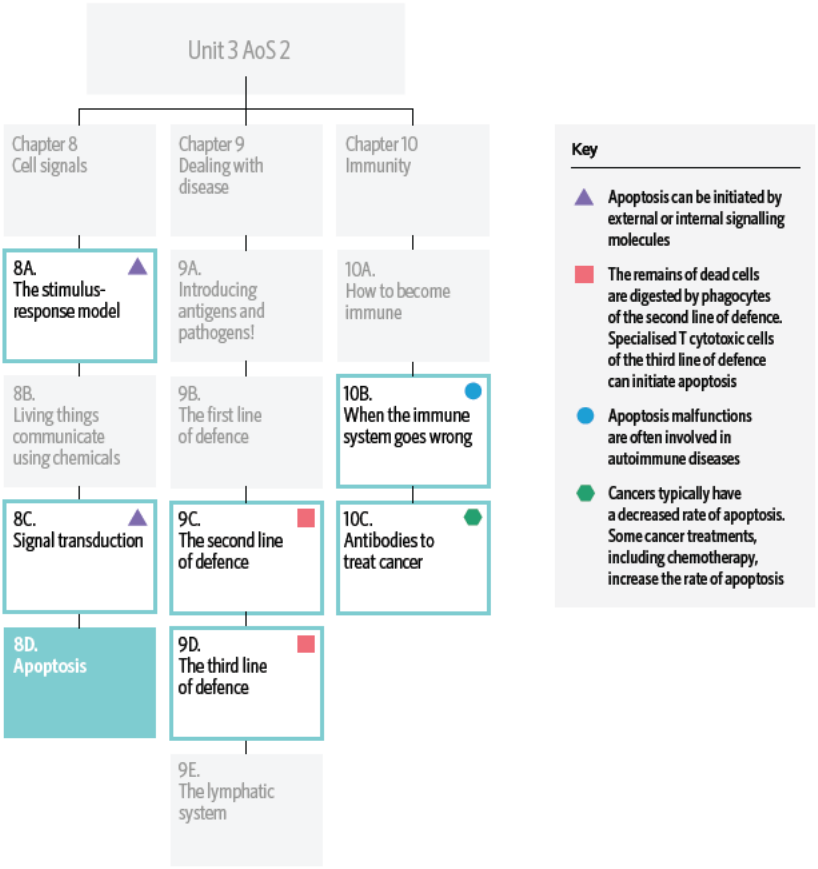
The students could not agree on the polarity of the molecules. Akmed stated that molecule A is nonpolar, as nonpolar substances can easily cross the plasma membrane whereas polar ones such as molecule B cannot. Ling believed that molecule A is polar since polar molecules such as water can easily cross the membrane but nonpolar ones such as molecule B cannot.

Which student is correct? Justify your response. (2 MARKS)

Adapted from VCAA 2018 Section A Q19

8D APOPTOSIS

One cell, two cell, dead cell, blue cell.



In this lesson you will learn that apoptosis regulates the total number of cells in our body, is important for our development, and is an essential method of removing malfunctioning or diseased cells. You will also learn the two pathways of apoptosis (mitochondrial vs death receptor) and the five steps of apoptosis. Finally, you will consider the consequences and diseases associated with apoptosis malfunctions.

Study design dot points

- apoptosis as a natural, regulatory process of programmed cell death, initiated after a cell receives a signal from inside (mitochondrial pathway) or from outside (death receptor pathway) the cell resulting in the removal of cells that are no longer needed or that may be a threat to an organism, mediated by enzymes (caspases) that cleave specific proteins in the cytoplasm or nucleus (details of specific cytoplasmic or nuclear proteins are not required)
- malfunctions in apoptosis that result in deviant cell behaviour leading to diseases including cancer

Key knowledge units

Introduction to apoptosis	3.2.4.1
Apoptosis as a five step process	3.2.4.2
When apoptosis goes wrong	3.2.5.1

Introduction to apoptosis 3.2.4.1

OVERVIEW

Apoptosis is the natural and controlled death of cells within our body which plays an important role in our development and day–to–day lives. It can be initiated by one of two pathways: the mitochondrial pathway or the death receptor pathway.

THEORY DETAILS

Why we like apoptosis

Our body is made up of 30 – 40 trillion cells. Of these, 300 million die every minute, and are usually replaced by healthy cells. These cells typically die through the natural process of **apoptosis**, commonly known as programmed cell death. When a cell begins to malfunction, is damaged, or has become unnecessary it will receive signals that initiate apoptosis, causing the eventual death of the cell. Apoptosis cannot be reversed once it has begun.

There are two pathways of apoptosis: the **mitochondrial** and the **death receptor pathways**, both of which cause the activation of **caspase** enzymes. Following caspase activation, the two pathways become nearly identical.

Initiating apoptosis: the mitochondrial pathway

When internal components of the cell (such as DNA) are damaged, specific proteins cause the initiation of the mitochondrial pathway of apoptosis by acting directly on the mitochondria of a cell. The mitochondria release **cytochrome c** into the cytosol, which binds with cytosolic proteins to form the apoptosome. This begins a cascade of reactions which result in the activation of caspase enzymes.

Initiating apoptosis: the death receptor pathway

Certain extracellular signals and molecules are recognised by 'death receptor proteins' on the membrane surface. These molecules are often cytokines released by **T cytotoxic (T_c) cells**, or cytokines released by various other immune cells. Following activation, the death receptor proteins begin a cascade of reactions within the cell which result in the activation of caspase enzymes.

apoptosis the controlled death of cells in the body. Also known as **programmed cell death**

mitochondrial pathway the pathway of apoptosis which is initiated by the detection of internal cellular damage. Also known as the **intrinsic pathway**

death receptor pathway the pathway of apoptosis which is initiated by the reception of extracellular death signalling molecules. Also known as the **extrinsic pathway**

caspase enzymes that cleave specific intracellular proteins during apoptosis

cytochrome c a protein embedded in the inner mitochondrial membrane. Involved in the electron transport chain of aerobic cellular respiration and the mitochondrial pathway of apoptosis

T cytotoxic cell (T_c) a differentiated T lymphocyte that is responsible for the destruction of infected or abnormal cells

Tip There are many different families of proteins that play a role in the process of apoptosis. In particular, VCAA have talked about Fas receptor proteins (common death receptor proteins that recognise apoptosis-causing cytokines) and the BCL-2 family of proteins (which can either repress or induce the mitochondrial pathway of apoptosis). You don't need to memorise the role of these proteins, but don't be surprised if they (and others) are included as part of the stimulus in an exam question.

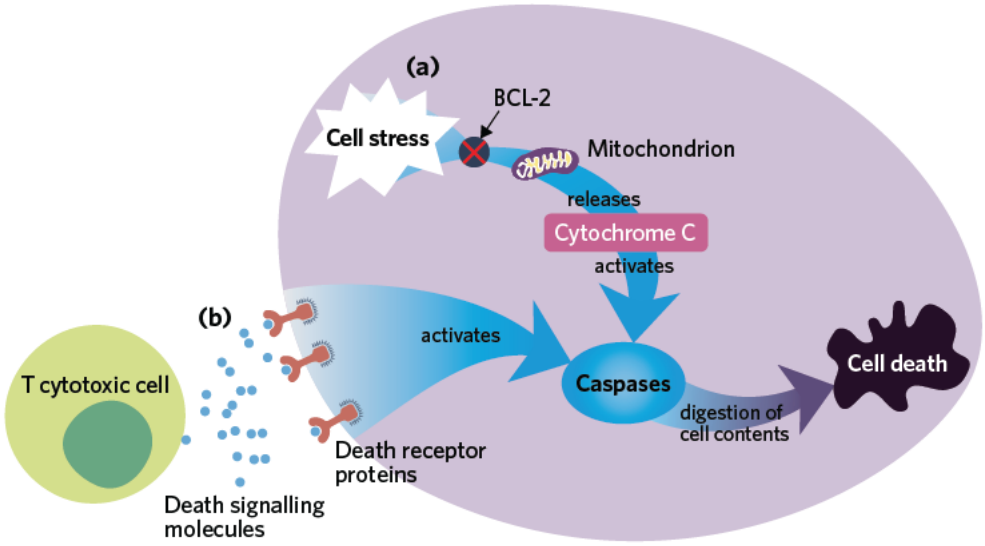


Figure 1 The **(a)** mitochondrial and **(b)** death receptor pathways of apoptosis

Tip Another way that cells can die is called 'necrosis'. Necrosis is the unregulated death of cells initiated by significant damage which causes the cell to swell, burst, and release cell contents into the surrounding environment. This may lead to inflammation and damage of nearby cells and tissues.

While not explicitly mentioned in the VCAA study design, concepts related to necrosis have been mentioned in previous exams, particularly distinguishing between apoptosis and necrosis.

lesson link T cytotoxic cells are extremely important and are heavily involved in the immune system's third line of defence. Their main roles include inducing apoptosis in abnormal, threatening, or infected somatic cells by releasing cytokines. T cytotoxic cells will be covered further in ***lesson 9D***.

Memory device To remember each pathway, remember that you find the mitochondria inside a cell, which means the mitochondrial pathway is the internal pathway of apoptosis and is triggered by signals inside the cell. This leaves the death receptor pathway as the external pathway of apoptosis and is triggered by signals external to the cell.

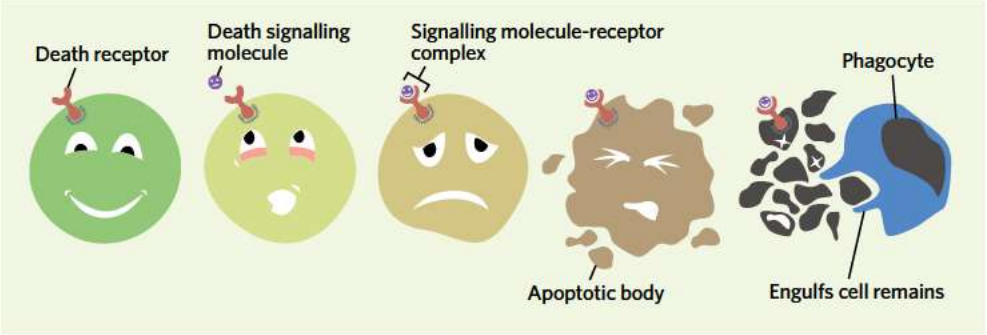


Figure 2 The very friendly cell that undergoes apoptosis

Apoptosis as a five step process 3.2.4.2

OVERVIEW

Following initiation, apoptosis is a five step process that involves: caspase activation, intracellular digestion, cell shrinkage, blebbing and breakage, and digestion by phagocytes.

THEORY DETAILS

After initiation by either the mitochondrial or death receptor pathway, apoptosis progresses as a five step process:

1. Caspase activation – both the mitochondrial and death receptor pathways initiate the activation of intracellular caspase enzymes by cleaving certain amino acid sequences from their structure. Once activated, caspase enzymes travel around the cell, digesting specific proteins.
2. Digestion of cell contents – the caspase–mediated digestion of proteins initiates a cascade of reactions that cause the digestion of all organelles.
3. Cell shrinks – the cell and nucleus shrink as intracellular material is digested.
4. **Blebbing** and breakage – as the cytoskeleton is digested, the structural integrity of the cell is weakened. The membrane warps and detaches from the cell in membrane–enclosed vesicles known as **apoptotic bodies** which contain the digested intracellular contents.
5. Signalling of macrophages - as the cell breaks apart, chemicals are released. These chemicals attract **phagocytes** such as macrophages to the broken down cell. Note that it is only after apoptosis is complete that phagocytes consume apoptoic bodies by **phagocytosis**.

lesson link Phagocytic cells are part of the immune system's second line of defence. Their main role includes the digestion of foreign material and pathogens by phagocytosis. They will be covered further in ***lesson 9C.***

blebbing the bulging of the plasma membrane to form separate apoptotic bodies

apoptotic bodies vesicles containing cell contents that are released from a dying cell during apoptosis and engulfed by phagocytes

phagocyte a group of leukocytes responsible for the endocytosis and destruction of pathogens and foreign material

phagocytosis endocytosis of solid material or food particles

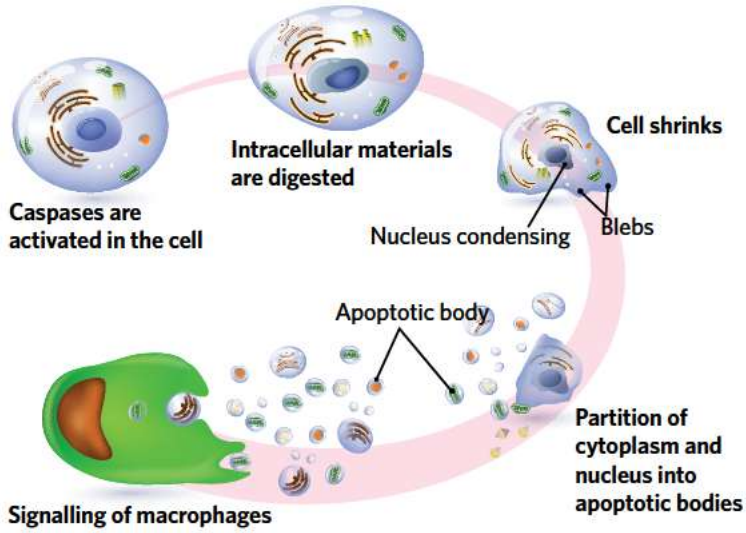


Image: Designua/Shutterstock.com

Figure 3 The process of apoptosis

When apoptosis goes wrong 3.2.5.1

OVERVIEW

Too much apoptosis and we become sick and die. Too little apoptosis and we also become sick and die. It's all about the perfect balance.

THEORY DETAILS

When functioning properly, apoptosis is vital to the healthy functioning and development of almost all eukaryotic organisms. However, apoptosis–related malfunctions are the root cause of deviant cell production and some of the most deadly diseases that we know of.

Increasing apoptosis causes the death of too many cells and may lead to neurological disorders such as Huntington's disease and Alzheimer's (a type of dementia). Insufficient apoptosis can allow cells to replicate exponentially, allowing the formation of tumours and cancers.

cancer a disease caused by the uncontrolled replication of cells

Case study

Increasing apoptosis: diseases and disorders

While already common, apoptosis is sometimes kicked into overdrive, and otherwise healthy cells begin programmed cell death. This excessive cell death can have far-reaching impacts on an individual's health and functioning.

Many neurological disorders (diseases that affect the nervous system) are linked to an increased rate of apoptosis in cells of the brain (e.g. neurons and glial cells). As these cells die, the total number of neurons and neurological connections in the brain is reduced. Difficulty in movement, changes to mood, and significant decreases in cognitive ability are all common symptoms of neurological diseases such as Huntington's disease, Parkinson's disease, and Alzheimer's dementia.

Increases in the rate of apoptosis are often caused by the overproduction of proteins which stimulate a pathway of apoptosis, or the overstimulation of death receptor proteins by T cytotoxic cells.

While there is often no known effective treatment for these types of neurological disorders, some drugs under investigation aim to decrease the rate of apoptosis by suppressing cells of the immune system (such as T cytotoxic cells).

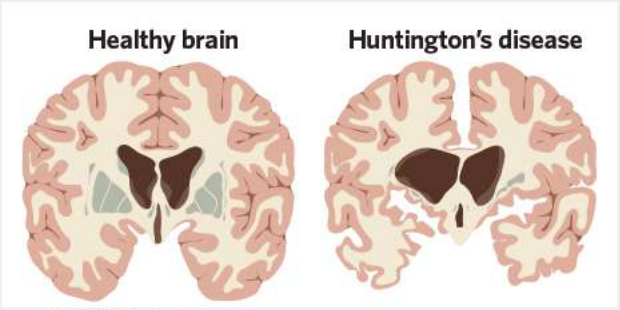


Image: Blamb/Shutterstock.com

Figure 4 Sufferers of Huntington's disease often have large tissue gaps caused by excessive cell death.

Case study

Decreasing apoptosis: diseases and disorders

When you decrease the rate of cell death, you increase the rate of cell growth. Unfortunately, when the rate of apoptosis decreases too much, cell growth can increase exponentially, resulting in the formation of large masses called tumours. As these tumours are growing so quickly, they require large amounts of energy. Thus, tumours can literally 'sap a person of their strength' and their rapid growth can interfere with organ and tissue function.

Too little apoptosis can also cause developmental abnormalities. As we grow, our body can mark entire areas of cells for cell death. For example, as foetuses, our fingers and toes are all fused together by skin. As we grow, our body induces apoptosis in the cells of the skin between our fingers to form individual fingers.

A decrease in the rate of apoptosis can allow this skin to remain and our fingers to be fused together after we are born. This disorder is known as 'syndactyly' (Figure 6). Syndactyly is not life-threatening and can be managed through surgery.

Decreases in the apoptosis rate are often caused by the overexpression of proteins which repress the pathways of apoptosis (such as the BCL-2 family of proteins seen in Figure 1), or malfunctions in proteins such as the death receptor proteins.

Many of the treatments for diseases caused by a decrease in the rate of apoptosis (such as cancer) rely on increasing the rate of apoptosis in cells by causing intracellular DNA damage. This is how most chemotherapy drugs operate.

Image: napocska/Shutterstock.com

Figure 5 Cancer can sometimes be treated with chemotherapy.

Image: JorgeMRodrigues/Shutterstock.com

Figure 6 The fingers on this girl's hands are still fused together after birth due to insufficient apoptosis in the skin cells between those fingers during foetal development.

Theory summary

Apoptosis is an integral process of the body. It is necessary during foetal development, for controlling total cell numbers in the body, and for the removal of diseased or damaged cells. There are two general methods of apoptosis initiation: the mitochondrial pathway (which recognises intracellular signals) and the death receptor pathway (which recognises extracellular signals).

Once initiated, apoptosis progresses as the five step process: caspase activation, digestion of cell contents, cell shrinkage, cell blebbing and breakage, and digestion of apoptotic bodies by phagocytes.

Changes in the total rate of apoptosis can have major health implications. An increase in the rate of apoptosis can cause the death of too many cells, resulting in neurological disorders such as Huntington's disease or Alzheimer's dementia, and a decrease in the rate of apoptosis can cause diseases and disorders such as cancer and syndactyly.

8D QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a disease caused by a decrease in apoptosis that involves the growth of tumours

b _____ occurs when protrusions form on the membrane of a cell during apoptosis

c _____ by releasing cytokines, this cell can begin the death receptor pathway of apoptosis

d _____ the pathway of apoptosis that begins with internal cell damage

e _____ a series of changes within a cell that result in programmed cell death

f _____ vesicles that are digested by phagocytes during apoptosis

Question 2

Apoptosis

A causes a cell to die and release chemicals that are recognised by phagocytes.

B only begins after significant mitochondrial damage.

C is initiated due to regulated gene expression.

D causes a cell to expand and rupture.

Question 3

The sequence of events occurring during apoptosis has been shuffled.

1 Blebbing followed by formation of apoptotic bodies

2 Activation of caspase enzymes by amino acid cleavage

3 Phagocytosis of apoptotic bodies

4 Shrinkage of the cell and nucleus

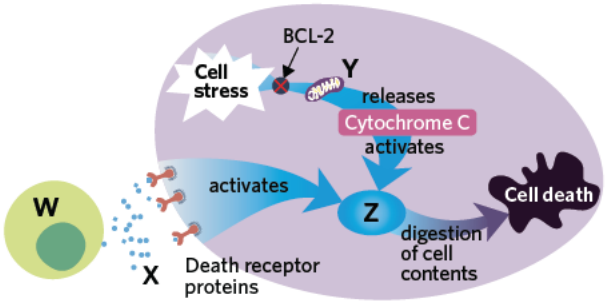
5 Digestion of intracellular contents

Choose the correct sequence of events in the table.

A	2, 4, 5, 1, 3
B	1, 2, 3, 4, 5
C	1, 4, 2, 3, 5
D	2, 5, 4, 1, 3

Question 4

Identify the structures W, X, Y, and Z in the figure.



	W	X	Y	Z
A	phagocyte	death signalling molecules	nucleus	transcription of enzymes
B	phagocyte	death receptor protein	mitochondrion	transcription of enzymes
C	T cytotoxic cell	death signalling molecules	mitochondrion	caspases
D	T cytotoxic cell	death signalling molecules	nucleus	caspases

Question 5

Fill in the blanks in the following sentences.

Many diseases are caused by an alteration in the rate of apoptosis in particular tissues in the body. _____**I**_____ in the rate of apoptosis can be caused by the overstimulation of _____**II**_____ by T cytotoxic cells, increasing the chances of developing _____**III**_____.

	I	II	III
A	An increase	death receptor proteins	neurological diseases
B	A decrease	the mitochondria	syndactyly
C	A reduction	apoptosis repressor proteins	Alzheimer's
D	A rise	apoptosis promoter proteins	cancer

Exam-style questions

Within lesson

Question 6 (1 MARK)

Cells can die by apoptosis or necrosis. Apoptosis

A begins after the plasma membrane is pierced by extracellular proteins.

B is a highly regulated and controlled cell death pathway.

C always follows damage to the mitochondria.

D causes a cell to swell and burst.

Adapted from VCAA 2013 Section A Q12

Question 7 (1 MARK)

Death receptor proteins

A are an important part of the mitochondrial pathway of apoptosis.

B detect the presence of a death signalling molecule.

C can only be found in the cytosol of the cell.

D initiate necrosis in cells.

Question 8 (1 MARK)

During apoptosis, blebbing

A is preceded by the production of apoptotic bodies.

B is only caused by damage done to the DNA of a cell.

C causes a cell to appear smoothed out and stretched.

D can be characterised by bulging of the plasma membrane.

Question 9 (1 MARK)

Alzheimer's dementia is relatively common, affecting almost 350 000 individuals in Australia alone. The disease is characterised by changes in mood and personality, general confusion, and significant decreases in cognitive ability. Recent studies suggest that some forms of Alzheimer's are caused by the excessive death of neurons via apoptosis.

In the brain of someone suffering from Alzheimer's, you would expect to find

A excessive tumours.

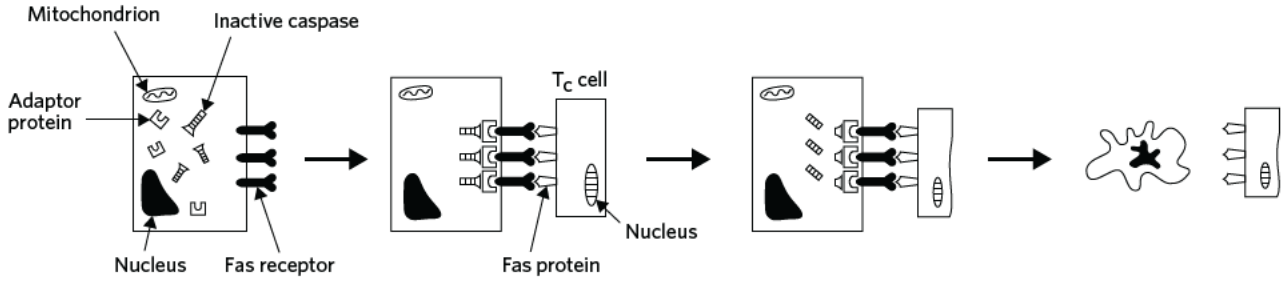
B increased numbers of old neurons.

C high concentrations of phagocytic cells.

D high concentrations of free-floating caspase enzymes.

Use the following information to answer Questions 10–12.

Regulated cell death occurs in aging and damaged cells. This process involves activated enzymes called caspases. Caspase activation leads to the breakdown of the cytoskeleton, the mitochondrial membrane, and the nuclear membrane. The pathway for caspase activation can be initiated by cells of the immune system's third line of defence, the T cytotoxic cell (T_C). A T_C cell initiating apoptosis in a target cell is shown in the diagram.



Question 10 (1 MARK)

In the diagram, apoptosis is initiated

A via the mitochondrial pathway.

B after the T_C cell undergoes apoptosis.

C following the reception of T_C produced hormones by the Fas receptor.

D by caspases being activated after binding with the adaptor protein and Fas receptor.

Adapted from VCAA 2015 Section A Q11

Question 11 (1 MARK)

The final stage of apoptosis involves

A engulfment by T cytotoxic cells.

B the attraction of phagocytes to the cell.

C the apoptotic cell shrinking and blebbing.

D the cell releasing cytokines, causing swelling and inflammation.

Adapted from VCAA 2014 Section A Q9

Question 12 (1 MARK)

In some human diseases, malfunctions in programmed cell death result in the death of too many cells.

At a cellular level, excessive cell death by apoptosis may be caused by

A decreased production of caspase enzymes.
B an increase in the production of cytotoxic T cells.
C an increase in the production of the Fas inhibitor protein, BCL–2.
D blunt trauma applied to the skin, causing cells to swell and burst.

Adapted from VCAA 2018 Section B Q2c

Question 13 (1 MARK)

Apoptosis can be initiated by damage to intracellular contents such as DNA or organelles. Following such damage

A the cell will shrink.
B DNA will be transcribed to produce caspase enzymes.
C the cell will release pheromones and become engulfed by phagocytic white blood cells.
D specific proteins will puncture the cell membrane, causing the cell contents to leak out.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q11

Question 14 (4 MARKS)

Damage to the DNA in a cell can initiate programmed cell death.

a Would apoptosis in this cell be initiated by the death receptor pathway? Justify your response. (2 MARKS)

b Describe one change that occurs external to the cell during apoptosis. (1 MARK)

Adapted from VCAA 2018 Section B Q2a

c What role is carried out by phagocytes during apoptosis? (1 MARK)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q4a

Multiple lessons

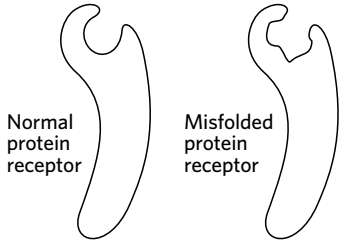
Question 15 (1 MARK)

Cytochrome c

A hydrolyses starch to produce glucose.
B binds to and transports oxygen around the body.
C can recognise and activate death receptor proteins.
D plays a role in the electron transport chain of aerobic cellular respiration.

Question 16 (6 MARKS)

Thyroid lymphoma is a type of cancer characterised by large tumours in the neck. The chance of someone suffering from thyroid lymphoma is increased by malfunctions in the structure and function of membrane death receptor proteins.



a Misfolding of the receptor protein has been linked to an increase in the chance of developing thyroid lymphoma.
  i How might misfolding impact the function of the receptor protein? (2 MARKS)
  ii How might misfolding of the receptor protein increase chances of developing thyroid lymphoma? (2 MARKS)

b BCL–2 proteins are known to be able to repress the mitochondrial pathway of apoptosis.
Predict the activity of the BCL–2 protein in cancerous cells compared to normal cells. Justify your response. (2 MARKS)

Key science skills

Question 17 (6 MARKS)

Treating malfunctions in apoptosis

Apoptosis (commonly known as 'programmed cell death') is the body's way of regulating diseased or damaged cells, and managing the total number of cells in the body. You can often find cancer and senescent cells in tissues which have insufficient rates of apoptosis.

Cancer cells replicate extremely quickly and resist apoptosis. Masses of these cancer cells are called 'tumours' and these tumours can cause health complications and even death. Current treatments for cancer often cause cancer cells to undergo apoptosis. For example, many chemotherapy drugs damage DNA within cancer cells. This damage is recognised by the cell and the cell begins apoptosis.

Chemotherapy is considered effective when compared to other anticancer drugs, but is criticised for low specificity as chemotherapy can cause apoptosis in a wide range of cell types.

Senescent cells resist apoptosis but, unlike cancer cells, they do not replicate. While seemingly innocuous and difficult to identify, senescent cells can release cytokines which cause inflammation in surrounding cells and rarely perform any useful role. As senescent cells do not undergo apoptosis, they accumulate within certain tissues of the body and have been linked to aging in humans.

'Senolytic' drugs recognise certain proteins only expressed by senescent cells and selectively initiate apoptosis in these cells. Studies have found that senolytic drugs can cause the release of cytochrome c within a cell. Mice treated with senolytic drugs have an increased life expectancy of up to 30%. In Australia, senolytic drugs have not yet been approved for human trials.

a Identify two mechanisms by which a cell may become 'apoptosis-resistant'. (2 MARKS)

b Do chemotherapy and senolytic drugs activate the same pathway of apoptosis? Justify your response. (2 MARKS)

c Which drug type is likely to have more severe side effects associated with their use? Justify your response. (2 MARKS)

ACTIVITIES

How do plants respond to light?

Phototropism is the term that describes the growth of a plant toward or away from light. Plants that grow toward light are said to be positively phototropic; plants that grow away from light are said to be negatively phototropic.

Phototropism is mediated by a plant hormone called auxin. Auxin is produced in the growing tip of a plant coleoptile (the protective covering of shoot tip) and diffuses from cell to cell toward the plant body. Auxin stimulates cell elongation in shoot tips. The movement of auxin is inhibited by light. Therefore, as the auxin diffuses away from the coleoptile, it is most concentrated on the side away from the light, where it also stimulates cell elongation. Since the cells on the side of the coleoptile away from the light grow longer than those facing the light, the plant grows towards the light source.

Materials and apparatus

- Bean seeds
- Petri dish containing moist soil or cotton wool
- Lamp (preferably with a Grolux globe)
- Cardboard box
- Ruler
- Aluminium foil
- Cling wrap

Procedure

1. Grow 15 bean seeds on the Petri dish in the dark until the shoots are just emerging from the seed.
2. Divide the group into three groups, with each group containing five seeds.
3. In one group, place an aluminium foil cap on the coleoptile of each of the shoots.
4. In a second group, place a cling wrap cap on the coleoptile of each of the shoots.
5. Do nothing to the third group.

   Each group should look similar to the diagrams given.

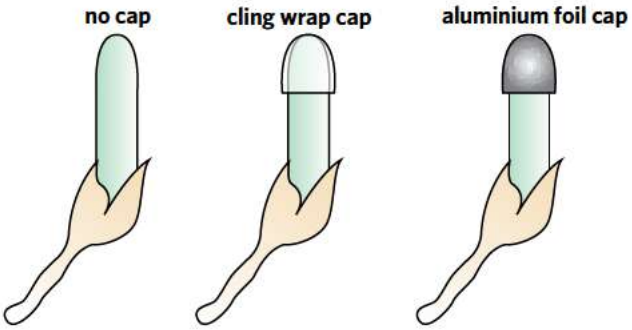


Figure 1 The three experimental bean groups

6. Place the Petri dish containing all 15 shoots in the cardboard box. Cut a hole in one side of the box and position the lamp so it is shining into the box through the hole.
7. After two days, photograph the Petri dish from both sides. Print the photographs and use a protractor to measure the angle of each shoot from its base to its tip, with 0° being vertical and 90° being horizontal.
8. Copy the table given onto a sheet of paper and record the angle of each shoot.

Results table

	No cap	Plastic wrap cap	Aluminium foil cap
Shoot 1			
Shoot 2			
Shoot 3			
Shoot 4			
Shoot 5			
Average (mean)			

Questions

1 After reading the procedure, what is your hypothesis for the experiment?

2 Assuming plant growth follows the stimulus–response model, what is the stimulus in this experiment?

3 One of the groups involved used an aluminium foil cap. Explain why this group was included.

4 One of the groups involved used a plastic wrap cap. Explain why this group was included.

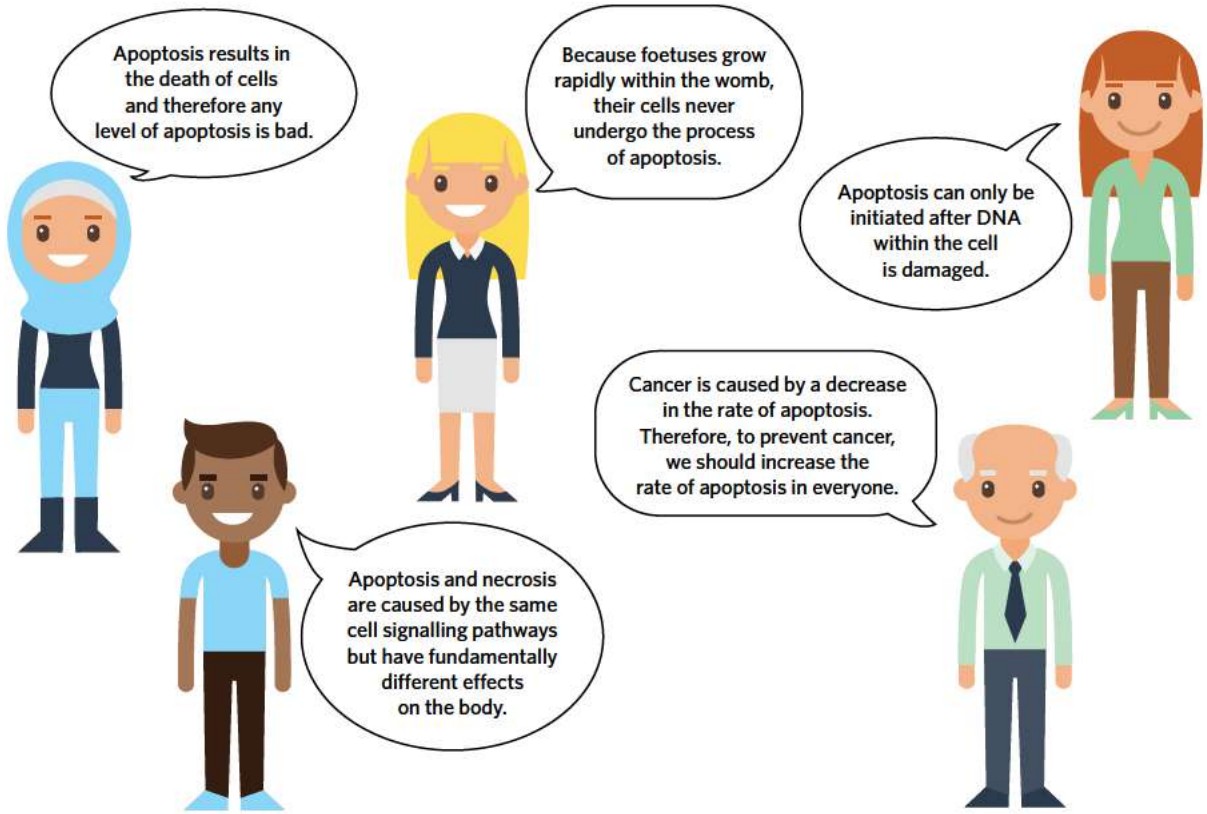
5 One of the groups involved used no cap. Explain why this group was included.

6 Did you notice any differences between the experimental groups?

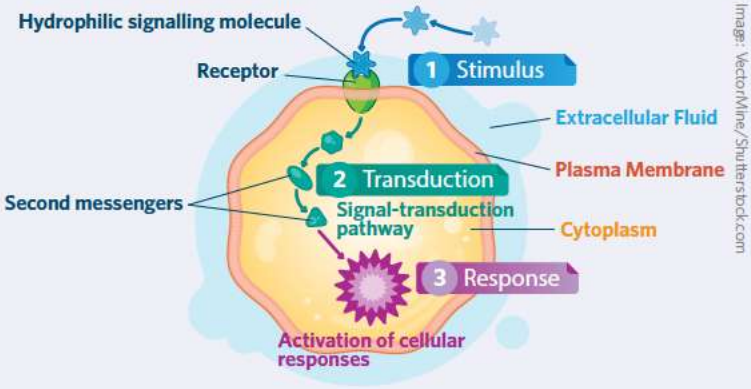
7 Do the results of the experiment support your hypothesis? If yes, why? If not, why not? Make sure you include the terms auxin and signal transduction.

Education outreach

Many people do not have a background in biological studies, and often misunderstand important biological concepts. Five statements concerning apoptosis are given. For each one, pretend you are having a discussion with someone and respond by saying whether you agree or disagree, and why. If you do not know enough to respond to the statement in full, conduct your own independent research to find the answer.



CHAPTER SUMMARY



Signalling molecules and the stimulus-response model

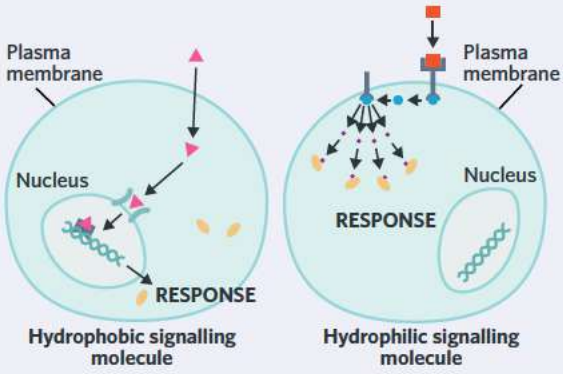
The stimulus-response model can be used to describe how a signalling molecule interacts with a target cell. For example:

1 A hydrophilic signalling molecule binds to the receptor and is the stimulus.
2 The signal is carried in a transduction cascade.
3 A response is initiated within the cell.

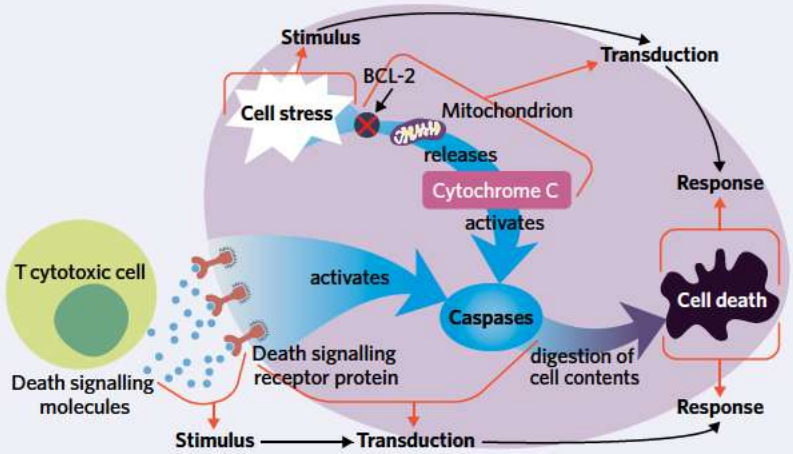
Signalling molecule	Key points	Sources	Mode of transmission	Hydrophilic or hydrophobic
Animal hormones	Three types: • Steroid • Peptide/protein • Amino-acid derived	Glands of the endocrine system	Endocrine (in the blood), paracrine, or autocrine signalling	Steroid – hydrophobic Protein – hydrophilic Amino-acid – hydrophilic (mostly)
Plant hormones	Five types: • Auxin – phototropism & geotropism • Cytokinins – cell division • Abscisic acid – seed dormancy • Gibberellins – growth accelerator • Ethylene – ripening, leaf dropping	The majority of plant cells can make many different hormones, depending on the cells' needs	Variety, including cell to cell contact and in xylem and phloem	Mostly hydrophilic
Pheromones	Excreted by one organism to cause a response when received by another individual (typically of the same species)	Seen in many insects and vertebrates such as cats and dogs	Airborne, typically received by the olfactory system	Both
Neurotransmitters	Released by neurons and travel across a synapse in the nervous system	Neurons	Paracrine signalling across a synapse	Hydrophilic
Cytokines	Involved in communication within the immune system	Cells of the immune system	Typically autocrine or paracrine signalling	Hydrophilic

Signal transduction pathways

	Receptor location	Mode of action
Hydrophobic signalling molecules	Cytosol or nucleus – as the lipophilic molecules can diffuse across the plasma membrane with ease	Bind to intracellular receptors and directly cause a cellular response. The response is often a change in gene expression or enzymatic activity.
Hydrophilic signalling molecules	Embedded in the plasma membrane – as lipophobic molecules cannot freely cross the plasma membrane	Bind to transmembrane receptors and trigger a change within the cell. A cascade of second messengers carry the signal, which can also be amplified, to its destination. The response is often a change in gene expression, enzymatic activity, or protein channel functioning.



Apoptosis



Steps of Apoptosis

1 Caspase activation
- Activated by either the mitochondrial (internal) or death receptor (external) pathway, caspases digest specific intracellular proteins

2 Digestion of cell contents
- Caspases cause a cascade that leads to digestion of all organelles

3 Cell shrinkage
- Cell shrinks due to digestion

4 Blebbing and breakage
- Organelles and cytoskeleton are digested, apoptotic bodies detach from the cell

5 Signalling of macrophages
- Phagocytes recognise chemicals released by the cell

QUESTIONS

SECTION A (15 MARKS)

Question 1 (1 MARK)

When a cell is suffering from a viral infection, it often secretes large amounts of a chemical signalling molecule. Surrounding cells can recognise this signal and prepare for viral infection.

This chemical is most likely

A a cytokine.
B an enzyme.
C a carbohydrate.
D a neurotransmitter.

Adapted from VCAA 2017 Sample Exam Section A Q18

Question 2 (1 MARK)

Caspases are a large group of proteins that play an important role in the regulation of cells in our body.

Caspases

A initiate DNA replication.
B direct how cells differentiate and arrange themselves.
C cleave specific proteins in the cell as part of apoptosis.
D initiate a response which causes cells to rapidly multiply.

Question 3 (1 MARK)

Neurotransmitters are an example of a signalling molecule.

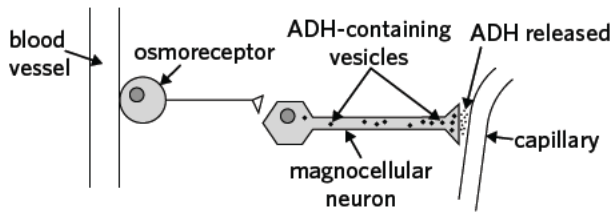
Neurotransmitters

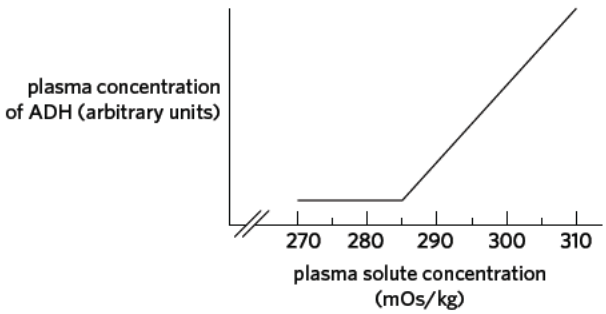
A can be released into an organism's external environment for communication purposes.
B are released after being triggered by an action potential.
C are excreted by cells in response to viral infections.
D travel through the xylem in plants.

Adapted from VCAA 2017 Section A Q20

Use the following information to answer Questions 4 and 5.

Antidiuretic hormone (ADH) is a hormone involved in the regulation of blood plasma solute concentration. Osmoreceptors detect changes in blood plasma solute concentration and stimulate magnocellular neurons. Magnocellular neurons are special neurons that synthesise ADH, storing ADH in vesicles until stimulated to release it. ADH diffuses across a gap and into a capillary. The release of ADH into the bloodstream can trigger the constriction of arterial walls and increases the reabsorption of solute-free water from the kidneys back into the bloodstream. This process is shown in the diagram. The graph shows the concentration of ADH in the blood at different plasma concentrations.





Question 4 (1 MARK)

Based on the information given and your own knowledge, which one of the following is a correct statement?

A At plasma solute concentrations below 285 mOs/kg, the neuron does not synthesise ADH.

B At plasma solute concentrations above 285 mOs/kg, the osmoreceptor cannot detect changes.

C At plasma ADH concentrations above 285 mOs/kg, the magnocellular neuron will release ADH directly into a capillary.

D At plasma solute concentrations below 285 mOs/kg, the frequency of electrical impulses within the magnocellular neuron do not trigger the release of ADH containing vesicles.

Adapted from VCAA 2016 Section A Q14

Question 5 (1 MARK)

When considering the ADH transduction pathway, the stimulus is the

A release of solute-free water from the kidneys.

B feeling of thirst associated with high solute concentrations in the blood.

C plasma solute concentration (mOs/kg) within the blood stimulating the osmoreceptor.

D stimulation of the magnocellular neuron, triggering the release of ADH into the bloodstream.

Question 6 (1 MARK)

In plants, a signalling molecule is released which stimulates the growth and elongation of particular cells.

This signalling molecule is most likely

A a pheromone.

B a cytokine.

C an auxin.

D ethylene.

Question 7 (1 MARK)

In apoptosis

A cells release large amounts of neurotransmitters.

B cells rapidly multiply, causing diseases such as cancer.

C certain proteins are cleaved by various caspases.

D DNA is ejected from the cell and taken up by surrounding bacteria.

Adapted from VCAA 2014 Section A Q9

Question 8 (1 MARK)

In multicellular organisms, cells have receptors for death-signalling molecules which play a role in apoptosis.

These death-signalling molecules

A initiate a cascade of reactions which cause the cell to erupt and release cell contents.

B play an important role in the natural development of an organism.

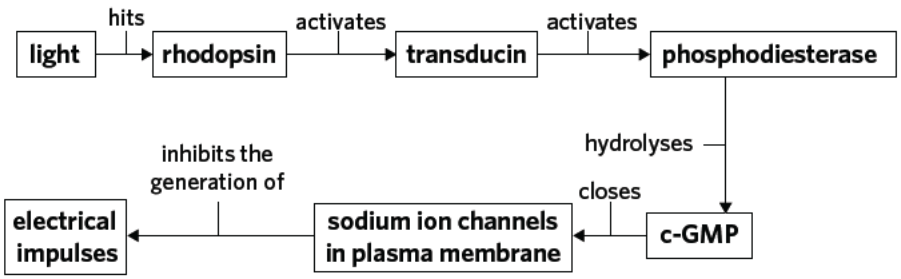
C initiate the production of caspases.

D increase the rate of cell divisions.

Adapted from VCAA 2013 Section A Q12

Use the following information to answer Questions 9 and 10.

The flow chart summarises a sequence of events occurring inside a rod cell in the retina of the human eye.



Question 9 (1 MARK)

In the summarised sequence of events, the response is the

A closure of sodium ion channels in the plasma membrane.

B inhibition of electrical impulses.

C light hitting the rod cells.

D activation of transducin.

Adapted from VCAA 2012 Exam 1 Section B Q6bi

Question 10 (1 MARK)

In the summarised sequence of events, the stimulus is the

A light hitting rhodopsin.

B activation of transducin.

C generation of electrical impulses.

D closure of sodium ion channels in the plasma membrane.

Adapted from VCAA 2012 Exam 1 Section B Q6bi

Question 11 (1 MARK)

An experiment was conducted to explore the effect of the plant growth regulator indoleacetic acid (IAA).

In the experiment, radish seedlings were grown in different concentrations of IAA, as indicated in the table.

Concentration of IAA (parts per million)	Stimulation (+)/inhibition (–) of shoot growth (%)	Stimulation (+)/inhibition (–) of root growth (%)
0	0	0
0.00001	+0.10	–30
0.0001	+6	–50
0.001	–20	–70
0.01	–60	–85
1	–70	–90
10	–80	–95
100	–90	–100

Which one of the following hypotheses is supported by the results of the experiment?

A Any concentration of IAA will always inhibit shoot growth.

B Concentrations of IAA above 0.001 stimulate the replication of DNA.

C High concentrations of IAA inhibit shoot growth and have no effect on root growth.

D Concentrations of IAA above 0.001 parts per million inhibit both shoot and root growth.

Adapted from VCAA 2016 Section A Q15

Question 12 (1 MARK)

Which one of the following statements is correct about chemical signalling molecules?

A They always contain an active site.

B They are always a part of the nervous system.

C They can induce different effects in different cell types.

D They act as carrier proteins to transport nutrients around the body.

Adapted from VCAA 2015 Section A Q13

Question 13 (1 MARK)

When a hydrophobic signalling molecule reaches a target cell, which sequence of steps occurs?

A binding to DNA within the cell, transduction, response

B binding to a protein receptor on the cell surface, transduction, response

C binding to a cytoplasmic receptor molecule, transduction, response

D binding to a protein channel on the cell surface, passing through protein channel, transduction, response

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q7

Question 14 (1 MARK)

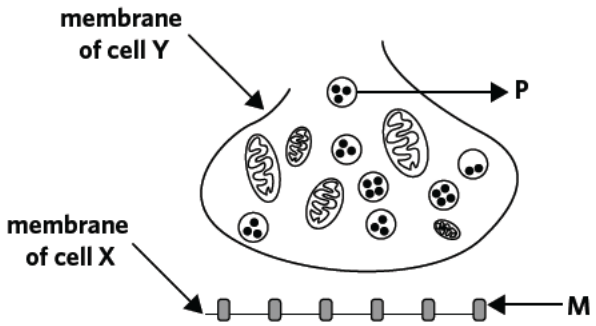
The diagram represents a synapse. It is reasonable to suggest that

A neurotransmitter molecules pass through the membrane of cell Y by passive diffusion.

B neurotransmitter molecules are uptaken by cell X via endocytosis.

C neurotransmitter molecules are recognised by structure M.

D structure P contains positively charged ions.



Adapted from VCAA 2012 Exam 1 Section A Q17

Question 15 (1 MARK)

A common neurotransmitter is acetylcholine (ACh), which excites the post-synaptic neuron. Lack of ACh in brain synapses has been linked to Alzheimer's disease. A number of other chemicals also act at synapses. The table outlines some of these chemicals and their actions.

Chemical	Source in nature	Effect at synapse
Botulinum	*Clostridium* bacteria	Prevents release of ACh from the pre-synaptic membrane
Eserine	African calabar bean	Inhibits acetylcholinesterase, the enzyme which breaks down ACh after post-synaptic stimulation
Curare	South Americal plant *Chondrodendron* sp.	Blocks post-synaptic receptors
Nicotine	Tobacco plant	Stimulates the brain in the same way as ACh

Based on this information, a possible treatment for Alzheimer's disease is to

A synthesise and administer a drug with similar structure to Eserine.

B drink *Chondrodendron* sp. infused tea.

C recommend a patient stop smoking.

D inject Botulinum as a drug.

Adapted from VCAA 2011 Exam 1 Section A Q18

SECTION B (25 MARKS)

Question 16 (4 MARKS)

The thyroid gland has a large role in the regulation of many essential bodily functions, including metabolic rate, breathing, pulse rate, temperature regulation, and muscle mass.

The thyroid gland produces two main signalling molecules, known as thyroxine and triiodothyronine. Over multiple studies, scientists have noted that the binding of these two signalling molecules to specific cellular receptors influences gene expression, cell differentiation, and plays a role in triggering apoptosis. Responses to thyroid hormones have been noted to differ between cells extracted from the heart and kidneys.

a What name is given to the process by which the thyroid signalling molecules cause cellular responses? (1 MARK)

Adapted from VCAA 2016 Section B Q3a

b The receptors are made up of many molecular monomers called 'amino acids'. What group of biomacromolecules do the cellular receptors belong to? (1 MARK)

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q1a

c Receptors for thyroid hormones are found in the cytosol of cells. What does this suggest about the nature of thyroid hormones? (1 MARK)

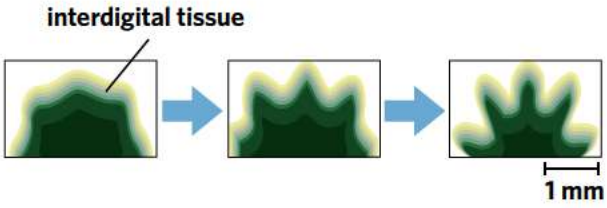
Adapted from VCAA 2015 Section B Q2b

d Suggest how the same thyroid hormones can produce different cellular responses in heart and kidney cells. (1 MARK)

Adapted from VCAA 2013 Section B Q3cii

Question 17 (6 MARKS)

Apoptosis plays a vital role in the development and regulation of cells both during and after embryonic development. The diagram shows the formation of a mouse's paw during embryonic development. The interdigital tissue is removed over successive timesteps due to the process of apoptosis.



a Considering the development of mice paws, explain the consequence of a reduced rate of apoptosis. (1 MARK)

b Other than assisting in paw formation, state two benefits of apoptosis in mice. (2 MARKS)

Adapted from VCAA 2018 Section B Q2b

c Apoptosis can be initiated internally by a cell. Explain how apoptosis can be initiated by the intrinsic signalling pathway. (2 MARKS)

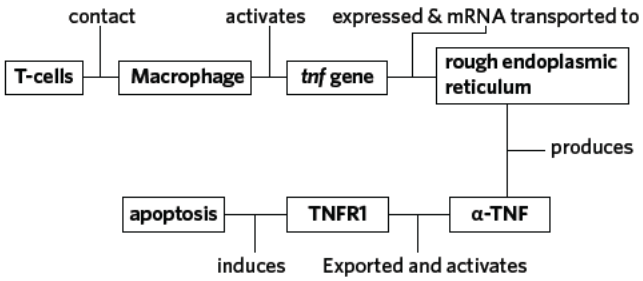
d What are the role of caspases in apoptosis? (1 MARK)

Adapted from VCAA 2017 Sample Exam Section B Q4a

Question 18 (10 MARKS)

The TNFR1 is a death receptor which plays an important role in the initiation of apoptosis in many cell types. Research into TNFR1-induced apoptosis has shown promise for the future of cancer research. The TNFR1 transmembrane protein is activated by the cytokine TNF (tumour necrosis factor). α–TNF is a cytokine produced by a number of cell types, including macrophages, neutrophils, smooth muscle cells, lymphocytes, and endothelial cells.

One pathway for the production of α–TNF has been documented by scientists, where macrophages within the joints of patients suffering from rheumatoid arthritis have been documented to be stimulated by contact with specialised cells. The flow chart summarises the sequence of events occurring inside the joint which results in the eventual apoptosis of affected cells.



a Explain why the macrophage is the receptor in this system. (1 MARK)

b TNFR1 is a transmembrane death receptor protein.

i What does this suggest about the nature of α-TNF? (1 MARK)

Adapted from VCAA 2015 Section B Q2b

ii Describe how the attachment of a molecule, such as α-TNF, to a transmembrane receptor can bring about a response within a cell. (2 MARKS)

c The simplified diagram shows the α-TNF death signalling molecule.

Draw and label a cell being stimulated by the α-TNF death signalling molecule. Be sure to include the TNFR1 death signalling receptor, cell membrane, and the α-TNF death signalling molecule. (2 MARKS)

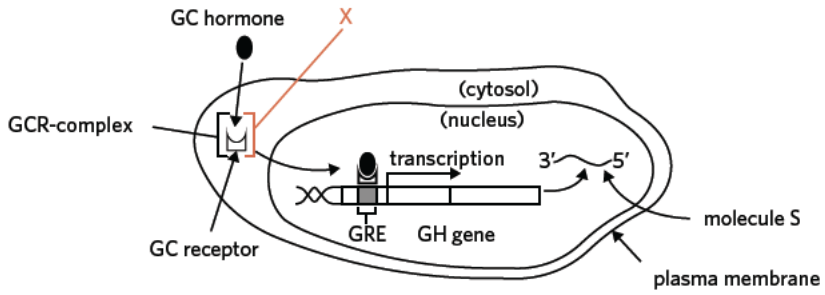
d Outline the main stages in cell apoptosis once stimulated by an extrinsic signalling molecule. (3 MARKS)

e The overproduction of α-TNF molecules can result in the overstimulation of cells, increasing the rate of apoptosis. State a consequence of an increase in the rate of apoptosis. (1 MARK)

Question 19 (5 MARKS)

Glucocorticoid (GC) is a hormone in rats that binds to a receptor, as shown in the diagram. The glucocorticoid–receptor complex (GCR–complex) moves into the nucleus and attaches to the DNA, causing transcription to begin.

GC signal transduction in rat pituitary glands



The location where the GCR–complex attaches to the DNA is called the glucocorticoid response element (GRE). The GRE is located approximately 250 base–pairs upstream of the growth hormone (GH) gene. Following the attachment of the GCR–complex to the GRE, an enzyme catalyses the transcription of the gene.

a Identify what stage of the cell signalling pathway occurs in region X. (1 MARK)

b Scientists have discovered molecules which can competitively inhibit the GC receptor protein found in rats. Explain the effect of these molecules on the expression of the GH gene in rats. (2 MARKS)

c Molecule S contains the genetic information required to produce a protein. Name the process that occurs at the ribosome during protein production. (1 MARK)

d The glucocorticoid (GC) hormone can produce different cellular responses in different cell types. Suggest whether the structure of the growth hormone (GH) protein differs between cell types. (1 MARK)

UNIT 3 AOS 2, CHAPTER 9

Dealing with disease

09

9A Introducing antigens and pathogens!

9B The first line of defence

9C The second line of defence

9D The third line of defence

9E The lymphatic system

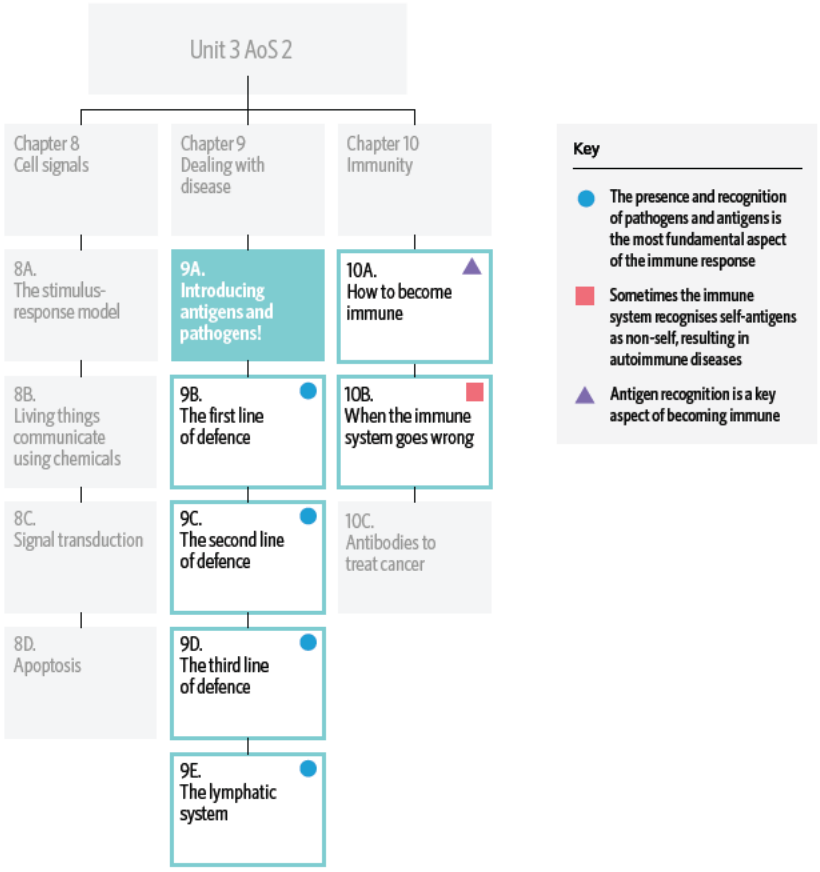
Key knowledge

- an antigen as a unique molecule or part of a molecule that initiates an immune response including the distinction between non-self antigens, self-antigens, and allergens
- invading cellular and non-cellular pathogens as a source of non-self antigens, and preventative strategies including physical, chemical, and microbiological barriers in animals and plants that keep them out
- the characteristics and roles of components (macrophages, neutrophils, mast cells, dendritic cells, complement proteins) of the innate (non-specific) immune response to an antigen including the steps in the inflammatory response
- the characteristics and roles of components of the adaptive (specific) immune response including the actions of B lymphocytes and their antibodies (including antibody structure) in humoral immunity, and the actions of T helper and T cytotoxic cells in cell-mediated immunity
- the role of the lymphatic system in the immune response including the role of secondary lymphoid tissue (with reference to lymph nodes) as the site of antigen recognition by lymphocytes, and as a transport system for antigen-presenting cells including dendritic cells

Image: Rost9/Shutterstock.com

9A INTRODUCING ANTIGENS AND PATHOGENS!

Some people say the body is a temple but it's more like a highly fortified building, with the immune system serving as the fingerprint scanner on the door checking everyone coming in. If they don't have the right fingerprint (or 'antigen') then the immune system calls upon a whole armada of cells to kill them. Talk about a hostile welcome!



In this lesson you will learn how the body distinguishes between self and non-self molecules, as well as the types of pathogens that try to invade the body on a daily basis.

Study design dot points

- an antigen as a unique molecule or part of a molecule that initiates an immune response including the distinction between non-self antigens, self-antigens, and allergens
- invading cellular and non-cellular pathogens as a source of non-self antigens, and preventative strategies including physical, chemical, and microbiological barriers in animals and plants that keep them out

Key knowledge units

Antigens	3.2.6.1
Types of pathogens	3.2.7.1

Antigens 3.2.6.1

OVERVIEW

The immune system uses antigens to recognise if a cell or molecule is self or non-self. If it is identified as non-self, an immune response is initiated.

lesson link Antigens are an important component of triggering the adaptive immune response, interacting with receptors on B and T cells. This process is covered in detail in ***lesson 9D***.

THEORY DETAILS

The immune system protects your body by scanning for and destroying agents that cause disease, also known as **pathogens**. This is a classic case of 'easier said than done', as your immune system has to recognise a huge variety of different pathogens whilst ensuring that it doesn't harm any of your own self-cells. When you consider that the average human body contains 37.2 trillion cells, it begs the question – how does it do this? The answer – **antigens**.

Antigens are substances that interact with the immune system. Overall, there are two types of antigens – self-antigens and **non-self antigens**. Self-antigens mark the cells of an organism as 'self' so that the immune system doesn't attack them. In humans, the most important self-antigens take the form of **major histocompatibility complex (MHC) proteins**. There are two classes of MHC proteins – MHC I, which are expressed on all the cells in the human body (except for red blood cells), and MHC II, which are found on certain cells in the immune system.

Sometimes an error in the immune system can occur resulting in it recognising these self-antigens as non-self and attacking the cells that express them. When the immune system begins attacking self-cells it's known as an **autoimmune disease**.

Foreign antigens are non-self antigens. That is, they are antigens that originate from somewhere other than the host's body. For example, if a pathogen such as a bacterium enters the body, the immune system will recognise certain proteins on its surface as foreign and will launch an attack in response (Figure 1). In this case, these bacterial proteins are serving as antigens. Foreign antigens can exist as many different types of molecules, including proteins, sugars, and DNA/RNA. Furthermore, MHC proteins differ between individuals. In an organ transplant, for example, the MHC proteins expressed on the donor organ will be different to the MHC proteins of the organ receiver, stimulating the receiver's immune system to launch an attack on the organ.

An important subcategory of antigens are **allergens**. Allergens are antigens that the immune system recognises as non-self and initiates a strong immune response towards. In actual fact, allergens aren't pathogens and can't cause the body any harm. The immune response they generate, therefore, is unwarranted and is what we call an **allergic reaction** (Figure 2).

pathogen agents that cause disease which include bacteria, viruses, fungi, protozoa, prions, and worms

antigen a substance that is recognised by the immune system as either foreign or self. A foreign antigen will trigger an immune response

non-self antigen a molecule from outside the body that is recognised by the immune system and initiates an immune response. Also known as a **foreign antigen**

major histocompatibility complex (MHC) proteins a group of proteins present on the surface of self cells that enable the immune system to distinguish between self/non-self material. Also known as **self-antigens**

autoimmune disease a disease in which an individual's immune system initiates an immune response against their own cells

allergen a non-pathogenic antigen that triggers an allergic reaction

allergic reaction an inappropriate immune response to a non-pathogenic antigen

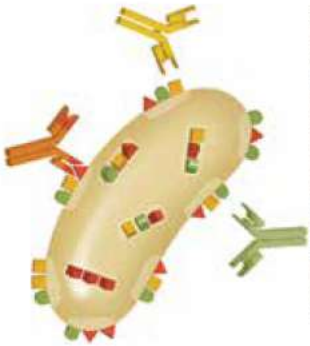


Image: Aldona Griskeviciene/Shutterstock.com

Figure 1 A bacterium with antigens on its surface. The antigens are interacting with antibodies as part of the adaptive immune response (see lesson 9C).

Image: Africa Studio/Shutterstock.com

Figure 2 This unfortunate soul is allergic to dogs. Her immune system recognises some aspect of the dog's fur as a foreign antigen. In this instance, however, the fur is serving as an allergen, since it isn't actually harmful to the body.

Case study

Red blood cells part 1

As mentioned earlier, red blood cells (RBCs) don't have MHC proteins on their surface to serve as self-antigens. Instead, RBCs have different glycoproteins on their surface that label them as 'self.' These glycoproteins are the basis of how we categorise blood types.

People with type A blood display the A antigen on the surface of their RBCs. People with type B blood display the B antigen. Some people have both A and B antigens on their RBCs – these people are type AB. Finally, people with O blood type have neither antigen A nor antigen B present on their RBCs.

When giving a blood transfusion to a patient we have to be careful to match the blood type of the sample to their own blood type. If they are given blood with different antigens to their own, their immune system will recognise the different RBC antigen(s) as non-self and launch an attack against these cells. This means that someone with AB blood can safely accept all blood types and type O blood can be safely accepted by everyone. If the body does initiate an immune response it can make the patient who received the blood extremely ill and, in some cases, die.

You can read part 2 of this case study in lesson 9D.

	Type O	Type A	Type B	Type AB
Red blood cell type				
Antigens in red blood cells	None	Antigen A	Antigen B	Antigen A and Antigen B

Image: Designua/Shutterstock.com

Figure 3 Antigens present in each blood type

lesson link Autoimmune diseases and allergic reactions are explored in more detail in ***lesson 10B***.

Types of pathogens 3.2.7.1

OVERVIEW

There are many different types of pathogens that can infect organisms and make them sick, including bacteria, fungi, worms, protozoa, viruses, and prions.

THEORY DETAILS

Pathogens come in all shapes and sizes – not to mention domains of life! One of the key ways we characterise pathogens is whether they're **cellular pathogens** or **non-cellular pathogens**. Cellular pathogens are pathogens that have a cellular structure and are living organisms; non-cellular pathogens are pathogens that don't have a cellular structure and are non-living.

Table 1 summarises the key pathogens you need to know. VCAA often assess your knowledge of these pathogens, so it's important you understand what they are and their individual structures.

Table 1 Summary of key pathogens

Type of pathogen	Description	Cellular or non-cellular	Diseases caused by pathogen
Bacteria (Figure 4a)	Unicellular prokaryotes that can infect almost any part of the body.	Cellular	• *Neisseria meningitidis* causing meningitis • *Clostridium tetani* causing tetanus
Fungi (Figure 4b)	Eukaryotic organisms that include yeasts and moulds and contain long, branching filaments called **hyphae**. They can cause a variety of diseases in humans including thrush and athlete's foot.	Cellular	• Thrush • Athlete's foot
Worms (Figure 4c)	Multicellular invertebrate **parasites** whose development include egg, larval, and adult stages.	Cellular	• Parasite (e.g. tapeworm) infection leading to malnutrition
Protozoa (Figure 4d)	Single-celled eukaryotes that can be free-living or parasitic.	Cellular	• *Plasmodium* causing malaria
Viruses (Figure 4e)	An infectious agent composed of genetic material (DNA or RNA) inside a protein coat (capsid). In some instances the protein coat is surrounded by a lipid envelope. Viruses are not able to independently reproduce, instead they insert their genetic material into a host's cell and using the cell to replicate.	Non-cellular	• Rhinovirus causing the common cold • Influenza causing the flu • Ebola virus causing ebola
Prions (Figure 4f)	Abnormally folded proteins that have the ability to induce normal proteins nearby to become misfolded. They only occur in mammals and only affect the brain and other neural structures. They are currently the only known infectious agents that don't contain nucleic acids.	Non-cellular	• Creutzfeldt–Jakob disease • Bovine spongiform encephalopathy (also known as mad cow disease)

cellular pathogen a pathogen that has a cellular structure and exhibits the processes of a living organism. Examples include bacteria, fungi, protozoa, and parasites such as worms

non-cellular pathogen a pathogen that does not have a cellular structure or exhibit the processes of a living organism. Examples include viruses and prions

bacterium (pl. bacteria) a group of single-celled, prokaryotic, microscopic organisms. They can live symbiotically with other organisms and/or act as pathogens

fungi eukaryotic organisms characterised by spore production and chitinous cell walls. They can act as a pathogen and cause a number of different diseases in humans

hyphae branching filaments of a fungus

worm an invertebrate that can cause disease in its host by acting as a parasite

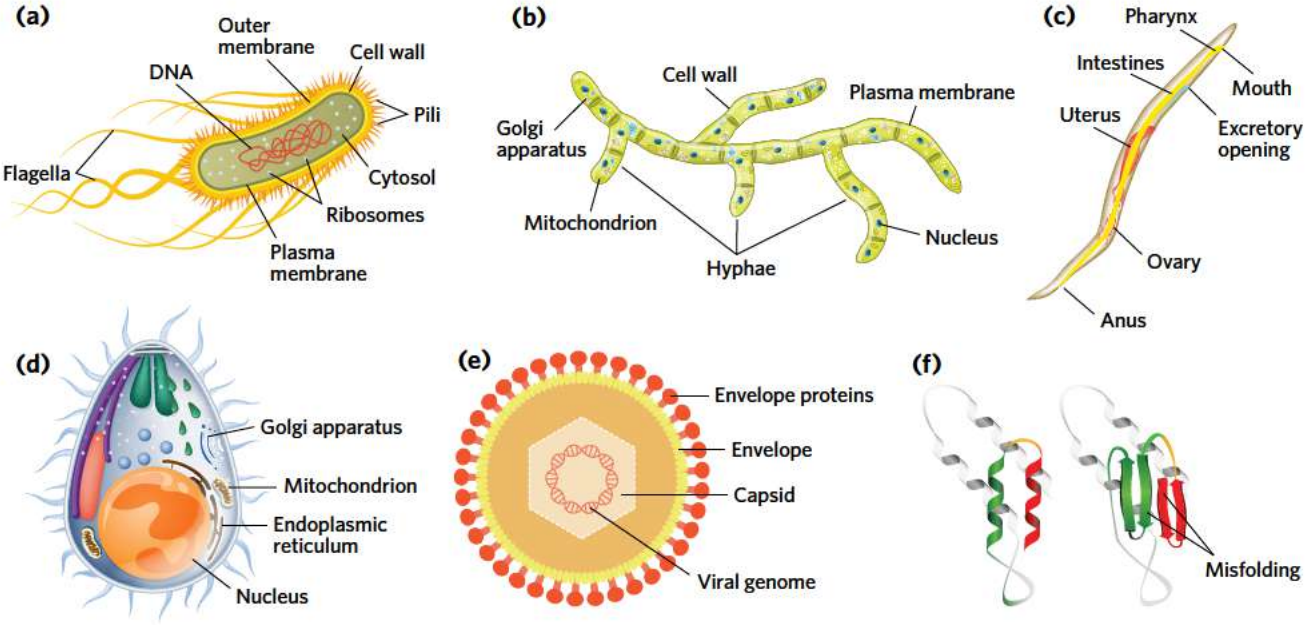
parasite an organism that lives in or on another organism, usually deriving nutrition from the host organism

protozoa a phylum of single-celled eukaryotes that can cause disease

virus an infective agent composed of genetic material enclosed in a protein coat that requires a host cell to multiply

prion an abnormally folded protein in the brain or central nervous system (CNS) of a mammal that induces other proteins to misfold. Causes a number of neurodegenerative diseases

lesson link If you've forgotten what it means to be a 'living' organism, it might be a good idea to revise ***lesson 2B***.



Images: (a) VectorMine/Shutterstock.com (b) Designua/Shutterstock.com (c) Timonina/Shutterstock.com (d) VectorMine/Shutterstock.com (e) Designua/Shutterstock.com (f) Designua/Shutterstock.com

Figure 4 The various types of pathogens: **(a)** bacteria, **(b)** fungi, **(c)** worms (*Ascaris*), **(d)** protozoa (*Plasmodium*), **(e)** virus, and **(f)** prion. Note that in **(f)** the two coloured alpha-helices have become two beta-pleated sheets, a misfolding that can be transmitted to other nearby proteins.

Theory summary

There are a large number of pathogens that can cause disease and make us sick. Our bodies respond after recognising antigens on their surface. Over the next few lessons, you'll be learning in detail about the variety of ways in which the immune system combats the millions of pathogens that organisms are exposed to each day, and will come to appreciate just how fully sick the immune system is.

lesson link ***Lesson 16C*** details the ways in which modern medicine combats a number of the pathogens introduced in this lesson.

9A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a living organism that causes disease

b _____ the part of a pathogen that the immune system recognises

c _____ proteins that prevent the immune system from attacking self-cells

d _____ prokaryotes that can cause disease

e _____ pathogens that have a capsid

f _____ a pathogen comprised of a series of amino acids

g _____ pathogens that steal nutrients from their host

Question 2

Which of the following is false?

A pathogens cause disease

B allergens are a type of pathogen

C antigens interact with the immune system

D autoimmune diseases occur due to an error in 'self' recognition

Question 3

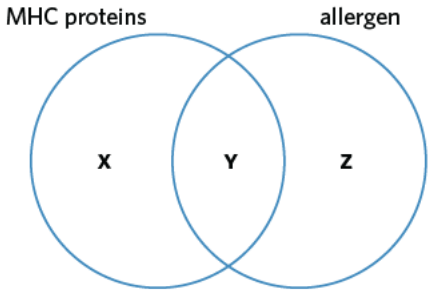
Which of the following completes the table describing the different types of important pathogens?

Type of pathogen	Description
K	composed of genetic material (DNA or RNA) inside a protein coat (capsid)
bacteria	**L**
protozoa	**M**
N	abnormally folded proteins

	K	L	M	N
A	prion	prokaryotes that can cause disease	single-celled eukaryotes that can cause disease	virus
B	prion	single-celled eukaryotes that can cause disease	prokaryotes that can cause disease	virus
C	virus	prokaryotes that can cause disease	single-celled eukaryotes that can cause disease	prion
D	virus	single-celled eukaryotes that can cause disease	prokaryotes that can cause disease	prion

Question 4

Complete the Venn diagram to compare different forms of antigens.



	X	Y	Z
A	mark cells as 'self'	interact with the immune system	cause allergic reaction
B	cause allergic reaction	interact with the immune system	mark cells as 'self'
C	cause allergic reaction	stimulate immune response	mark cells as 'self'
D	mark cells as 'self'	stimulate immune response	cause allergic reaction

Question 5

Identify which pathogens are cellular and non-cellular.

I viruses

II fungi

III worms

IV bacteria

V protozoa

VI prions

	cellular	non-cellular
A	I, II, III, IV	V, VI
B	II, III, IV, V	I, VI
C	I, III, V, VI	II, IV
D	I, III, IV	V, VI

Exam-style questions

Within lesson

Question 6 (1 MARK)

When making vaccines, scientists search for a molecule that is unique to a pathogen and stimulates the immune system.

Based on this information, which type of molecule could scientists use?

A an antigen
B an allergen
C an MHC protein
D a self molecule

Adapted from VCAA 2016 Section A Q24

Question 7 (1 MARK)

An example of a 'non-self' material in a human is

A cells lining the oesophagus.
B a red blood cell.
C an allergen.
D a neuron.

Adapted from VCAA 2014 Section A Q14

Question 8 (1 MARK)

In the future, scientists aim to grow full-size kidneys for transplants in patients with kidney disease using the patient's own skin cells. This would overcome the problem of rejection of the transplanted kidney by the immune system.

Which of the following is responsible for causing organ rejection?

A pathogens from the donor's kidney
B the MHC proteins on the donor's kidney
C the MHC proteins on the receiver's kidney
D self-antigens from the receiver's body not recognising the donor kidney cells

Adapted from VCAA 2014 Section A Q19

Question 9 (1 MARK)

Which one of the following is correct?

A Prions are cellular pathogens.
B Prions do not contain genetic material.
C Prions insert their genetic material into a host cell.
D Prions are eukaryotic cells that contain membrane-bound organelles.

Question 10 (1 MARK)

An example of 'self' material in an adult human includes

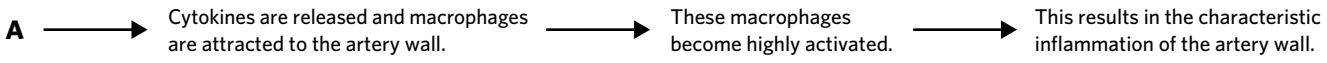
A bacterial colonies in the gut.
B lung cells obtained in a tissue sample.
C viral particles circulating in the bloodstream.
D red blood cells received in a transfusion that don't match their blood type.

Adapted from VCAA 2014 Section A Q14

Question 11 (1 MARK)

Temporal arteritis is an autoimmune disease in which the temporal arteries which supply blood to the brain become inflamed. This causes headaches and may result in blindness or stroke.

The sequence of immune responses in this disease is shown in the diagram.



Based on the information provided, which of the following could be represented by A in the diagram?

A Immune cells recognise an allergen and initiate a response.

B Immune cells recognise a foreign antigen and initiate a response.

C Immune cells recognise self MHC proteins as non-self and initiate a response.

D Pathogen cells attack the temporal arteries and the immune system initiates a response.

Adapted from VCAA 2016 Section A Q25

Question 12 (1 MARK)

Which of the following about allergens is false?

A All antigens are allergens.

B Allergens are also antigens.

C Allergens are antigens that cause an allergic reaction.

D In order for an allergen to affect someone, they must be sensitive to it.

Question 13 (4 MARKS)

Haemolytic disease of the newborn (HDN) can occur if a Rhesus-negative mother is pregnant with a Rhesus-positive fetus. A person who is Rhesus-positive has certain proteins on the surface of their red blood cells; a person who is Rhesus-negative does not have these proteins. During pregnancy and birth, some fetal blood cells may enter the mother's bloodstream, causing an immune response in her body.

a Identify and explain the role the rhesus proteins play in the mother's immune response. (2 MARKS)

b Are the fetal red blood cells serving as pathogens in the mother's body? Justify your response. (2 MARKS)

Adapted from VCAA 2014 Section B Q5b

Multiple lessons

Use the following information to answer Questions 14 and 15.

Canola is an economically important crop plant in Australia. Pathogens that reduce canola production are a concern to farmers. One significant disease is blackleg, caused by the fungus *Leptosphaeria maculans*. A detailed examination of infected canola stems has shown the presence of the fungus.

Question 14 (1 MARK)

The structure of the *L. maculans* pathogen would consist of

A a lipid envelope.

B abnormally folded proteins.

C MHC proteins on its surface.

D cells containing membrane-bound organelles.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q16

Question 15 (1 MARK)

Which of the following could be an antigen originating from *L. maculans*?

A a toxin

B a larva

C a capsid protein

D a bacterial ribosome

Use the following information to answer Questions 16 and 17.

In early 2016, there was an outbreak of food poisoning in Victoria linked to the consumption of pre-packaged lettuce. In investigations carried out by the Department of Health and Human Services, several products tested positive for the prokaryote *Salmonella anatum*.

Question 16 (1 MARK)

It is reasonable to say that *S. anatum* is

A a virus.

B a prion.

C cellular.

D non-cellular.

Adapted from VCAA 2016 Section A Q21

Question 17 (1 MARK)

Based on the information provided, which of the following structures would most likely be present in *S. anatum*?

A flagella

B a protein coat

C membrane-bound organelles

D a misfolded protein

Key science skills

Question 18 (5 MARKS)

Sharon wanted to investigate the effectiveness of a medication against an unknown pathogen. She prepared five different concentrations of the medication, which is known to kill pathogens by interfering with the production of their cell wall.

She wrote the following method.

1 Put on a pair of disposable gloves.

2 Collect the five agar plates containing nutrient agar.

3 Label each agar plate with the five different concentrations of the medication.

4 Collect a sample of the pathogen in a broth culture.

5 Measure 0.5 mL of broth in a pipette and place in the centre of the first agar plate.

6 Spread the pathogen evenly over the agar plate with the spreader provided.

7 Place a drop of the medication in the centre of the agar plate.

8 Close the lid of the agar plate and tape the lid to the bottom of the agar plate with sticky tape.

9 Repeat steps 6 to 8 with the other four concentrations of the medication.

10 Place the agar plates on the side bench and leave overnight.

11 Wash your hands and dispose of the gloves.

Sharon returned the next day and found that the medication had influenced the growth of the pathogen. Plates that had higher concentrations of the medication had lower rates of pathogen growth.

Adapted from VCAA 2017 Sample Exam Section B Q11

a Based on the information provided, what kind of pathogen is Sharon using in her experiment? (1 MARK)

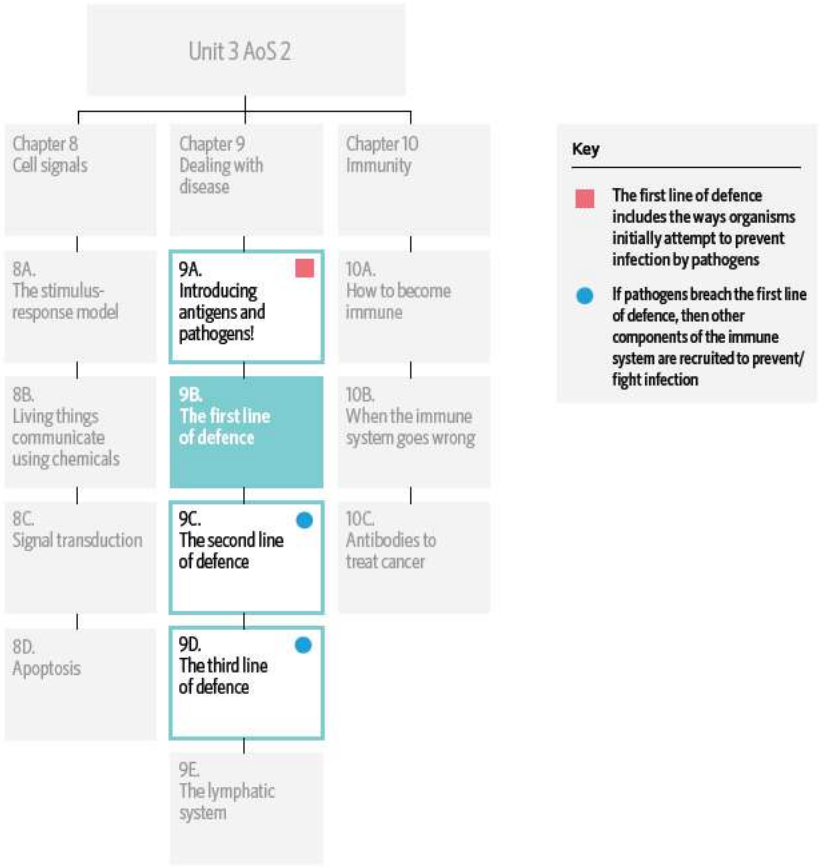
b Did Sharon use a control in her experiment? If so, identify what the control was. If not, explain what a control would have looked like. (2 MARKS)

c Explain why having a control is important in this experiment. (1 MARK)

d While setting up one of the plates, Sharon sneezed onto the agar. What kind of error does this represent? (1 MARK)

9B THE FIRST LINE OF DEFENCE

Imagine a person with bacteria-destroying tears and the ability to make acidic sweat. Sounds like a superhero, right? Wrong! It's you!



In this lesson you will learn about the components of the first line of defence in animals and plants.

Study design dot points

- Invading cellular and non-cellular pathogens as a source of non-self antigens and preventative strategies including physical, chemical, and microbiological barriers in animals and plants that keep them out

Key knowledge units

Barriers in animals	3.2.7.2
Barriers in plants	3.2.7.3

Barriers in animals 3.2.7.2

OVERVIEW

Animals have a number of first-line defences against pathogens, including physical barriers, chemical barriers, and microbiological barriers.

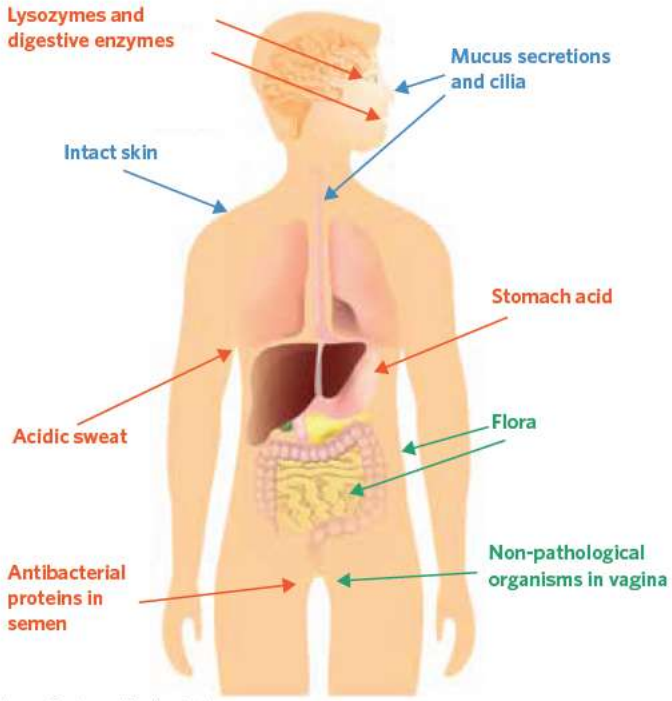


Image: Designua / Shutterstock.com

Figure 1 Barriers present in animals

first line of defence a component of the innate immune system characterised by the presence of physical, chemical, and microbiological barriers to keep pathogens out of the host organism

physical barrier a component of the first line of defence that features solid or fluid obstacles that block pathogen entry e.g. skin, mucus

chemical barrier a component of the first line of defence that features the use of chemicals to protect against pathogen invasion

microbiological barrier a component of the first line of defence in which the presence of normal flora limits the growth of pathogenic bacteria

non-specific describes a component of the immune system that responds the same way to all pathogens

cilium (pl. cilia) thin, hair-like projections that protrude from eukaryotic cells

flora naturally occurring, non-pathogenic bacteria present in an organism

THEORY DETAILS

Animals need to protect themselves against the pathogens identified in lesson 9A. As the saying goes, 'prevention is better than cure', and this is most certainly true when trying to combat pathogens. Whilst vertebrates have a number of mechanisms to deal with pathogens that have entered the body (these will be explored in the following lessons), ultimately the best way to avoid getting sick is to prevent pathogens from entering the body in the first place. This is where the first line of defence comes into play!

There are three types of barriers present in the **first line of defence** in animals – **physical**, **chemical**, and **microbiological**. These first-line defences are **non-specific** in nature – that is, they work in a similar manner against all pathogens. Key components of these barriers are summarised in Table 1.

Table 1 First line of defence in animals

Barrier type	Description	Examples
Physical	Barriers that block or hinder pathogens from entering the organism	• Intact skin and surfaces between external and internal environments (e.g. respiratory, gastrointestinal, and genitourinary tracts) • Mucous secretions and/or hairs in the respiratory tract that trap organisms, and **cilia** that sweep them away from the airways and into the throat where they are swallowed and destroyed by the gastrointestinal tract
Chemical	Barriers that work by producing chemical substances that make an environment unlivable for a pathogen	• Presence of lysozyme enzymes in tears and saliva that destroy bacterial cell walls • Antibacterial compounds in earwax • Stomach acid that destroys pathogens that have been eaten/swallowed • Acidic sweat that destroys pathogens growing on the surface of the body • Antibacterial proteins in semen • Low pH in the vagina
Microbiological	The presence of non-pathogenic bacteria (known as normal **flora**) in the body can prevent the growth of pathogenic bacteria as they compete for space and resources	• Presence of bacteria on the skin and in the lower gastrointestinal tract • Non-pathogenic organisms in the vagina

Barriers in plants 3.2.7.3

OVERVIEW

Plants also have physical and chemical barriers as first-line defence mechanisms, however they differ to those present in animals.

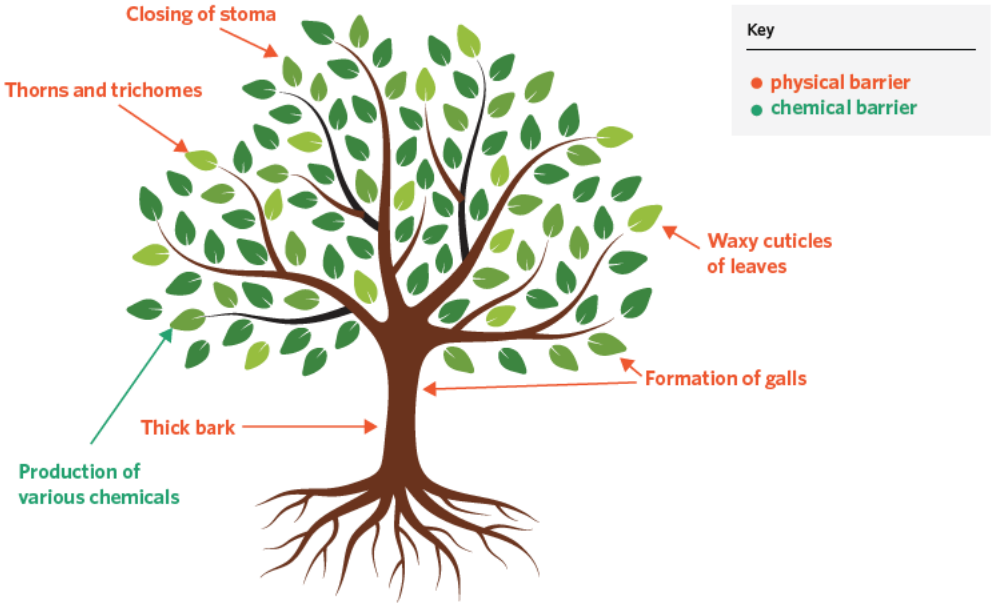


Image: alazur /Shutterstock.com

Figure 2 Barriers present in plants

cuticle a waxy protective film covering the surface of a plant leaf

gall abnormal outgrowths of tissue in plants designed to limit the spread of an invading pathogen

stoma (pl. stomata) small pores on the leaf's surface that open and close to regulate gas exchange

trichomes small hairs on the surface of plants used to deter pathogens and/or insects

THEORY DETAILS

Plants also need to protect themselves from pathogens and herbivory, but cannot move or run away like we can. Plants also don't have the more advanced forms of immunity that animals do. It's therefore vitally important that their first lines of defence are effective. The defences of plants are described in Table 2.

Table 2 First line of defence in plants

Barrier type	Description	Examples
Physical	Barriers that prevent pathogens from entering the organism	• Waxy **cuticles** of leaves • Thick bark • Formation of **galls** to prevent the spread of infection • Closing of **stomata** to prevent pathogen invasion during carbon dioxide uptake • Presence of thorns and **trichomes** to deter insects and grazers
Chemical	Barriers that involve the production of chemicals that can be toxins that are harmful to pathogens and/or enzymes that affect the functioning or development of pathogens. Some chemicals also act to repel insects/animals that may damage the plant	• Chitinases – enzymes that occur in a number of different plants and have antifungal properties • Oxalic acid – a substance that can be toxic if ingested • Phenols – secreted by wounded plants, phenols repel or kill many microorganisms • Saponins – disrupt the cell membranes of various fungi • Glucanases – defend plants against fungi • Defensins – small peptides that are toxic to microbes and fungi

Theory summary

Animals and plants have a variety of first-line defences designed to prevent pathogens from infecting them. These defences are comprised of a variety of physical, chemical, and microbial barriers. Fortunately for animals, if these first defences fail there's a backup plan – the second line of defence. You'll learn about these in the next lesson.

9B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the part of plants that can close to prevent pathogen invasion

b _____ the group of first-line defences that includes stomach acid and defensins

c _____ the waxy coating of leaves

d _____ an enzyme in human tears that destroys pathogens

e _____ the group of first-line defences that includes intact skin and thick bark

Question 2

Which of the following is false?

A Plants and animals both have advanced forms of immunity beyond the first line of defence

B Plants and animals both have first-line defences

C Plants use waxy cuticles as a physical barrier

D Animals do not produce phenols

Question 3

Fill in the blanks in the following sentences.

In plants, _____**I**_____ is the only form of defence against pathogens. This is comprised of different physical and chemical _____**II**_____. An example of a _____**III**_____ barrier in plants is _____**IV**_____.

	I	II	III	IV
A	the first line of defence	barriers	chemical	a waxy cuticle
B	a physical barrier	pathogens	microbiological	production of chemicals
C	a physical barrier	barriers	physical	cilia
D	the first line of defence	barriers	physical	closed stomata

Question 4

Classify the following animal barriers as either physical, chemical, or microbiological.

I Flora

II Mucous secretions in airways

III Stomach acid

IV Presence of lysozyme in tears

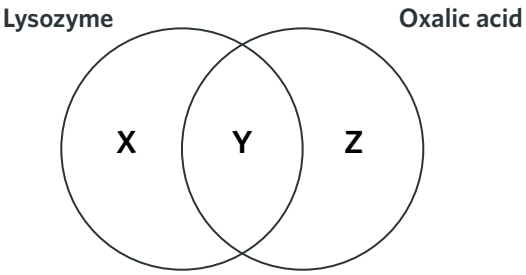
V Intact lining of the airway

VI Fine hairs present in the nose

	physical	chemical	microbiological
A	I, IV	V, VI	II, III
B	III, IV	I, II, VI	V
C	II, V, VI	III, IV	I
D	II, V, VI	III	I, IV

Question 5

Complete the following Venn diagram outlining some different forms of first-line defence mechanisms in plants and animals.



	X	Y	Z
A	present in human tears	chemical barrier	produced by some plants
B	produced by some plants	physical barrier	present in human tears
C	present in humans tears	physical barrier	produced by some plants
D	produced by some plants	chemical barrier	present in human tears

Exam-style questions

Within lesson

Question 6 (1 MARK)

As part of the first line of defence in the human immune system, naturally occurring barriers to invading pathogens do not include

A the normal flora in the gastrointestinal tract.
B the presence of acid in sweat.
C the creation of memory cells.
D the cilia lining the airway.

Adapted from VCAA 2013 Section A Q14

Question 7 (1 MARK)

In humans, the presence of lysozymes in tears is an example of

A a physical barrier.
B a chemical barrier.
C an adaptive barrier.
D a microbiological barrier.

Adapted from VCAA 2017 Sample Exam Section A Q21

Question 8 (1 MARK)

Which of the following is an example of a barrier against a pathogen that is common to both plants and animals?

A secretion of lysozymes
B an intact outer covering
C production of galls to wall off pathogens
D highly acidic portions of the gastrointestinal tract

Adapted from VCAA 2015 Section A Q17

Question 9 (1 MARK)

As part of the first line of defence in the human immune system, naturally occurring barriers to invading pathogens include

A lysozymes secreted in sweat.
B microflora on the surface of skin.
C the production of defensins by skin cells.
D gall formation around invading pathogens.

Adapted from VCAA 2014 Section A Q15

Question 10 (1 MARK)

Plants are a rich source of nutrients for many organisms, including bacteria, fungi, and viruses. Although plants lack an immune system that is comparable to animals, plants have evolved chemical barriers to stop invading pathogens from causing significant damage.

A plant barrier to pathogen invasion is

A lysozyme production in galls.
B the cilia lining the surface of stems.
C a waxy cuticle covering the surface of a leaf.
D mucous secretion on the surface of stomata.

Adapted from VCAA 2018 Section B Q3a

Question 11 (1 MARK)

Which one of the following is not an innate defence against pathogens?

A intact skin
B the production of antibodies
C sticky mucus lining the airways
D presence of acid in the stomach

Question 12 (1 MARK)

In humans, the presence of microflora in the small intestine is an example of

A a physical barrier.
B a chemical barrier.
C an adaptive barrier.
D a microbiological barrier.

Adapted from VCAA 2017 Sample Exam Section A Q21

Multiple lessons

Question 13 (1 MARK)

First-line defences are non-specific. With regards to antigens, this means that

A first-line defences are always the same, irrespective of the antigen present.
B first-line defences respond in particular ways to particular antigens.
C first-line defences recognise pathogenic antigens.
D first-line defences do not encounter antigens.

Question 14 (3 MARKS)

The first line of defence helps protect humans from invading pathogens. An example of a pathogen is bacteria.

a How do the mucus and cilia lining the airway help protect humans from invading bacteria? (1 MARK)

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q6a

b Identify two microbiological barriers that prevent pathogenic bacteria from entering the body. (2 MARKS)

Question 15 (7 MARKS)

Animals are a rich source of nutrients for many organisms, including bacteria, fungi, and viruses. Mammals have evolved extensive physical and chemical barriers to stop invading pathogens from causing significant damage.

Salmonella is a bacterial pathogen that infects the gastrointestinal tract and causes food poisoning. In Australia, most *Salmonella* infections occur after eating contaminated food, but also sometimes after contact with an infected person. Symptoms include diarrhoea, vomiting, and fever, and usually last for two to seven days.

a Recent evidence suggests gut flora may provide protection against *Salmonella* infection. Describe how this could occur. (1 MARK)

b Name two chemical barriers present in mammals that protect them from an invading pathogen. (2 MARKS)

c *Salmonella* bacteria contain many enzymes crucial for metabolic function. One of these enzymes is ATPase, which catalyses the endergonic reaction:

$$ADP + Pi \rightarrow ATP$$

i State the chemical barrier that *Salmonella* bacteria will encounter in the stomach. (1 MARK)

ii Outline the effect of this chemical barrier on the structure and function of ATPase, and the ultimate consequence this has for *Salmonella* bacteria. (3 MARKS)

Adapted from VCAA 2018 Section B Q3

Key science skills

Question 16 (7 MARKS)

The beet caterpillar is an insect pest of the tomato plant. When a beet caterpillar starts to eat a tomato plant, the plant responds by producing a chemical known as jasmonic acid. Jasmonic acid and its derivatives have a variety of odours.

a Identify which kind of barrier the production of jasmonic acid is an example of. (1 MARK)

b When examining the plant cells, the receptor for jasmonic acid is found to be on the plasma membrane. State what this suggests about the water solubility of jasmonic acid. (1 MARK)

c Anne, a keen biology student, hypothesised that jasmonic acid inhibits caterpillars' innate immunity to a particular lethal pathogen. She has isolated jasmonic acid in a spray, and has access to a large number of plants that do not produce jasmonic acid.

i Outline an experiment Anne could carry out to test her hypothesis, including three variables that must be controlled for. (3 MARKS)

Adapted from VCAA 2009 Exam 1 Section B Q4ai

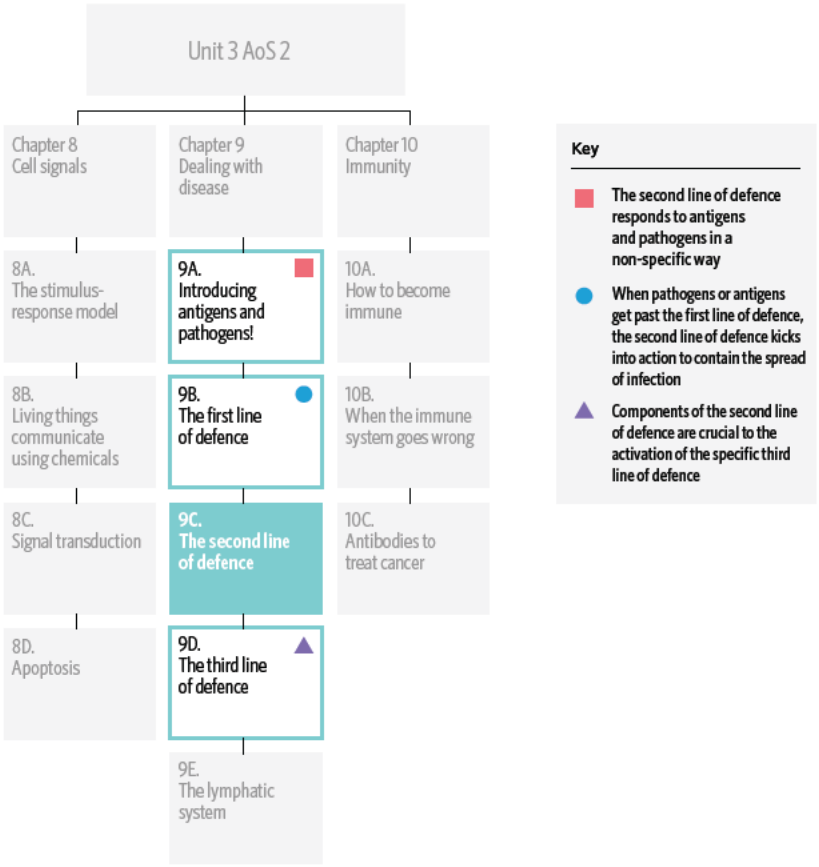
ii Describe the results that would support her hypothesis. (1 MARK)

Adapted from VCAA 2009 Exam 1 Section B Q4aii

iii Identify an ethical issue present in the design of Anne's experiment. (1 MARK)

9C THE SECOND LINE OF DEFENCE

The second line of defence is like a police officer patrolling their beat. It's constantly on the lookout for any trouble-making pathogens, and when it sees them it pounces on them and arrests them. Well, technically, it eats and/or kills them. Now THAT'S what you call taking a hard stance against crime!



In this lesson you will learn about the key components of the second line of defence, as well as the inflammatory response process and its outcomes.

Study design dot point

- the characteristics and roles of components (macrophages, neutrophils, mast cells, dendritic cells, complement proteins) of the innate (non-specific) immune response to an antigen including the steps in the inflammatory response

Key knowledge units

Cells and components of the innate immune response	3.2.8.1
Steps in the inflammatory response	3.2.8.2

Cells and components of the innate immune response 3.2.8.1

OVERVIEW

The second line of defence is a component of the innate immune system that is comprised of a variety of cells and molecules that destroy pathogens that have entered the body, stopping their spread.

THEORY DETAILS

Sometimes pathogens are able to slip past or breach the body's barrier defences, or first line of defence. Fortunately, our bodies have a backup plan for when this happens – the **second line of defence**!

second line of defence a component of the innate immune system characterised by the non-specific response to injury and pathogens by a variety of cells and molecules

The second line of defence is the second component of the **innate immune system.**

innate immune system a component of the immune system that is comprised of generalised and non-specific defences and/or responses to pathogens. Also known as the **non-specific immune system**

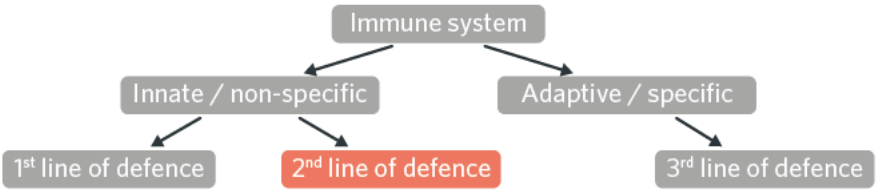


Figure 1 Breakdown of the immune system

The most important thing to remember about the second line of defence is that, being a component of the innate immune system, it's non-specific. This means that its components respond in the same way regardless of the type of pathogen or antigen present.

The second thing to remember about the second line of defence is that it responds to injury or antigens extremely quickly. Within minutes to hours, it starts working to limit the spread of infection within the body.

There are two components of the second line of defence – cellular, and non-cellular components. You'll take a closer look at these now.

Cellular components of the innate immune system

The innate immune response involves a variety of different cell types. All of the cells involved are called **leukocytes**, or white blood cells. Figure 2 shows the key innate immune cells you need to know. You only need to be aware of the bolded cells at the bottom of the diagram. The other information above them shows how the cells relate to each other. Knowing this might help you remember what each cell does, but you don't need to memorise the unbolded information.

leukocytes a group of blood cells responsible for protecting the body against pathogens and foreign material. Also known as **white blood cells**

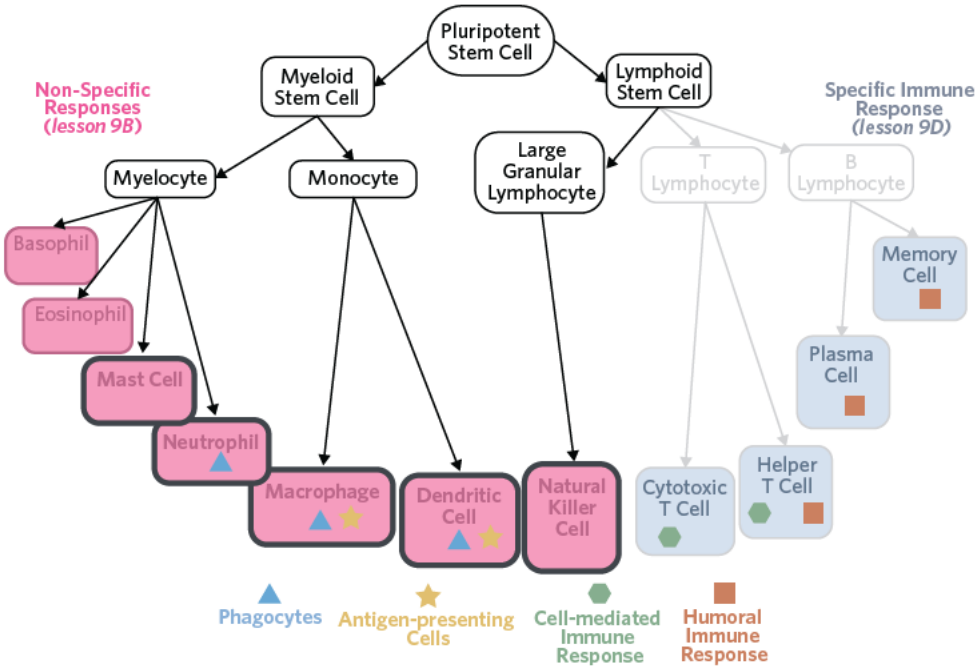


Figure 2 The cellular components of the innate immune system. You are most likely to be tested on mast cells, neutrophils, macrophages, dendritic cells, and natural killer cells.

We'll now take a closer look at each of the major cell types shown in Figure 2.

neutrophil the most common type of leukocyte in the body. Engages in phagocytosis of pathogens and foreign material, as well as the release of cytokines

macrophage a type of leukocyte found throughout the body that engages in phagocytosis and antigen presentation

dendritic cell a type of white blood cell that engages in phagocytosis and antigen presentation

phagocyte a group of leukocytes responsible for the endocytosis and destruction of pathogens and foreign material

antigen-presenting cell a subgroup of phagocytes that display the antigens from consumed pathogens on their surface and interact with the adaptive immune system

Phagocytes

In Figure 2 you will note that three types of cells – **neutrophils**, **macrophages**, and **dendritic cells** – are classified as **phagocytes.** Phagocytes are cells that partake in phagocytosis, a process in which they consume and destroy foreign or dead material present in the body by engulfing it. Once engulfed, lysozymes present in the cell destroy the foreign material (Figure 3).

Two of these phagocytes – macrophages and dendritic cells – are additionally called **antigen-presenting cells.** These cells not only consume and destroy foreign material but also present antigens from consumed material on their surface. Macrophages are found throughout the body, whereas dendritic cells tend to be found on or near the body's surfaces.

In lesson 9A you learned that whilst all cells of the body (except red blood cells) express MHC I on their surface, only specific cells in the body express MHC II. Antigen-presenting cells express MHC II which allows them to present consumed antigens on their surface (Figure 3). These cells will then interact with the adaptive immune system. This process will be covered in detail in the next lesson.

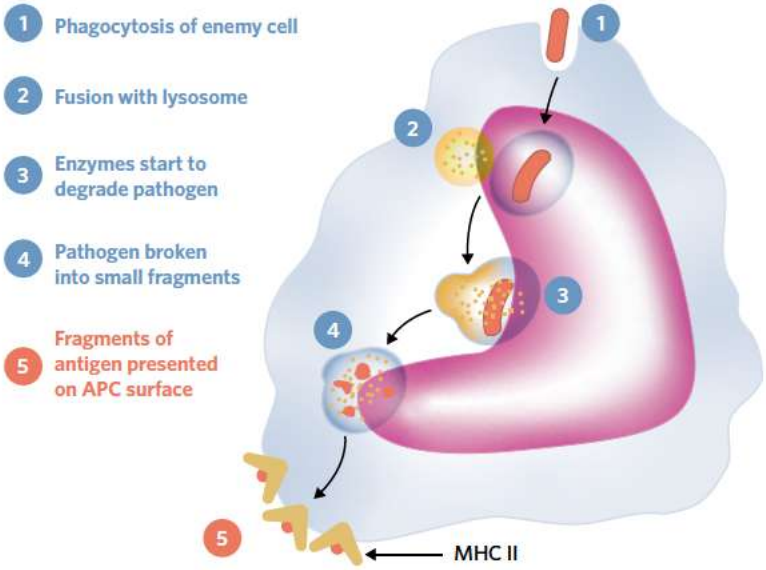


Figure 3 The process of phagocytosis (blue) and antigen presentation (red)

In addition to pathogens being phagocytosed, neutrophils also release a number of substances that help combat pathogens such as **cytokines**. Cytokines are important cell signalling molecules that help guide other immune cells to the site of infection/injury and help them function optimally.

Natural killer (NK) cells

The most important role of **natural killer cells** in the innate immune response is the destruction of abnormal or infected cells. When a cell becomes infected with a virus, antigens from the virus remain on the surface of the host cell. Natural killer cells recognise these viral antigens, and release cytotoxic chemicals that disrupt the infected cell's membrane, triggering apoptosis (Figure 4). Similarly, when a cell becomes cancerous, abnormal antigens are presented on its surface, triggering natural killer cells to kill it.

Importantly, because natural killer cells work by inducing apoptosis in cells they are only effective against intracellular pathogens (e.g. a virus inside a cell). If a natural killer cell comes across free viral particles or bacteria in the body it will not destroy them.

Mast cells

Mast cells reside in connective tissues throughout the body (Figure 5). When they detect injury to surrounding cells, or are stimulated by antigens or allergens, they become activated and release **histamine**. Histamine has a number of effects on the body and is particularly important in the **inflammatory response**.

Non-cellular components of the innate immune system

In addition to leukocytes, there are other key molecules and processes that play an important role in the innate immune response. These include **interferons**, **complement proteins**, **venom inhibitors**, and the initiation of a fever.

Interferons

When a cell is infected with a virus it releases cytokines called interferons. These interferons interact with receptors on neighbouring cells, causing them to undergo a number of changes that make them less susceptible to viral infection. This helps to stop the virus from spreading between cells.

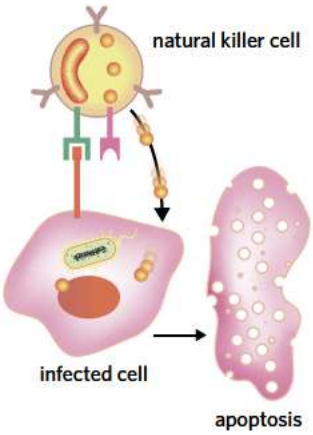


Figure 4 A natural killer cell destroying an infected cell

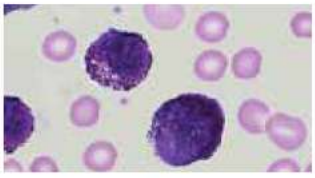


Figure 5 Mast cells containing dark-staining histamine

cytokine a signalling protein released by cells (typically in the immune system) that has an effect on other cells

natural killer (NK) cell a leukocyte responsible for the recognition and destruction of damaged and/or infected host cells

mast cell a type of leukocyte responsible for releasing histamine during allergic and inflammatory responses

histamine a molecule released by mast cells that plays a key role in inflammation

inflammatory response a series of biochemical events that occur in the body as a result of infection and/or trauma. Characterised by swelling, redness, pain, and heat in the affected tissue

interferons a cytokine released by virally infected cells that increases the viral resistance of neighbouring uninfected cells

complement proteins a number of different types of proteins found in the blood that opsonise, cause lysis, and attract phagocytes to invading pathogens

venom inhibitors a molecule in the blood that locks onto venom molecules (e.g. snake or spider venom) and prevents them from reacting with cells in the body

lesson link In ***lesson 10B***, you will learn more about how mast cells are involved in the allergic response.

Complement proteins

Within the blood there are a number of different complement proteins that together form the complement system. In the presence of certain pathogens, these proteins start reacting with each other in a series of reactions called the complement cascade. There are three major outcomes of this cascade:

1. **Opsonisation** of pathogens – complement proteins stick on the outside surface of pathogens and make it easier for cells of the immune system, such as phagocytes, to recognise them as foreign.
2. Chemoattraction of phagocytes – complement proteins gather near a pathogen and attract phagocytes to it, making it more likely to be destroyed.
3. Destruction of bacterial pathogens via **membrane attack complexes (MACs)** – complement proteins join together on the surface of bacteria and make pores in the bacterial membrane to cause lysis and kill them.

opsonisation the mechanism by which complement proteins attach to the surface of pathogens, making them easier to phagocytose

membrane attack complex (MAC) a pore formed by complement proteins in the cell membranes of a pathogen, disrupting the membrane and leading to the pathogen's death

Venom inhibitors

Venom inhibitors exist in the blood and bind with snake/spider venom, preventing it from reacting with cells in the body and causing damage.

Fever

A fever is an abnormally high body temperature. A complex series of responses raises the set temperature point of the body causing a person to shiver and feel cold, resulting in greater production of heat and increased efforts to conserve heat (e.g. putting on a jumper). This is an innate response to potential infection, as many pathogens cannot survive at the elevated temperatures that are created by a fever. Fevers are also thought to help the immune system by activating certain proteins in the body that bolster the strength of the body's defences.

> ***Tip*** The immune system is extremely complicated and there are many components such as defensins and perforins that haven't been covered in this lesson. VCAA, however, will most likely assess you on the cells and molecules that have been included in this lesson.

Steps in the inflammatory response 3.2.8.2

OVERVIEW

The process of inflammation increases blood flow to an injured area, bringing a greater number of immune cells and components to help clear debris and fight pathogens that may have entered the body. This increase in the amount of blood and fluid in the affected tissue causes swelling, pain, heat, and redness which are characteristic of inflammation.

THEORY DETAILS

The inflammatory response is designed to eliminate the effects of an injury, clear out cells that may have been damaged or destroyed, and initiate repair. It is a complex non-specific process that occurs in the same way regardless of the pathogen that's present or injury that's occurred. Below you'll look at an example of an injury and the body's acute inflammatory response to it.

The process of inflammation

There are three main aspects of the inflammatory response you need to know – initiation, **vasodilation**, and migration.

vasodilation the expansion of blood vessels

degranulation the release of granule contents from a cell

Initiation

Imagine you've been chopping up some wood for the fire. You go to pick a piece up, and you get a splinter in your finger. The splinter pierces the skin, damaging cells and introducing bacteria into the body. In response to this injury damaged cells release cytokines and mast cells **degranulate**, releasing histamine.

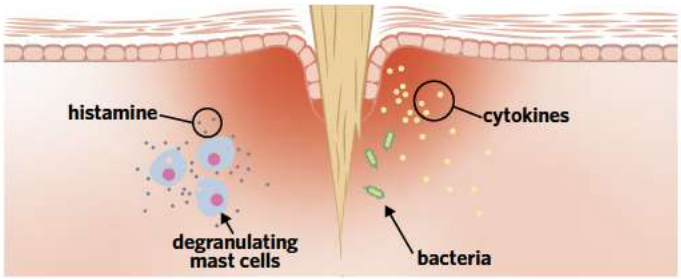


Figure 6 Initiation of inflammation involves cytokines being secreted from damaged cells and activation of mast cells causing the release of histamine.

Vasodilation

The histamine released from the mast cells travels to nearby blood vessels where it causes vasodilation. This means the blood vessels become bigger, and the vessel walls become more permeable through the formation of gaps. This increases blood flow to the injured site, and is the reason behind the swelling, redness, and warmth you associate with inflammation.

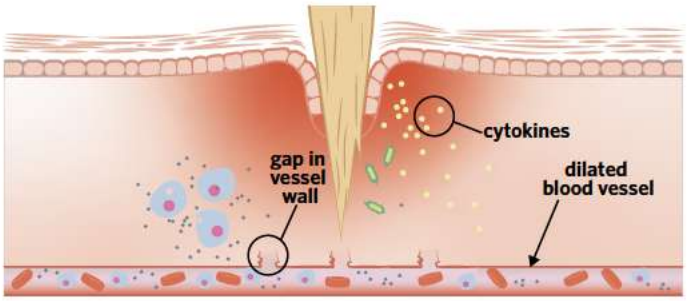


Figure 7 Histamine has caused the blood vessel to dilate and become 'leaky'.

Migration

Vasodilation and the increased leakiness of blood vessels allow for a number of innate immune system components to leave the bloodstream and enter the site of injury:

- Phagocytes are guided by the cytokines secreted by damaged cells to the site of injury where they phagocytose pathogens
- Complement proteins are attracted to pathogens and make it easier for phagocytes to destroy them
- **Platelets** travel to the wound and stop active bleeding.

platelets a component of blood responsible for forming clots and stopping bleeding

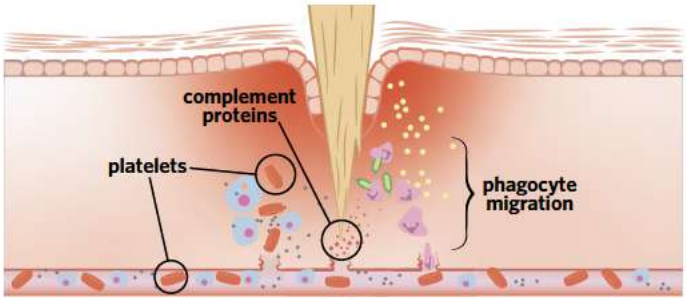


Figure 8 Various components of the innate immune system are able to access the site and destroy pathogens.

The response continues until the site has been cleared of pathogens and debris, and the site of injury has been healed. Finally, the pus that comes out of an injured area is fluid containing a large amount of dead immune cells and pathogens. Think about that next time you're popping a pimple!

Theory summary

The second line of defence is comprised of a number of non-specific cells and molecules that work quickly to limit the spread of injury or infection. An important example of the ways in which these components interact with each other is the inflammatory response.

Table 1 Components of the second line of defence and their roles

Cells	
Neutrophil	Phagocytosis of pathogens
Macrophage	Phagocytosis of pathogens and antigen presentation to the adaptive immune system
Dendritic cell	Phagocytosis of pathogens and antigen presentation to the adaptive immune system
Natural killer cell	Destroys infected or abnormal cells via induction of apoptosis
Mast cell	Causes inflammation by the release of histamine
Molecules	
Interferons	Released by viral-infected cells and causes changes in neighbouring cells that make them less susceptible to infection
Complement proteins	React with each other and aid in the destruction of pathogens via opsonising pathogens, attracting phagocytes to pathogens, and the formation of membrane attack complexes
Venom inhibitors	Prevent venom from reacting with cells in the body and causing damage
Fever	An abnormally high body temperature that is an attempt by the body to kill pathogens

9C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the molecule that causes vasodilation of blood vessels

b _____ phagocytes that interact with the adaptive immune system

c _____ a non-specific leukocyte that releases cytotoxic chemicals to destroy virally-infected cells

d _____ proteins that opsonise bacteria via a cascade of reactions with each other

e _____ the compound released by virally-infected cells to increase viral resistance in neighbouring cells

Question 2

Which of the following statements about the second line of defence is false?

A It is non-specific.

B Neutrophils are a form of antigen-presenting cell.

C It includes the destruction of pathogens by phagocytosis.

D Inflammation results in increased blood flow to the site of injury.

Question 3

Which of the following statements about the inflammatory response is true?

A Cytokines released by damaged cells attract leukocytes to the site of infection.

B Inflammation results in increased blood flow and bleeding at the site of injury.

C Complement proteins form MACs on the surface of viruses.

D Natural killer cells destroy bacteria via phagocytosis.

Question 4

Fill in the blanks in the following sentences.

As part of the inflammatory response, _____**I**_____ release histamine, causing vasodilation. _____**II**_____ migrate to the site of infection or injury, and consume pathogens/debris. _____**III**_____ assist these cells in destroying pathogens in a number of different ways, including _____**IV**_____.

	I	II	III	IV
A	mast cells	Phagocytes	Complement proteins	opsonisation
B	phagocytes	Complement proteins	Mast cells	opsonisation
C	neutrophils	Phagocytes	Complement proteins	opsonisation
D	mast cells	Phagocytes	Platelets	inducing apoptosis

Question 5

Which of the following options contains all true statements about these innate immune molecules?

	Histamine	Complement proteins	Venom inhibitor	Cytokines
A	Released by mast cells	Attract phagocytes to pathogens	Control/stimulate other immune cells	Prevents venom from reacting with cells in the body
B	Released by mast cells	Opsonise bacteria	Prevents venom from reacting with cells in the body	Control/stimulate other immune cells
C	Causes vasoconstriction	Increase viral resistance in neighbouring cells	Prevents venom from reacting with cells in the body	Control/stimulate other immune cells
D	Causes vasodilation	Form MACs	Control/stimulate other immune cells	Prevents venom from reacting with cells in the body

Question 6

Which of the following options contains all true statements about these innate immune cells?

	Dendritic cell	Mast cell	Natural killer cell	Neutrophil
A	Phagocytoses pathogens	Releases histamine	Kills infected cells	Presents antigens to adaptive immune system
B	Releases histamine	Presents antigens to adaptive immune system	Phagocytoses pathogens	Kills infected cells
C	Presents antigens to adaptive immune system	Releases histamine	Kills infected cells	Phagocytoses pathogens
D	Releases histamine	Presents antigens to adaptive immune system	Presents antigens to adaptive immune system	Phagocytoses pathogens

Exam-style questions

Within lesson

Question 7 (1 MARK)

The inflammatory response is a defence mechanism that evolved in higher organisms to protect them from infection and injury. This response

A is specific to particular antigens.

B is part of the first line of defence.

C involves the degranulation of mast cells.

D occurs independently of the complement cascade.

Adapted from VCAA 2016 Section A Q20

Question 8 (1 MARK)

The inflammatory response helps to prevent infection by

A making blood vessels less permeable.

B promoting phagocytosis of pathogens.

C activating natural killer cells to kill bacteria.

D releasing interferon to activate the complement cascade.

Question 9 (1 MARK)

A girl is carrying a piece of wood. A splinter breaks off and becomes embedded in her finger. The next day, she notices an inflammatory response occurring in her finger. In the region around the small piece of wood embedded in her finger

A antigens from the foreign material would be presented on the surface of neutrophils to cells of the adaptive immune system.

B mast cells would be leaving the blood vessels and phagocytosing foreign material.

C cytokines from damaged cells would be attracting leukocytes to the site of injury.

D phagocytes would be releasing histamine to cause vasodilation.

Adapted from VCAA 2015 Section A Q18

Question 10 (1 MARK)

As part of the second line of defence in the human immune system, cells that present antigens to cells of the adaptive immune system include

A mast cells.

B neutrophils.

C dendritic cells.

D natural killer cells.

Adapted from VCAA 2013 Exam 1 Section A Q14

Question 11 (1 MARK)

Defence mechanisms against viral pathogens include

A neutralisation by cytokines.

B destruction of viral particles in the bloodstream by natural killer cells.

C interferons that protect uninfected cells from viral attack.

D formation of membrane attack complexes by complement proteins.

Adapted from VCAA 2013 Section A Q15

Question 12 (1 MARK)

When a viral pathogen penetrates the first line of defence, an immediate immune response is the

A activation of the adaptive immune system.

B release of complement proteins by mast cells.

C destruction of virally infected cells by natural killer cells.

D destruction of viral particles in the bloodstream by natural killer cells.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q7

Question 13 (1 MARK)

Cytokines are chemicals that

A attract phagocytes to the site of injury.

B protect infected cells from viral attack.

C cause blood vessels to vasodilate and become leaky.

D kill bacteria by producing holes in the bacterial cell membrane.

Adapted from VCAA 2012 Exam 1 Section A Q23

Question 14 (1 MARK)

Which of the following substances is responsible for protecting uninfected cells from viral attack?

A cytosol
B histamine
C interferons
D complement proteins

Question 15 (7 MARKS)

Neisseria meningitidis is a bacterium that causes meningitis. This disease causes inflammation of tissue surrounding the brain and spinal cord in humans.

Adapted from VCAA 2011 Exam 1 Section B Q5

a Explain three changes that would occur during the inflammatory response in the tissue surrounding the brain that would help combat the bacterial pathogen. (3 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q5bi

b Antigen-presenting cells also form an important component of the body's defence against pathogens.

i Identify two cell types belonging to the second line of defence that serve as antigen-presenting cells. (2 MARKS)
ii State the two roles of antigen-presenting cells in the innate immune system. (2 MARKS)

Multiple lessons

Question 16 (1 MARK)

Some components of the second line of defence destroy pathogens by disrupting the pathogen's cell wall. Which of the following pathogens would not be affected by this process?

A protozoa
B bacteria
C prions
D fungi

Question 17 (1 MARK)

An example of an innate response by the human immune system to a protein coat-bound pathogen is

A the release of interferons by infected cells.
B the release of complement proteins by mast cells.
C the opsonisation of the pathogen by complement proteins.
D the formation of membrane attack complexes by complement proteins.

Question 18 (4 MARKS)

Scientists have found that milk of the tammar wallaby (*Macropus eugenii*) contains high levels of peptides and chemicals from the innate immune system.

a Based on the information provided, state three chemicals of the innate immune system that scientists could expect to find in the milk. (3 MARKS)

Adapted from VCAA 2017 Section B Q4di

b State one reason why these compounds are considered part of the innate immune system. (1 MARK)

Key science skills

Question 19 (7 MARKS)

Scientists wanted to explore the response of the innate immune system to different concentrations of a pathogen in a population of mice. To do so, a group of 10 mice were used. Each mouse was infected with a different concentration of pathogenic bacteria under their skin. One mouse received no bacteria. After a few hours, the scientists then measured the levels of neutrophils and histamine present in the skin of the mice. This procedure was conducted once.

a State a hypothesis that the scientists could be testing with this experiment. (1 MARK)

b State whether a control was used in the experiment and identify what the control is/should be. (2 MARKS)

c Would this experiment enable the scientists to reliably draw scientifically valid conclusions about the response of the innate immune system to different concentrations of pathogen? Explain your response. (2 MARKS)

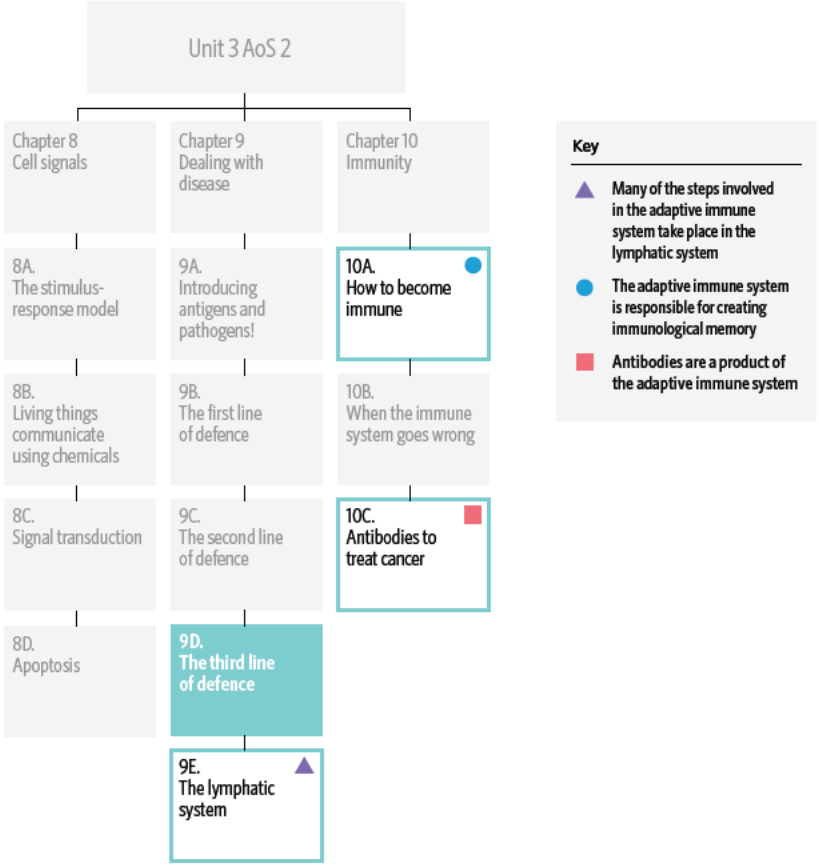
d Outline how neutrophils and histamine protect the mouse's body once a pathogen has gained entry to the internal environment. (2 MARKS)

Adapted from VCAA 2018 Section B Q3c

9D THE THIRD LINE OF DEFENCE

'I don't know who you are (yet). I don't know what you want. If you are looking for ransom, I can tell you I don't have money. But what I do have are a very particular set of skills, skills I have acquired over a very long career. Skills that make me a nightmare for pathogens like you. If you let my body go now, that'll be the end of it. I will not look for you, I will not pursue you. But if you don't, I will look for you, I will find you, and I will kill you.'

Adaptive immune system to pathogen upon first meeting (probably)



In this lesson you will learn about the cells and processes that make up the adaptive immune system.

Study design dot point

- the characteristics and roles of components of the adaptive (specific) immune response including the actions of B lymphocytes and their antibodies (including antibody structure) in humoral immunity, and the actions of T helper and T cytotoxic cells in cell-mediated immunity

Key knowledge units

Adaptive immunity	3.2.10.1
Immunological memory	3.2.10.2

Adaptive immunity 3.2.10.1

OVERVIEW

The third line of defence (also termed the adaptive immune system or the specific immune response) is comprised of two different types of responses to pathogens – the humoral and cell-mediated responses. These responses are specific to the pathogen being combatted, resulting in the formation of immunological memory.

THEORY DETAILS

The **third line of defence** is a key component of the immune system in vertebrates. Like the second line of defence, it is designed to combat and destroy pathogens that have breached the first line of defence. However, there are two unique features of the adaptive immune system that differentiate it from the second line of defence. They are:

1 Specificity – the adaptive immune system responds to each type of pathogen in a highly tailored way

2 The formation of **immunological memory** – the adaptive immune system results in the creation of cells that allow the body to respond to future re-infections by a previously encountered pathogen more quickly and effectively.

There are a number of different cell types that make up the adaptive immune system. These are shown in Figure 1. As in lesson 9C, you only need to be aware of the bolded cells.

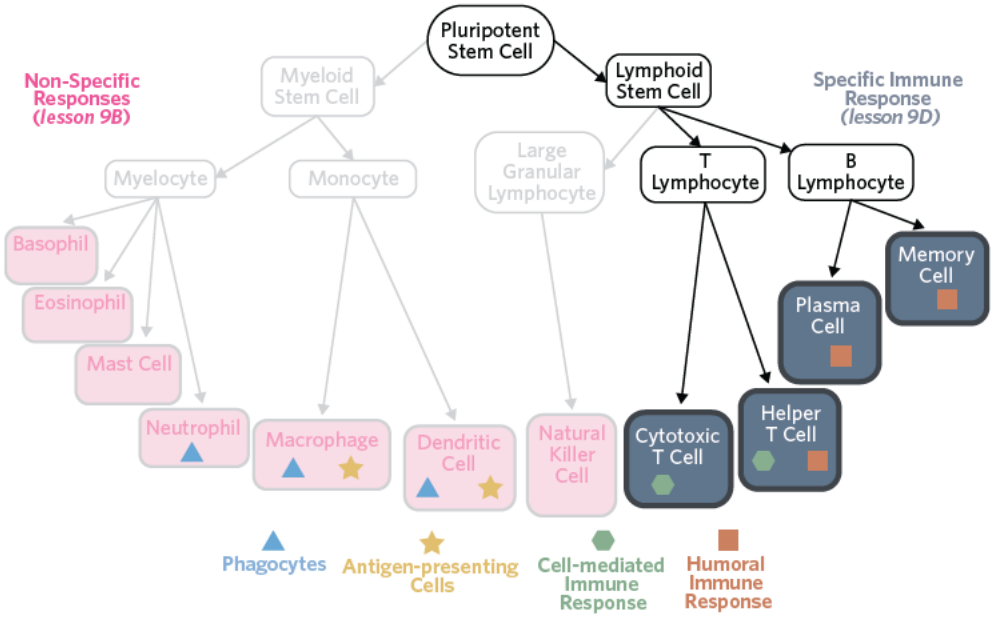


Figure 1 The cellular components of the adaptive immune system

Initiation of the adaptive immune response

A key process in the initiation of the two adaptive immune responses is the selection of a **T lymphocyte** called a **T helper cell** via a process called antigen presentation. This process is shown in Figure 2.

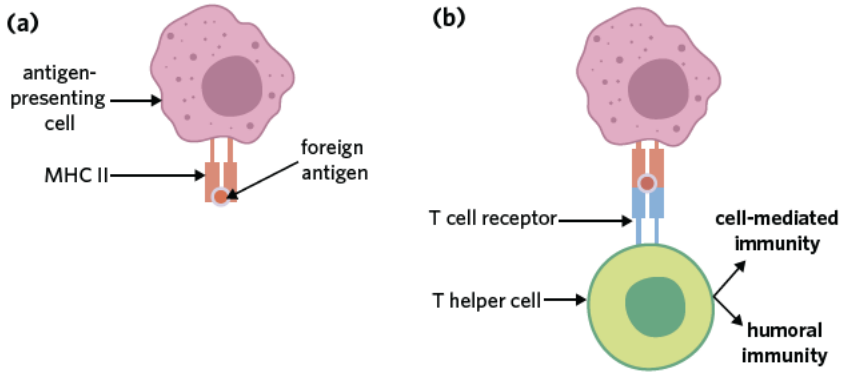


Figure 2 **(a)** an antigen-presenting cell displaying a foreign antigen via MHC II; **(b)** antigen-presenting cell presenting antigen to a complementary T cell receptor on a T helper cell and activating it

After engulfing and digesting a pathogen (as described earlier in 9C), **antigen-presenting cells** (APCs) present foreign antigens on their surface using MHC II proteins. This complex interacts with T cell receptors on the surface of T helper cells, each of which displays a T cell receptor that is slightly different in shape. When an APC presents an antigen to a T helper cell that is complementary in shape to the T cell receptor, that T helper cell becomes activated. This activated T helper cell then helps initiate the processes of **humoral** and **cell-mediated immunity**.

third line of defence a subset of the immune system within vertebrates that is comprised of the humoral and cell-mediated responses which create a specific immune response and form immunological memory. Also known as the **adaptive immune system** or **specific immune response**

immunological memory the ability of the immune system to quickly and aggressively combat a previously encountered pathogen due to T and B memory cells

T lymphocyte a type of lymphocyte that plays an important role in cell-mediated immunity which differentiates into cytotoxic T cells and T memory cells

T helper cells (T_h) a type of differentiated T lymphocyte that supports the functioning of a number of different immune cells, including the cloning and differentiation of selected T and B cells

antigen-presenting cell a subgroup of phagocytes that display the antigens from consumed pathogens on their surface and interact with the adaptive immune system

humoral immunity a component of the adaptive immune system in which pathogens are neutralised or destroyed via the production and secretion of antibodies. Also known as **B cell immunity**

cell-mediated immunity a component of the adaptive immune system in which infected/abnormal cells are destroyed by cytotoxic T cells. Also known as **T cell immunity**

antibody a protein produced by plasma cells during the adaptive immune response that is specific to an antigen and combats pathogens in a variety of ways. Also known as **immunoglobulin**

B lymphocyte a type of lymphocyte that plays an important role in humoral immunity and differentiates into plasma cells and B memory cells

Humoral immune response

Humoral immunity involves the neutralisation and/or destruction of a pathogen via the production and secretion of **antibodies**. The response is generated by interactions between T helper cells and **B lymphocytes**. Below the response is broken up into key individual steps.

1 B lymphocytes are a type of white blood cell that circulate around the body (Figure 3). Their surfaces are covered in B cell receptors, also known as antibodies. They travel around the body in the bloodstream, and reside in high numbers in lymph nodes.

2 A pathogen with an antigen that matches the antigen-binding site on the receptor of a B cell interacts with that B cell. When this happens, the B cell is said to have been 'selected' (Figure 3).

lesson link ***Lesson 9E*** will explore the lymphatic system, including lymph nodes, in more detail.

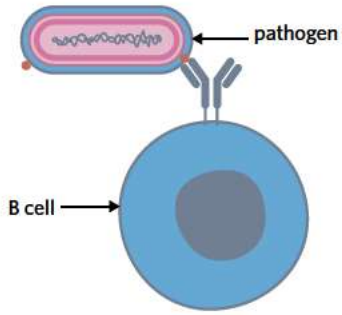


Figure 3 An antigen interacting with a B cell receptor

3 Once a B cell has been selected, a T helper cell with a matching receptor to the antigen will recognise the selected B cell and secrete a number of different **cytokines** (Figure 4a). These cytokines cause the B cell to undergo a **clonal expansion** in which many copies of the selected B cell are produced. The selection and expansion processes are referred to together as **clonal selection**.

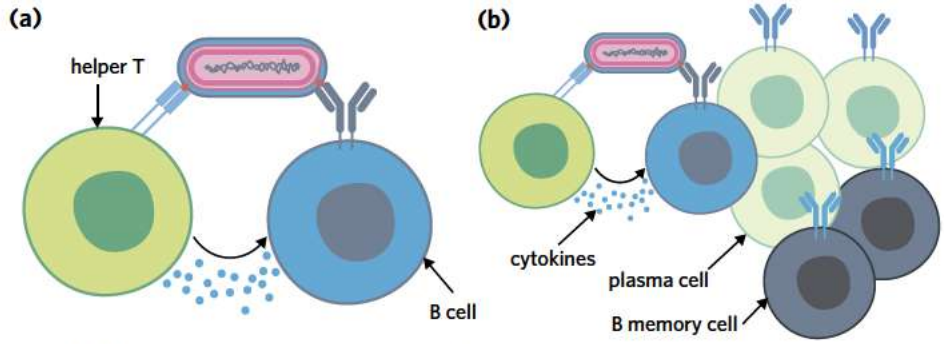


Figure 4 **(a)** A T helper secreting cytokines, causing **(b)** cloning and differentiation of selected B cell into plasma cells (light green) and B memory cells (grey)

4 In addition to cloning, the T helper cell also causes the B cell to undergo the process of **differentiation** (Figure 4b) in which the clones of the selected B cell are driven to differentiate into two different types of B cells – **B memory cells**, and **plasma cells**.

B memory cells (Figure 5a) are copies of the selected B cell that reside in the body for a long period of time and are responsible for immunological memory. These will be examined more thoroughly later in this lesson.

The majority of selected B cell clones differentiate into plasma cells (Figure 5b). Being clones of the originally selected B cell, plasma cells have the same antibody on their surface. Plasma cells, however, don't just keep these antibodies on their surface – instead, they secrete antibodies into the blood at an incredible rate of 2000 molecules per second.

differentiation the process in which cells develop specialised characteristics, typically transforming them from one cell type to another

B memory cell a differentiated B lymphocyte that is responsible for providing long-lasting immunological memory of an antigen

plasma cell a differentiated B lymphocyte that is responsible for the generation and secretion of antibodies during the humoral response

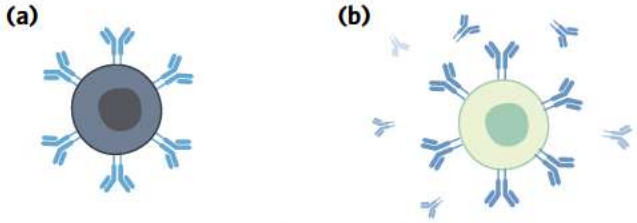


Figure 5 **(a)** a B memory cell; **(b)** a plasma cell secreting antibodies

Antibodies

Antibodies are proteins comprised of four polypeptide chains, including two heavy chains and two light chains. The two heavy chains are joined by a disulphide bridge. Each antibody also has a constant region and a variable region. Like T cells, each B cell produces receptors with a slightly different shape that is part of the variable region and is complementary in shape to a specific antigen. There are five types of antibodies – IgG, IgA, IgM, IgE, IgD – and each serves a slightly different function and occurs at a different time in the immune response (see Table 1 for details). Each antibody has two identical antigen-binding sites that allow it to bind with antigens on the surface of two different pathogens at once. Figure 6 depicts the structure of antibodies.

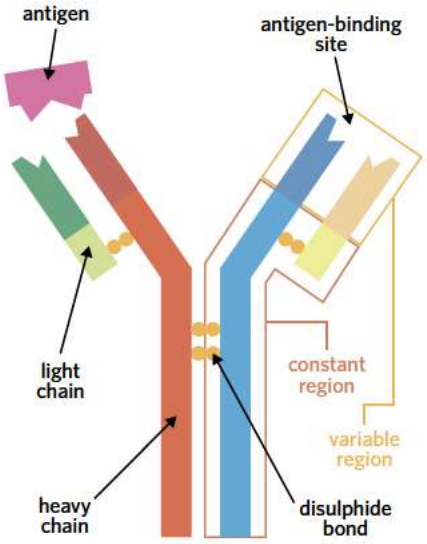


Figure 6 The structure of an antibody

Table 1 Types of antibodies

Type	Function
IgA	Found in mucus, breast milk, and saliva. Protects against pathogen invasion.
IgD	Important for activation of other immune cells
IgE	Protects against parasitic worms. Also responsible for allergic reactions.
IgG	Secreted by plasma cells. Able to cross the placenta and travel to the foetus.
IgM	Attached to B cells and secreted into the blood by plasma cells. The first form of antibody produced by plasma cells in response to an infection.

Step 5: Antibodies that have been secreted travel throughout the body and eventually come into contact with the pathogen that was originally presented to the selected B cell. Due to the process of clonal selection, these antibodies have a shape that is specific to the pathogen and complementary to its antigens.

Antibodies interact with pathogenic antigens in a number of key ways:

1. Neutralisation – antibodies can block the sites of pathogens that are used to attack host cells (e.g. can block the site used by a virus to enter a cell), and can block the active sites of toxins (Figure 7a).
2. Immobilisation – antibodies can immobilise pathogens.
3. **Agglutination** – antibodies can bind together with antigens on two separate pathogen surfaces, forming large **antigen-antibody complexes**. This process makes it easier for phagocytes to recognise the pathogens as foreign bodies and destroy them (Figure 7b).
4. Opsonisation – antibodies can bind directly to the surface of a pathogen to make it easier to phagocytose (Figure 7c).
5. Activation of complement proteins – antibodies attached to the surface of pathogens can facilitate the actions of complement proteins, including the formation of **membrane attack complexes (MACs)** (Figure 7d).

Tip VCAA doesn't expect you to know in detail what each type of antibody does. Where you need to know this to answer a question they will provide you with the information required. You are, however, expected to know about the general structure of antibodies (Figure 6).

lesson link In ***10B***, you will learn more about how IgE antibodies are involved in the allergic response.

agglutination the clumping of particles together in a solution

antigen-antibody complex formed by the interaction between antigen and antibody molecules

membrane attack complex (MAC) a pore formed by complement proteins in the cell membranes of a pathogen, disrupting the membrane and leading to the pathogen's death

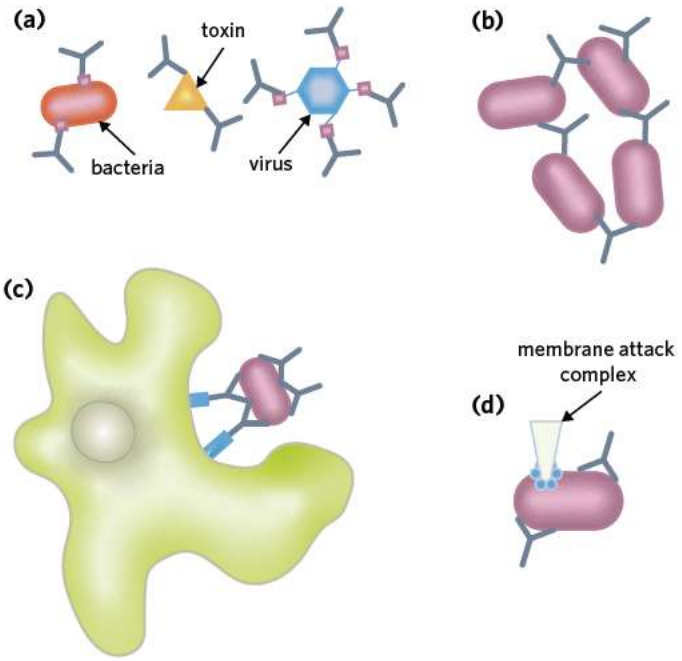


Figure 7 **(a)** neutralisation and immobilisation; **(b)** agglutination of pathogens; **(c)** opsonisation; **(d)** activation of complement proteins

Case study

Red blood cells part 2

In lesson 9A you learned that the antigens on the surface of red blood cells (RBC) are the basis of how we determine blood types. For example, a person with type A blood displays the A antigen on the surface of their RBCs.

Just like any antigen, RBC antigens are recognised by the immune system and stimulate the production of antibodies. An individual with type A antigens will have anti-B antibodies. If they are transfused blood that is type B, the anti-B antibodies in their blood will agglutinate the introduced type B RBCs. This is why patients who are transfused the wrong blood type become extremely sick so quickly – their preformed antibodies quickly react to the foreign antigen presented on the transfused blood and launch an immune attack against it.

The table shows the antigens and antibodies present in each blood type.

	Type O	Type A	Type B	Type AB
Red blood cell type				
Antibodies in plasma	anti-A + anti-B	anti-B	anti-A	none
Antigens in red blood cells	none	antigen A	antigen B	antigen A + antigen B

Figure 8 Antigens and antibodies present in each blood type

In addition to the ABO grouping system, another blood grouping system is based on the presence or absence of another common antigen – the **Rhesus antigen**. This antigen is either present (rhesus positive or R+) or absent (rhesus negative or R-) on the surface of a person's RBCs. Blood types are usually classified using these two systems (although other rarer blood type systems exist) giving 8 possible blood types:

- A+
- A-
- B+
- B-
- O+
- O-
- AB+
- AB-

Rhesus antigen an antigen on the surface of red blood cells that can cause an immune response if not matched correctly between donor and receiver

Case study

Haemolytic disease of the newborn

Haemolytic disease of the newborn (HDN) is an example of an antibody-mediated disease.

Normally a foetus' blood and its mother's blood remain separate. During birth, however, as the placenta separates from the wall of the uterus, some of the baby's blood can mix with the mother's circulating blood. This normally does not cause any issues. However, if the mother is rhesus negative (e.g. A-) but the baby is rhesus positive (e.g. A+), then the mother's immune system will recognise the rhesus positive antigen as foreign and produce antibodies against it (these are called anti-D or anti-Rh antibodies).

Fortunately, these anti-D antibodies don't affect the foetus as it is usually born by the time they're produced. If, however, the same woman becomes pregnant in the future with another rhesus positive foetus, then these anti-D antibodies can cross the placenta and destroy the RBCs of the second foetus. If this occurs the foetus can develop anaemia or, in severe cases, die.

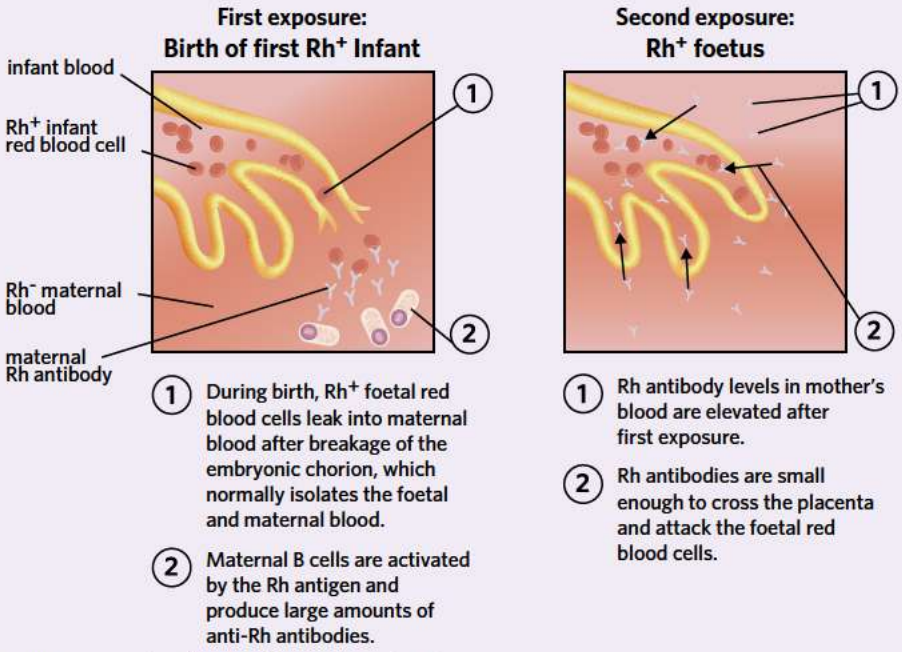


Figure 9 Haemolytic disease of the newborn (HDN)

Cell-mediated immunity

Cell-mediated immunity involves the destruction of infected or abnormal cells via the clonal selection of a **T cytotoxic cell**. This cell specifically recognises the abnormal antigen being presented by the cell.

T cytotoxic cell (T_c)
a differentiated T lymphocyte that is responsible for the destruction of infected or abnormal cells

1 Antigen-presenting cells present digested foreign antigens on their surface MHC II (Figure 10a). These cells then travel throughout the body and arrive at a lymph node.

2 In a similar way to the activation of T helper cells, these cells may eventually come upon a naive T cell with a T cell receptor that matches the antigen being presented (Figure 10a). If this occurs, these naive T cells become activated and stimulated further by cytokines secreted by the selected T helper cells and undergo the process of clonal selection and differentiation (Figure 10b).

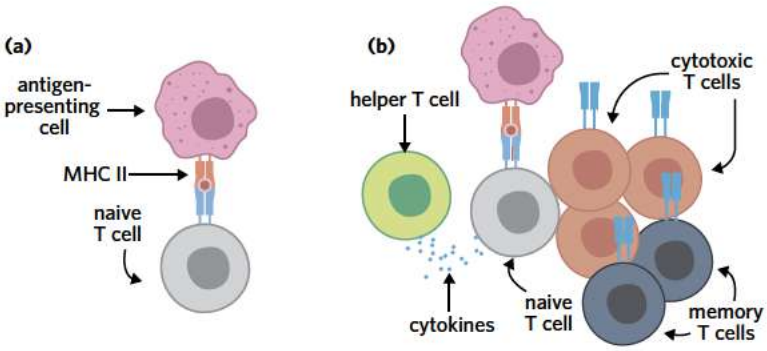


Figure 10 **(a)** antigen-presenting cell presenting antigen to a complementary T cell receptor on a naive T cell and activating it; **(b)** cloning and differentiation of selected T cell into cytotoxic T cells (red) and T memory cells (dark grey) via secretion of cytokines from selected helper T cell

3 The clones of the selected T cell are driven by the T helper cell to differentiate into two different types of T cells – cytotoxic T cells, and **T memory cells**. T memory cells, like B memory cells, are copies of the originally selected T cell that reside in the body for extended periods of time and help form immunological memory. The majority of selected T cell clones differentiate into cytotoxic T cells. These cells leave the lymph node and travel throughout the body, eventually arriving at the site of infection.

T memory cell a differentiated T lymphocyte that is responsible for providing long-lasting immunological memory

4 Due to selection and cloning, the cytotoxic T cells that arrive at the infected site have T cell receptors that are specific to the foreign antigen present. As discussed in 9A, all cells express MHC I. Other than its role in self-recognition, MHC I also displays antigens that have been broken down in a cell on the cell's surface. In a cell that's been infected with a virus, for example, MHC I will present some foreign viral antigens on the surface of the cell.

5 Once the cytotoxic T cell has found an abnormal cell that is presenting foreign antigens on its MHC I complex, it binds to it via interactions between its T cell receptor and the antigen-MHC I complex (Figure 11a). It then secretes chemicals that induce apoptosis in the cell (Figure 11b).

Tip Humoral immunity acts primarily against extracellular pathogens, whereas cell-mediated immunity acts primarily against intracellular pathogens. Cell-mediated immunity is also responsible for destroying cells that have become abnormal (e.g. cancer cells), and is the primary source of organ rejection (it recognises the non-self organ as foreign and creates cytotoxic T cells that attack the transplanted organ).

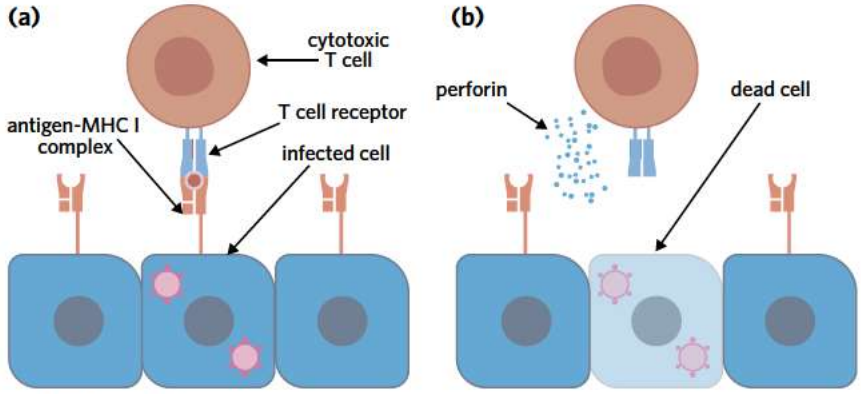


Figure 11 **(a)** a cytotoxic T cell recognising an infected cell via interaction with its MHC I receptor; **(b)** cytotoxic T cells kill infected cells by releasing chemicals that induce apoptosis.

Immunological memory 3.2.10.2

OVERVIEW

B memory cells and T memory cells formed during the adaptive immune response stay in the blood for an extended period of time, allowing the body to respond to pathogens it has previously encountered quickly and effectively.

THEORY DETAILS

A key component of both the humoral and cell-mediated adaptive immune responses is the creation of B and T memory cells, respectively. Each of these cells confer the body with long lasting immunological memory.

B memory cells contribute to immunological memory by rapidly dividing and forming new antibody-producing plasma cells when they encounter an antigen that matches their receptor. Similarly, T memory cells proliferate rapidly into T helper cells and cytotoxic T cells upon stimulation by an antigen-presenting cell that is presenting a previously encountered antigen.

B memory cells also create immunological memory by constantly secreting low amounts of their antibody. In this way, a person who is immune to a pathogen will always have trace amounts of the antibody against that pathogen in their blood.

Immunological memory has a number of advantages, including creating a more rapid and effective immune response upon re-infection, as antibodies are produced at a greater rate and cytotoxic T cells are created more rapidly to kill any infected cells. This is why the effectiveness of Botox injections decrease over time (see case study).

Case study

Bye bye botox!

Botox injections are a common cosmetic treatment used to reduce the appearance of people's wrinkles. But did you know that the substance injected into patients is actually a toxin produced by the bacteria *Clostridium botulinum*? This toxin paralyses muscle fibres by interfering with the nerves that control them, preventing the muscle from contracting.

These 'relaxed' muscles no longer pull on the overlying skin, seemingly making wrinkles disappear! (Figure 12)

In some people, the effectiveness of Botox treatment decreases over time. This is due to immunological memory. In these people the immune system has recognised Botox as a non-self antigen and has initiated an adaptive immune response, including the production of antibodies and memory B cells. These memory B cells reside in the body for an extended period of time. When they encounter a Botox antigen again they are able to quickly produce a large amount of antibodies to neutralise the toxin, thereby reducing its effect.

TanyaLovus/Shutterstock.com

Figure 12 Before and after Botox treatment

Theory summary

The adaptive immune system is comprised of two responses. The humoral response results in the destruction of pathogens via the release of antibodies from plasma cells. The cell-mediated response results in the killing of infected or abnormal cells. Both the humoral and cell-mediated responses result in the creation of immunological memory which allows the body to respond more quickly and effectively when it re-encounters a pathogen.

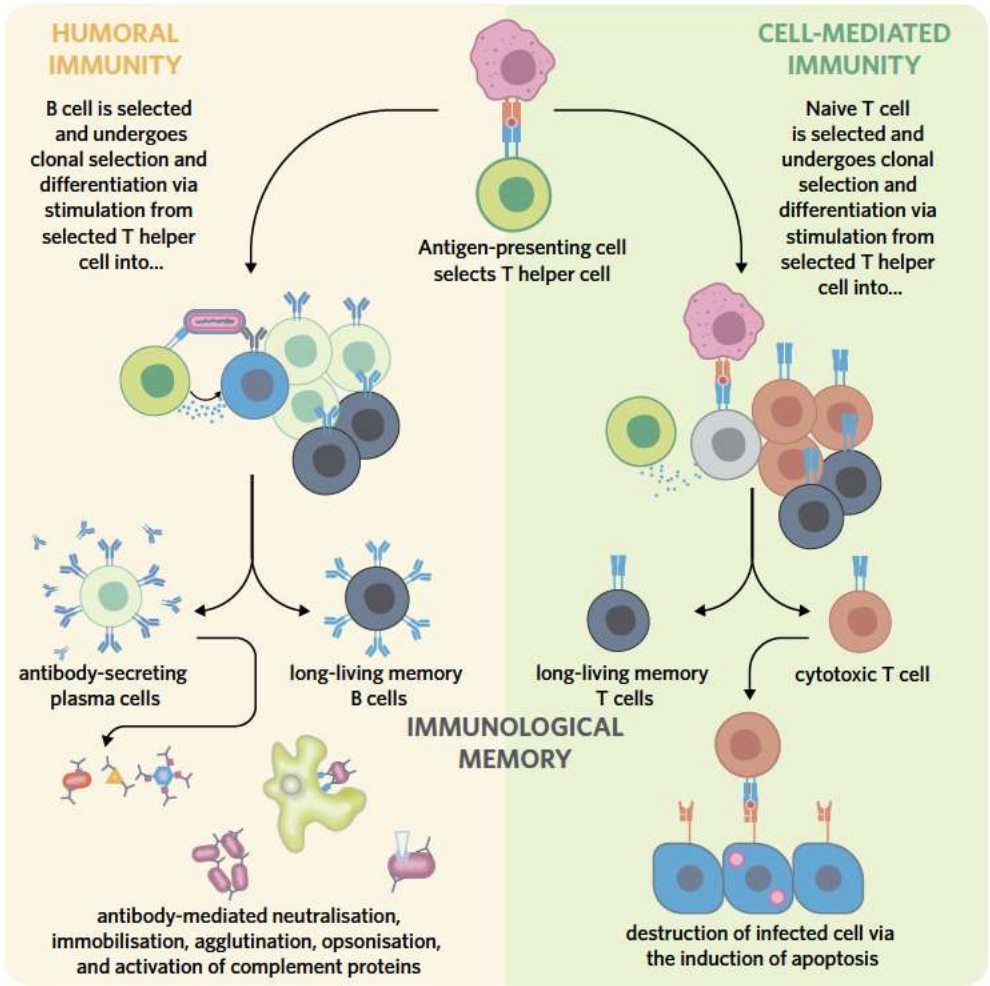


Figure 13 Summary of the third line of defence

9D QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ cell responsible for the secretion of antibodies

b _____ the ability of the adaptive immune system to more quickly combat a re-encountered pathogen

c _____ cell responsible for the destruction of virally-infected cells

d _____ a structure comprised of two heavy chains and two light chains

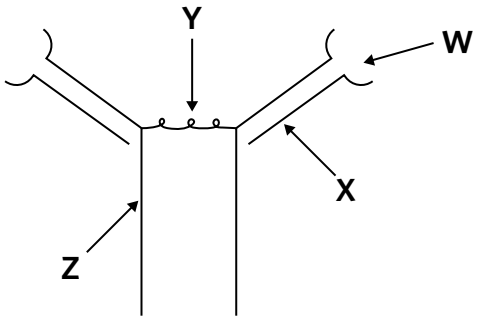
e _____ molecules secreted by T helper cells that drive cloning and differentiation of a selected lymphocyte

f _____ the part of an antibody responsible for the unique shape of the antigen-binding site

g _____ lymphocyte responsible for the differentiation of B cells and cytotoxic T cells

Question 2

Which of the options correctly identifies the structures W, X, Y, and Z?



	W	X	Y	Z
A	light chain	antigen-binding site	heavy chain	disulphide bridge
B	constant region	heavy chain	variable region	light chain
C	antigen-binding site	light chain	disulphide bridge	heavy chain
D	heavy chain	disulphide bridge	light chain	variable region

Question 3

Order the following steps in the humoral response.

I T helper cells produce cytokines to stimulate B cells

II Cytotoxic T cells secrete antibodies

III Antigens are detected by T helper cells

IV B cells differentiate into plasma cells

V Antibodies travel to the pathogen and destroy it

A III, I, IV, V

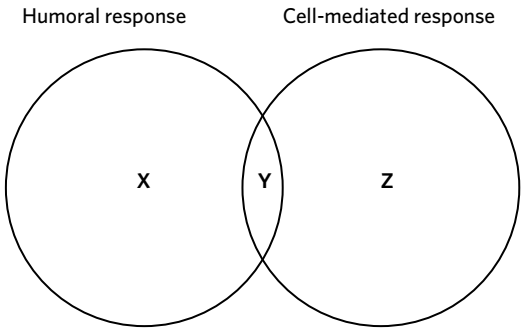
B III, I, IV, V, II

C II, III, V, IV

D V, I, III, IV

Question 4

Complete the Venn diagram outlining the differences and similarities between the humoral and cell-mediated responses.



	X	Y	Z
A	stimulation by T helper cells	antibody-mediated destruction of pathogens	killing of infected cells by cytotoxic T cells
B	antibody-mediated destruction of pathogens	stimulation by T helper cells	killing of infected cells by cytotoxic T cells
C	antibody-mediated destruction of pathogens	killing of infected cells by cytotoxic T cells	stimulation by T helper cells
D	killing of infected cells by cytotoxic T cells	stimulation by T helper cells	antibody-mediated destruction of pathogens

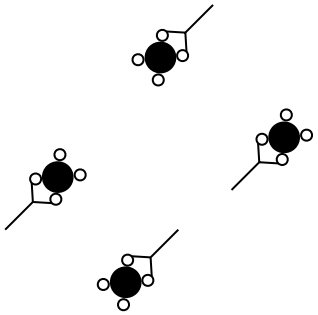
Exam-style questions

Within lesson

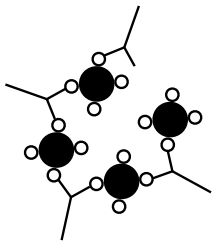
Question 5 (1 MARK)

Which of the following correctly depicts an antigen-antibody complex?

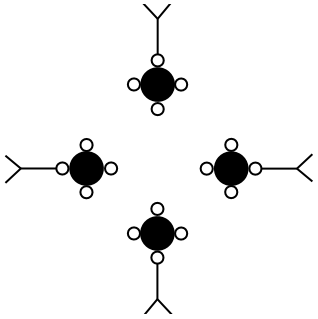
A



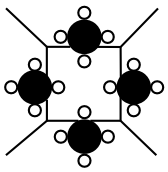
B



C



D



Question 6 (1 MARK)

Non-Hodgkin lymphoma is a type of cancer. In most patients with non-Hodgkin lymphoma, the B lymphocytes multiply uncontrollably and are unable to differentiate. The patient can develop recurring infections from normally non-pathogenic bacteria such as *Staphylococcus epidermidis*.

Based on the information provided, which of the following statements about patients with non-Hodgkin lymphoma is true?

A These patients won't be able to form memory B cells.

B These patients won't be able to form cytotoxic T cells.

C These patients will have non-functioning T helper cells.

D These patients will have more antibodies in their system.

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q2b

Question 7 (1 MARK)

Botox injections are a cosmetic treatment which reduces facial wrinkles by paralysing the muscles connected to nerve cells. Botox injections contain small amounts of weakened botulinum toxin. The muscle paralysis from the initial injections lasts for about four months. Muscle paralysis from subsequent injections lasts for shorter periods of time.

The production of which of the following cells could be responsible for the decreasing effectiveness of the Botox injections over time?

A Antigen-presenting cells
B Cytotoxic T cells
C Memory B cells
D T helper cells

Adapted from VCAA 2018 Section B Q4c

Question 8 (1 MARK)

The third line of defence against pathogens includes the

A killing of infected cells by memory T cells.
B formation of antigen-antibody complexes.
C secretion of antibodies by cytotoxic T cells.
D presentation of antigens to lymphocytes by neutrophils.

Adapted from VCAA 2014 Section A Q15

Question 9 (5 MARKS)

Antigen-presenting cells engulf pathogens and present antigens on their surface to T helper cells.

a Describe the humoral response that would take place once a T helper cell has detected an antigen present on an antigen-presenting cell. (3 MARKS)

Adapted from VCAA 2013 Section B Q4b

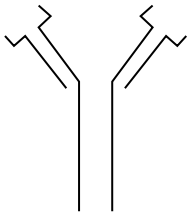
b In addition to the humoral response, a cell-mediated response can also occur. Outline the key steps of this process. (2 MARKS)

Multiple lessons

Question 10 (8 MARKS)

Immunoglobulins, or antibody molecules, have an important role in the immune system. They are made up of two heavy chains and two light chains.

a The diagram shows an antibody.



i Draw a generalised pathogen against which this antibody would be effective. Include four surface antigens in your drawing and label them. (2 MARKS)

Adapted from VCAA 2014 Section B Q4b

ii State three ways antibodies provide protection against pathogens. (3 MARKS)

Adapted from VCAA 2014 Section B Q4cii

b Immunoglobulin molecules display tertiary and quaternary structure. Explain what 'tertiary' structure is and what is responsible for its formation. (2 MARKS)

Adapted from VCAA 2016 Section B Q1c

c The molecular monomers of immunoglobulin chains are amino acids. State the reaction that takes place between amino acids to form proteins. (1 MARK)

Question 11 (4 MARKS)

Both the adaptive and innate immune systems in vertebrates feature phagocytes.

a A phagocytic cell found in the body has MHC II proteins displayed on its surface and plays an important role in the adaptive immune response. Name this cell type and explain how MHC II assists this cell in performing its function. (2 MARKS)

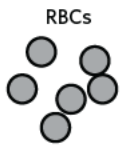
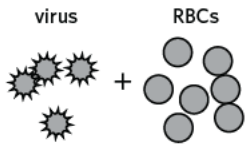
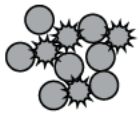
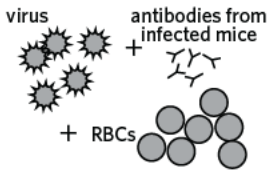
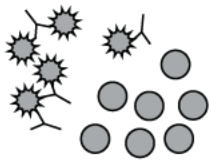
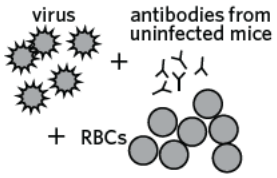
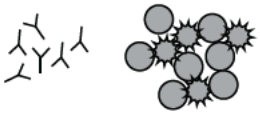
Adapted from VCAA 2015 Section B Q5c

b One type of phagocytic cell is not classified as part of the adaptive immune response. Identify which cell type this is, and explain why it is not classified as an adaptive immune system cell. (2 MARKS)

Key science skills

Question 12 (6 MARKS)

Scientists performed an experiment in which they observed the interaction of red blood cells (RBCs), the influenza virus, and antibodies extracted from influenza-infected mice *in vitro*. Two different mixtures of antibodies were used. The first mixture of antibodies (antibody type 1) was extracted from a mouse that was infected with influenza whilst the second mixture (antibody type 2) was extracted from a mouse that had never been exposed to the virus. The results are shown in the table.

	Components added to the well	Interaction	Observation
Well A			no clumping of red blood cells
Well B			clumping of red blood cells
Well C			no clumping of red blood cells
Well D			clumping of red blood cells

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q17

a State a hypothesis that the scientists could be testing with this experiment. (1 MARK)

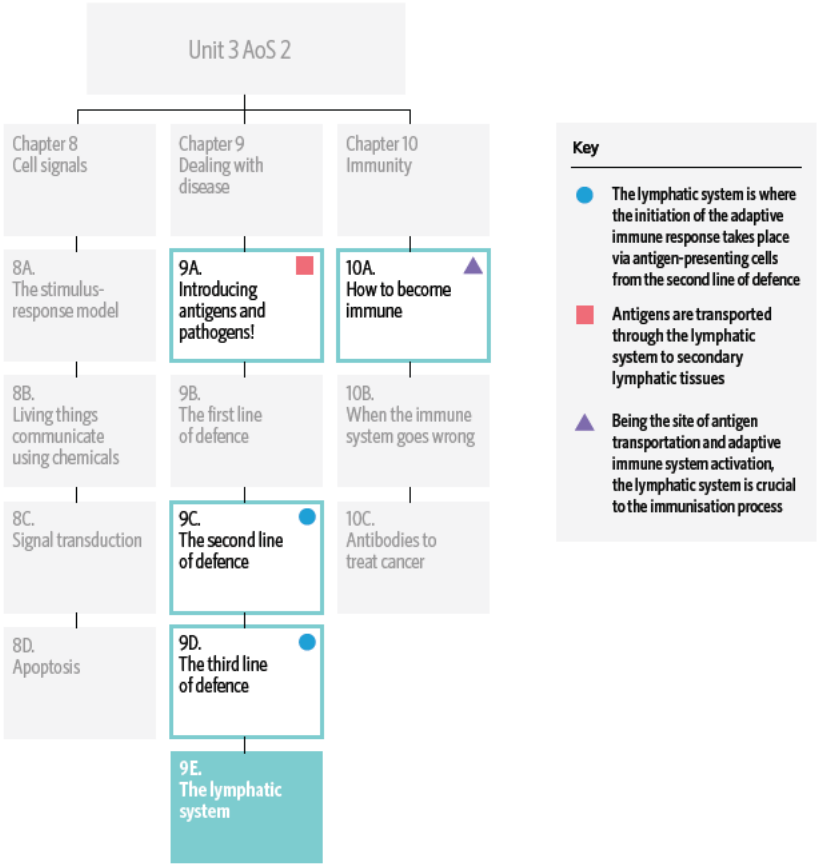
b Identify which of the wells served as the control group. Explain your reasoning. (2 MARKS)

c Identify the dependent and independent variables in this experiment. (2 MARKS)

d Explain one mechanism by which the antibodies prevent the clumping of red blood cells. (1 MARK)

9E THE LYMPHATIC SYSTEM

What do the lymphatic system, Hogwarts, and Edrolo Head Office have in common? They're all places where 'the magic' happens!



In this lesson you will learn about the structure and function of the lymphatic system. Specifically, you will learn how it serves as the transport system for antigen-presenting cells and pathogens and how it functions as the site of antigen recognition by lymphocytes.

Study design dot point

- the role of the lymphatic system in the immune response including the role of secondary lymphoid tissue (with reference to lymph nodes) as the site of antigen recognition by lymphocytes, and as a transport system for antigen-presenting cells including dendritic cells

Key knowledge unit

The lymphatic system	3.2.9.1

The lymphatic system 3.2.9.1

OVERVIEW

The **lymphatic system** is a large network of vessels throughout the body through which **lymph** flows. It has two primary functions – to act as a transport system for antigen-presenting cells and pathogens and to serve as the location for the process of clonal selection that initiates the adaptive immune response.

lymphatic system a large network of vessels and tissues throughout the body that form an important component of both the circulatory and immune systems

lymph a pale fluid that flows through the lymphatic system and has a high concentration of leukocytes

THEORY DETAILS

Everyone's heard of the 'rockstar' systems of the body – the circulatory system, the digestive system, the nervous system. The lymphatic system, however, is the Luke Hemsworth of body systems – it's just as important as the others (just ask Mrs Hemsworth!), yet doesn't get anywhere near as much attention. Well, all that's about to change!

The lymphatic system is a core component of the body's immune system. It has a number of major functions:

- The transportation of antigen-presenting cells to secondary lymphoid tissues for antigen recognition and initiation of the adaptive immune response
- The production of leukocytes, including lymphocytes
- The removal of fluid from tissues around the body
- Absorption of fatty acids from the digestive system.

VCAA requires you to know in detail about the first immune system-based role presented here – the others have just been listed for completeness.

The lymphatic system is comprised of a series of **afferent and efferent lymphatic vessels** throughout the body, and a number of **primary** and **secondary lymphoid tissues**. Figure 1 shows the key components of the lymphatic system that you need to be aware of.

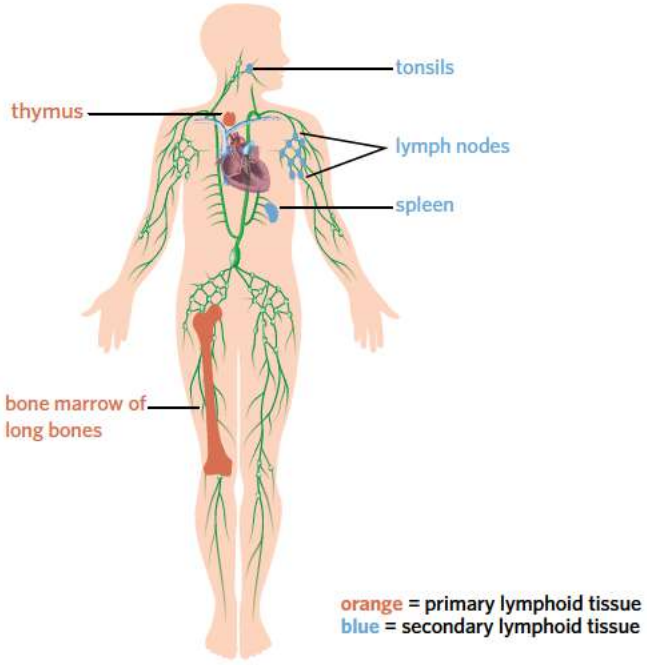


Image: Alila Medical Media/Shutterstock.com

Figure 1 Overview of the lymphatic system

Now that you know what the lymphatic system looks like, it's time to dive in and see how it actually works!

afferent lymphatic vessel thin-walled structures that collect lymph from the tissues of the body and deliver it to lymph nodes

efferent lymphatic vessels thin-walled structures that collect lymph that has drained through lymph nodes and returns it to the circulation

primary lymphoid tissue components of the lymphatic system that are responsible for the production and maturation of lymphocytes. Includes bone marrow and the thymus

secondary lymphoid tissue components of the lymphatic system that are responsible for the maintenance of mature lymphocytes and the activation of the adaptive immune response. Includes lymph nodes (including the tonsils) and the spleen

lymphatic capillaries the smallest form of lymphatic vessel. Located in the spaces between cells

Tip In the past, VCAA have not assessed how the lymphatic system works. This has been added here to give you the foundations on which to understand what you are expected to know. VCAA focuses on the immune-related purposes of the lymphatic system, the different primary and secondary lymphatic tissues, including the interaction between APCs and the adaptive immune system in lymph nodes.

How the lymphatic system works

Figure 2 summarises how the lymphatic system works. You'll learn about each stage of this diagram now.

1. Lymphatic drainage

As you'll remember from lesson 9C, fluid from blood vessels leaks into the tissues of the body. The leakage is dramatically increased during an inflammatory response. If fluid is constantly leaking into tissues, then why is it we don't swell up like a water balloon? The answer – the lymphatic system!

Lymphatic capillaries are extremely small vessels that exist throughout the tissues of the body that collect fluid in tissues, as well as any pathogens that might be present, to drain into the capillaries (Figure 3). Once this clear fluid enters the lymphatic capillaries it is called lymph and is carried away into the lymphatic system where it eventually arrives at a lymph node.

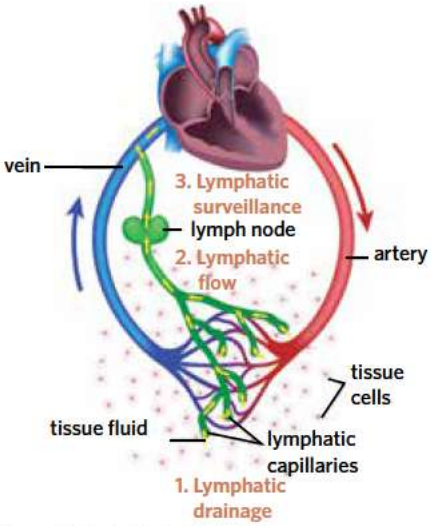


Image: AlilaMedicalMedia/Shutterstock.com

Figure 2 Function of the lymphatic system

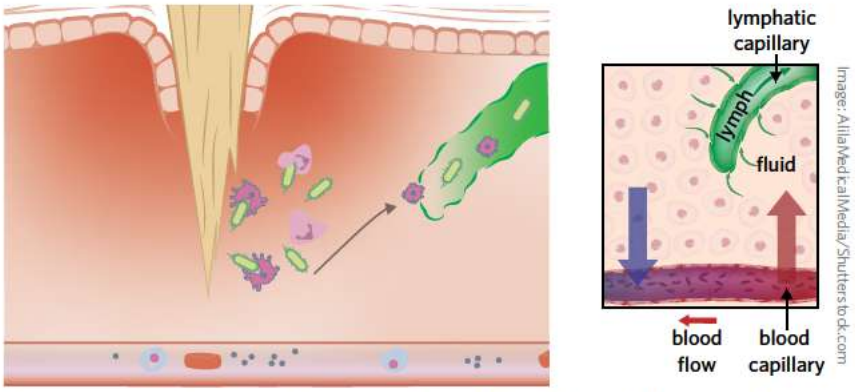


Figure 3 Lymphatic drainage of an injured site. Fluid from tissues is drained through lymphatic capillaries into the lymphatic system for antigen surveillance.

Figure 3 should look familiar – it's a diagram from **lesson 9C** illustrating the inflammatory response. This time, however, we have included the lymphatic vessels that are present in the tissues that have been affected by the splinter. Note that pathogens from the site of injury, as well as antigen-presenting cells that have consumed pathogens, have been drained from the tissues and are now in the lymphatic system.

2. Lymphatic flow

The small lymphatic capillaries throughout the body gradually join together to form larger and larger vessels that contain an increasing amount of lymph. These vessels have thin walls and rely on surrounding muscle movements to squeeze lymph fluid through the system. It's important to note, therefore, that the heart is not responsible for pumping lymph.

Lymph vessels feature a number of one-way valves (Figure 4). These ensure that as muscle movements pump lymph, the lymph fluid moves in one direction only – away from the tissues and towards the **lymph nodes**.

lymph node a small secondary lymphoid tissue of the lymphatic system that is where antigen-presenting cells activate the adaptive immune system

clonal selection the process in which B and T cells encounter an antigen that matches their antigen-binding site, then generate many copies of themselves

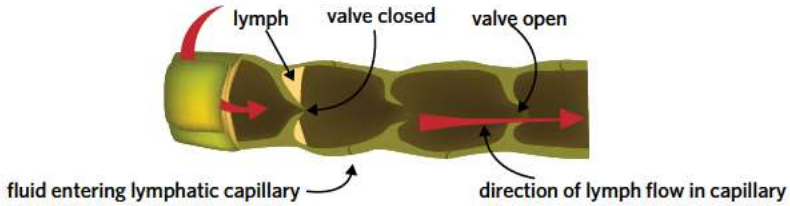


Image: AlilaMedicalMedia/Shutterstock.com

Figure 4 One-way flow of lymph fluid via valves prevents lymph from flowing backwards.

3. Lymphatic surveillance

The lymphatic vessels draining fluid from tissues eventually arrive at their destination – a lymph node (Figure 5).

Lymph is delivered to lymph nodes through afferent lymphatic vessels and drains through clusters of B and T cells. It is here, as the lymph drains through these clusters, that antigen-presenting cells and pathogens are most likely to meet with a lymphocyte that has a matching antigen-binding site and stimulate the process of **clonal selection**.

Lymph that has drained through the clusters of immune cells is taken away from the lymph node via the efferent lymphatic vessel. This lymph contains any antibodies or cytotoxic T cells that may have been created if an adaptive response was initiated. It is then returned to the circulation near the heart, where the lymphatic vessels join with the large veins returning the blood back to the heart to be pumped around the body.

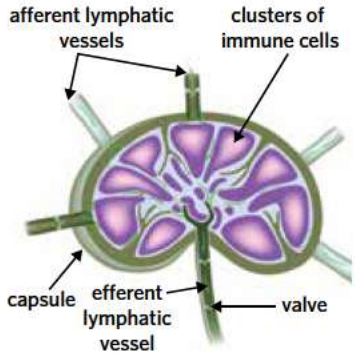


Image: Sakurra/Shuttetstock.com

Figure 5 Structure of lymph nodes

Analogy

Imagine you've just slipped off the monkey bars and you're worried you've broken your arm. What do you do next? Well, you could run up to all the people who are nearby asking if any of them are doctors, or you could phone an ambulance and get it to take you to the hospital where there are plenty of doctors standing around waiting for someone to look after.
Clearly the second option makes much more sense. The lymphatic system thinks so too. Rather than just leave an antigen-presenting cell floating around the body in the vague hope that it will find a matching B or T cell, it ferries it along to the lymph node where a huge number of B and T cells are waiting to find their perfect match.

lesson link If you're unsure about clonal selection and the processes involved in the adaptive immune response, it might be a good idea to revise the material in ***lesson 9D***.

Primary and secondary lymphoid tissues

There are two groups of lymphoid tissues in the body that you need to be aware of. They are the primary and secondary lymphoid tissues.

Primary lymphoid tissues

Primary lymphoid tissues are responsible for the creation and maturation of lymphocytes. The main primary lymphoid tissues are **bone marrow** and the **thymus**.

Lymphocytes are created in bone marrow, which is found inside certain bones of the body including the ribs, pelvis, sternum, vertebrae, and long bones (e.g. the femur bones in the legs, the humerus bones in the arms). Some of these lymphocytes stay in the bone marrow and mature further – these lymphocytes become B cells, and immediately enter the bloodstream and travel to the lymph nodes.

Other lymphocytes travel to the thymus gland in the chest to mature. The cells that travel here mature to become T cells. The thymus decreases in size as people grow older, and the proportion of fat that it contains increases. This means that older people produce fewer T cells and have a reduced immune response.

Secondary lymphoid tissues

Secondary lymphoid tissues are responsible for maintaining mature lymphocytes and initiating the adaptive immune response. In these tissues, mature lymphocytes are clustered together and 'scan' the lymph for the presence of any pathogens or foreign antigens that match their receptors, undergoing clonal selection and differentiation when encountering a matching antigen. This results in a large number of B and T cells being created within these tissues, which is why your lymph nodes swell up when you're sick! (Figure 6)

Examples of secondary lymphoid tissues are the lymph nodes (including the **tonsils**) and the **spleen**.

bone marrow semi-solid tissue found within bones. Serves as the primary site of the creation of red blood cells and leukocytes

thymus a primary lymphoid organ located in the chest. Serves as the site of T cell maturation

tonsils the name given to the two lymph nodes that reside at the back of the throat

spleen an organ located in the upper abdomen that serves a variety of functions in the immune system and the regulation of red blood cells

Memory device **B** cells mature in **b**one marrow, whereas **T** cells mature in the **t**hymus.

Image: Singjai5tock/Shutterstock.com

Figure 6 A person with an enlarged lymph node in their neck, indicating the presence of a pathogen in the mouth and/or throat

Theory summary

The lymphatic system is a series of vessels and organs that link the different components of the immune system. It transports antigen-presenting cells around the body, specifically from the site of infection to a lymph node, and is the site of clonal selection. There are a number of key structures involved in the lymphatic system, which are outlined in Table 1.

Table 1 Summary of lymphoid tissues

	Structure	Functions
Primary lymphoid tissues	Bone marrow	Production of immature B and T cells Maturation of B cells
	Thymus	Maturation of T cells
Secondary lymphoid tissues	Lymph nodes	Site where APCs meet lymphocytes Location of clonal selection and expansion of T and B cells, and initiation of the adaptive immune response
	Spleen	

9E QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ small lymphatic vessels that exist between cells

b _____ lymphoid tissues that mature lymphocytes and are the location of clonal selection

c _____ the location of T cell maturation

d _____ fluid contained within lymphatic vessels

e _____ group of structures responsible for the production of lymphocytes

Question 2

Which of the following are all true about the lymphatic system?

A	lymph is pumped via the contractions of the heart	lymphatic capillaries drain lymph from between cells	pathogens travel through the lymphatic system to lymph nodes where they are destroyed by hydrochloric acid	B cells are produced in bone marrow
B	lymph is pumped via the movement of muscles surrounding lymphatic vessels	lymphatic capillaries drain lymph from between cells	pathogens travel through the lymphatic system to lymph nodes where they are destroyed by hydrochloric acid	B cells are produced in bone marrow
C	lymph is pumped via the movement of muscles surrounding lymphatic vessels	lymphatic capillaries drain lymph from between cells	antigen-presenting cells travel through the lymphatic system to lymph nodes where they may initiate clonal selection	T cells are produced in bone marrow
D	lymph is pumped via the movement of muscles surrounding lymphatic vessels	lymphatic capillaries drain lymph from arteries	antigen-presenting cells travel through the lymphatic system to lymph nodes where they may initiate clonal selection	T cells are produced in bone marrow

Question 3

In the table, classify each of the following organs/tissues as either primary or secondary lymphoid tissues.

I Tonsils
II Spleen
III Bone marrow
IV Thymus
V Lymph nodes

	Primary lymphoid tissue	**Secondary lymphoid tissue**
A	III, IV	I, II, V
B	III, V	I, II, IV
C	IV, V	I, II, III
D	II, V	I, III, IV

Question 4

Fill in the blanks in the following sentences.

Lymph arrives at the lymph node via the _____**I**_____. Here it is filtered through _____**II**_____ where it may cause _____**III**_____ to occur. It is then drained via the _____**IV**_____.

	I	**II**	**II**	**IV**
A	veins	clusters of immune cells	innate immunity	lymphatic capillaries
B	lymphatic vessels	antigen-presenting cells	clonal selection	efferent lymphatic vessels
C	lymphatic vessels	clusters of immune cells	innate immunity	efferent lymphatic vessels
D	lymphatic vessels	clusters of immune cells	clonal selection	efferent lymphatic vessels

Exam-style questions

Within lesson

Question 5 (1 MARK)

In the lymphatic system

A T cells differentiate into plasma cells.
B transport of antigen-presenting cells occurs.

C clonal selection occurs via the interaction of antigens and antibodies.

D lymph vessels collect red blood cells and return them to the circulation.

Adapted from VCAA 2013 Section A Q20

Question 6 (1 MARK)

The structure/s responsible for the unidirectional flow of lymph throughout the lymphatic system is/are

A valves in lymph vessels.

B bone marrow.

C lymph nodes.

D the thymus.

Adapted from VCAA 2015 Section B Q5a

Question 7 (1 MARK)

The lymphatic system plays an important role in defending the human body against disease. Which one of the following is not true of the lymphatic system?

A Lymph vessels collect fluid that is drained from tissues around the body.

B Lymph nodes contain cells that can recognise foreign antigens.

C B cells mature in the lymph nodes.

D T cells mature in the thymus.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q12

Question 8 (8 MARKS)

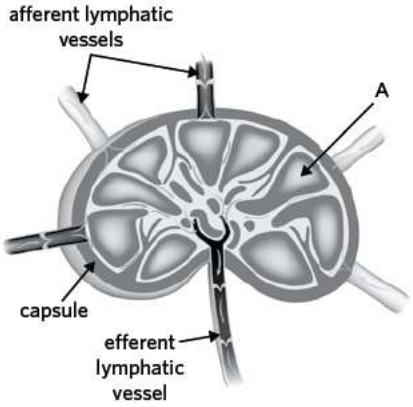
The human lymphatic system consists of primary and secondary lymphoid tissues.

a State the two primary lymphoid tissues and explain their role in the lymphatic system. (3 MARKS)

Secondary lymphatic tissues include the lymph nodes, spleen, and tonsils.

b Explain the role of secondary lymphatic tissues. (2 MARKS)

c Consider the following diagram of a lymph node.



i Explain the role of the afferent lymphatic vessels. (1 MARK)

Adapted from VCAA 2015 Section B Q5a

ii An immune cell type expressing receptors with a single antigen-binding site that interacts with antigen-presenting cells is present in structure A. Name this cell type and explain its role in the adaptive immune response. (2 MARKS)

Adapted from VCAA 2015 Section B Q5c

Multiple lessons

Question 9 (1 MARK)

It is reasonable to infer that an infection has occurred if

A inflammation has occurred.

B mast cells have degranulated.

C bacteria are found on the surface of the skin.

D a person's lymph nodes have become swollen.

Adapted from VCAA 2011 Exam 1 Section A Q6

Question 10 (1 MARK)

The human lymphatic system

A contains the site where B cell clonal selection occurs.

B initiates the inflammatory response.

C is part of the first line of defence.

D produces gametes

Adapted from VCAA 2017 Sample Exam Section A Q23

Question 11 (6 MARKS)

Macrophages are one type of cell circulating within the lymph and lymph nodes of humans.

a Describe how macrophages perform their function within the human lymphatic system. (2 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q2a

b Acute lymphoblastic leukaemia (ALL) is a type of cancer. In patients with ALL, the precursor cell to B and T lymphocytes, called a lymphoid blast, is overproduced and does not further differentiate into B and T lymphocytes. The patient can develop frequent and recurring infections as a result.

i Explain why an ALL patient's immune system would find it difficult to eliminate an infection caused by a virus. (2 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q2b

ii Explain what would happen in the lymph nodes of a patient with ALL who became infected with a bacterial pathogen and the consequence of this for the patient. (2 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q2b

Key science skills

Question 12 (6 MARKS)

Research suggests that the microorganisms that normally live on the skin have a very complex and beneficial relationship with their hosts. *Staphylococcus epidermidis* is one of the most common species of bacteria on human skin. To investigate the possible beneficial role of this bacterium, scientists designed an experiment as follows.

Two groups of mice were used. The mice in Group 1 had equal amounts of *S. epidermidis* applied to their skin whereas mice in Group 2 had no *S. epidermidis* applied to their skin. The mice in both Group 1 and Group 2 were infected with a pathogenic fungus. The mice were left for several days, and then scientists measured the levels of antigen-presenting cells (APCs) and cytotoxic T cells (T_c cells) in the skin of the mice from both groups.

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q6

a Name two cell types that function as antigen-presenting cells. (1 MARK)

b In addition to the levels of APCs and T_c cells, the growth of the pathogenic fungus was also measured in all of the mice. The results of this experiment are summarised in the table.

Mice	Level of APCs	Level of Tc cells	Growth of the pathogenic fungus
Group 1	high	high	no growth on skin
Group 2	low	low	fungus covering a large area of skin

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q6d

i Identify the independent variable and the dependent variables in this experiment. (2 MARKS)

ii Describe two roles of the lymphatic system in this experiment. (2 MARKS)

iii One of the young laboratory assistants who was responsible for infecting the mice in Group 1 with *S. epidermidis* forgot to use gloves whilst infecting two of the mice, resulting in those mice having unusually high levels of APCs and T_c cells. Name the type of error this represents. (1 MARK)

ACTIVITY

Blood Typing

There are a number of different antigens found on the surface of erythrocytes (red blood cells). Two of the most important are the ABO antigens and the Rhesus factor (RhD) antigen.

ABO blood group

The ABO blood group system refers to one antigen (called the H antigen) on the surface of human red blood cells. The gene encoding this antigen has its locus on the long arm of chromosome 9.

Rhesus blood type

On the short arm of chromosome 1, a different gene controls the presence or absence of another common antigen – the Rhesus antigen, RhD. The RhD antigen is either present (Rh+) or absent (Rh–). A patient who is Rh+ can receive a transfusion of Rh– blood because Rh– blood lacks the RhD antigen so it will not trigger an immune response in the patient. On the other hand, Rh+ blood cannot be given to an Rh– patient as the RhD antigen is foreign to the patient and will cause an antibody response.

Usually hospitals describe a patient's blood type as a combination of their ABO phenotype and their Rhesus phenotype.

Therefore, there are eight blood types:

- A+
- A–
- B+
- B–
- O+
- O–
- AB+
- AB–

1 Explain why a person with AB+ blood can receive a blood transfusion of A– blood.

2 Explain why a person with A– blood cannot receive a transfusion of AB+ blood.

3 List the blood types that can be safely given to a person who has AB– blood.

4 Explain why O– blood is in highest demand by blood banks.

Rhesus incompatibility

Rhesus incompatibility describes a situation where a mother with Rh– blood develops immunity to the Rh+ blood type of her unborn foetus.

Normally the baby's blood and the mother's blood do not mix. The baby's blood circulates through the placenta, exchanging gases and nutrients with the mother's blood that circulates through the endometrium lining her uterus. However, when the placenta separates from the endometrium (usually during childbirth), some of the baby's blood can enter the mother's bloodstream. Blood that enters the mother in this way will cause an immune response in the mother against the RhD antigen. Because the IgG antibodies produced by the mother against Rh+ blood (called anti-D) can cross the placenta into the baby, they can cause a haemolytic disease of the newborn. In most cases, this will not affect the first Rh+ child, which is already born when the mother starts to produce anti-D. But if the mother has a second child with Rh+ blood, the baby will be affected.

To prevent this, when a woman with Rh– blood is pregnant, she is given an injection of anti-D (antibodies against the RhD antigen) at 28 weeks of gestation, and another injection immediately prior to birth.

5 Suggest why two injections of anti-D antibodies are given to the mother: the first at 28 weeks of gestation and the second immediately prior to birth.

6 Rh– blood (d) is recessive to Rh+ blood (D). Therefore, a woman with Rh– blood must be homozygous (dd) for Rh– blood. If the father of the baby also has Rh– blood (dd), it is not possible for their baby to have Rh+ blood. In this case, giving the mother an injection of anti-D antibodies is unnecessary. Nevertheless, most hospitals administer an injection of anti-D antibodies in this situation regardless. Suggest why.

7 Explain why it is not necessary to give an injection of anti-D antibodies to mothers with Rh+ blood, even if her unborn child has Rh– blood.

CHAPTER SUMMARY

9B THE FIRST LINE OF DEFENCE

- Comprised of **physical**, **chemical**, and **microbiological** barriers
- If these barriers are breached, the second line of defence kicks into action
- Designed to keep pathogens (lesson 9A) out of the organism
- A non-specific/innate line of defence

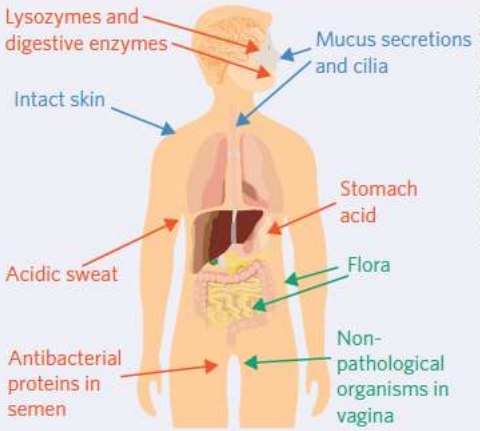
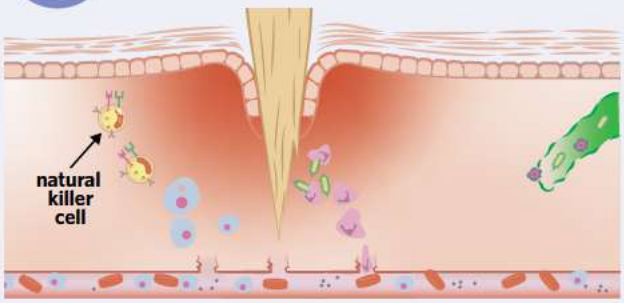


Image: Designua/Shutterstock.com

9C THE SECOND LINE OF DEFENCE



- Non-specific cellular response aiming to quickly destroy pathogens that have gained access to the interior of the body
- Includes the inflammatory response:
  - Initiation – degranulation of mast cells releases histamine
  - Vasodilation – histamine causes blood vessels to dilate and leak
  - Migration – innate immune components (complement, phagocytes) can reach site of infection
- Natural killer cells kill infected or abnormal cells by recognising foreign antigens on cellular surfaces
- Lymphatic vessels carry away lymph comprised of antigen-presenting cells and pathogens into the lymphatic system

9E THE LYMPHATIC SYSTEM

- Series of vessels throughout the body that drain tissues
- Vessels act as a transport-system for antigen-presenting cells and pathogens, and clusters of immune cells in secondary lymphoid tissues serve as the location for the processes involved in activating the third line of defence

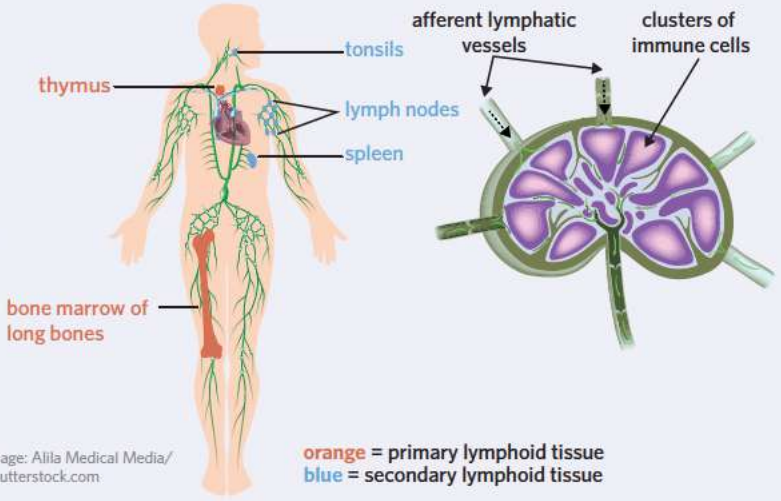
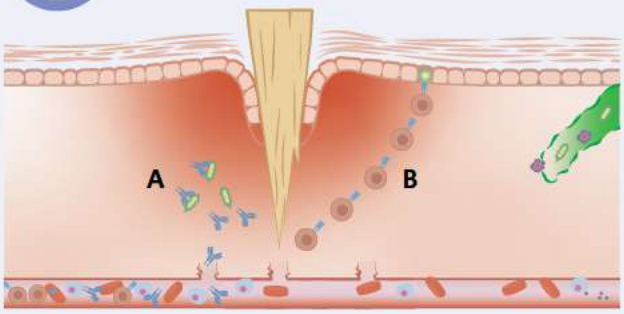


Image: Alila Medical Media/ Shutterstock.com

orange = primary lymphoid tissue
blue = secondary lymphoid tissue

9D THE THIRD LINE OF DEFENCE



- Specific cellular response tailored to an individual pathogen
- Through the process of clonal selection, B and T cells with receptors that match the pathogenic antigen present undergo clonal selection and differentiation
- B cells differentiate into memory B cells and antibody-secreting plasma cells, forming humoral immunity
- T cells differentiate into memory T cells and cytotoxic T cells, forming cell-mediated immunity
- Antibodies and cytotoxic T cells travel to infected site via bloodstream where:
  - **A** – Antibodies neutralise, immobilise, agglutinate, and opsonise pathogens and activate complement proteins
  - **B** – Cytotoxic T cells induce apoptosis in infected cells

CHAPTER REVIEW QUESTIONS

SECTION A (13 MARKS)

Question 1 (1 MARK)

In the search for a malaria vaccine, scientists are looking for an antigen they can use to base their vaccine on.

Which of the following is an example of an antigen the scientists could use?

A a complement protein
B an antibody to malaria
C a protein on the surface of the malaria parasite
D a protein that attaches to the surface of the malaria parasite

Adapted from VCAA 2016 Section A Q24

Question 2 (1 MARK)

Which one of the following is an example of a plant defence against a pathogen?

A open stomata
B mast cells that play a key role in inflammation
C cytotoxic T cells that attack and kill pathogens
D production of defensins that are toxic to microbes

Adapted from VCAA 2015 Section A Q17

Question 3 (1 MARK)

Which of the following matches a molecule correctly with its role in an immune response?

	Molecule	Role
A	complement protein	released from mast cells during the inflammatory response
B	histamine	chaperones intracellular peptides for presentation to T cell receptors
C	interferon	a cytokine that is important for immunity against viruses
D	MHC	gets activated as part of a cascade that results in the stimulation of phagocytes

Adapted from VCAA 2017 Section A Q22

Question 4 (1 MARK)

Within the clusters in lymph nodes different types of immune cells are found. One of these cell types has a large nucleus and extensive rough endoplasmic reticulum, and plays an important role in an adaptive immune response. Which of the following cells fits this description?

A a mast cell
B a plasma cell
C a memory cell
D a macrophage

Adapted from VCAA 2015 Section A Q5c

Question 5 (1 MARK)

In the future, scientists aim to grow full-size kidneys for transplants in patients with kidney disease using the patient's own skin cells. This would overcome the problem of rejection of the transplanted kidney by the immune system.

Rejection of transplanted organs results mainly from an attack from the

A patient's innate immune system.
B patient's adaptive immune system.

C organ donor's innate immune system.

D organ donor's adaptive immune system.

Adapted from VCAA 2014 Section A Q19

Question 6 (1 MARK)

In the lymphatic system

A lysozyme is produced.

B mucus is generated to trap bacteria.

C antigen-presenting cells are transported to lymph nodes.

D mast cells release histamine to increase vessel permeability.

Question 7 (1 MARK)

Which one of the following is not true of prions?

A They are transmissible.

B They contain nucleic acids.

C They cause some brain diseases.

D They contain chains of amino acids.

Adapted from VCAA 2015 Section A Q15

Question 8 (1 MARK)

Canola is an economically important crop plant in Australia. Pathogens that reduce canola production are a concern to growers. One significant disease is blackleg, caused by the fungus *Leptosphaeria maculans*. A detailed examination of infected canola stems has shown the presence of the fungus.

The structure of the *L. maculans* pathogen would not consist of

A hyphae.

B mitochondria.

C membrane-bound nucleus.

D a protein coat and a lipid envelope.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q16

Question 9 (1 MARK)

Which one of the following cells is part of the second line of defence?

A phagocytes

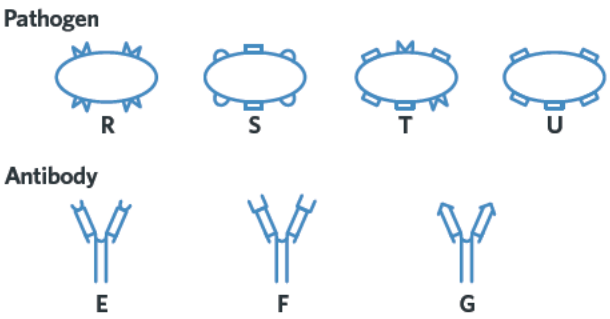
B plasma cells

C memory cells

D cytotoxic T cells

Question 10 (1 MARK)

Consider the following diagram of four pathogens and three antibodies.



Which one of the following statements is incorrect?

A Antibody E is only effective against pathogen S.

B Antibody F would be effective against pathogen T.

C Antibody G would be effective against pathogen R and pathogen T.

D Antibody F would not be effective against both pathogen U and pathogen S.

Adapted from VCAA 2015 Section A Q16

Question 11 (1 MARK)

A girl is carrying a piece of wood. A splinter breaks off and becomes embedded in her finger. The next day, she notices an inflammatory response occurring in her finger.

In the region around the small piece of wood embedded in her finger, the inflammatory response would not include

A mast cells releasing histamine.

B phagocytes engulfing pathogens.

C the blood vessels increasing in permeability.

D the cloning of B lymphocytes to produce plasma cells.

Adapted from VCAA 2015 Section A Q18

Question 12 (1 MARK)

Antigen-presenting cells deliver antigens to T helper cells found in lymphoid tissue. These lymphocytes recognise these antigens as being non-self, causing the T helper cells to become activated.

Following the activation of T helper cells you could expect

A the activation of dendritic cells.

B the production of complement proteins.

C an increase in the number of mast cells.

D the differentiation of B cells into plasma cells.

Adapted from VCAA 2018 Section A Q17

Question 13 (1 MARK)

It is reasonable to infer that an allergic response has occurred if

A a scab has formed on a cut in the skin.

B bacteria are found in the large intestine.

C pathogens are found in leg muscle tissue.

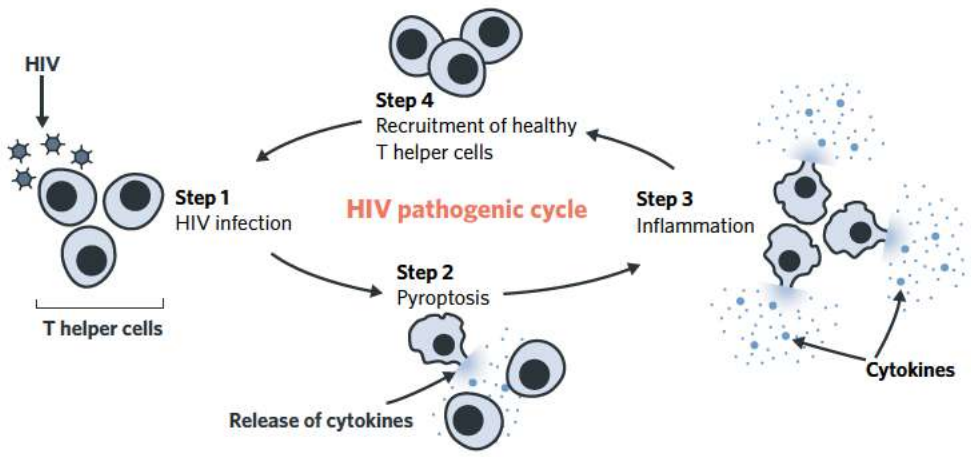
D an allergen has triggered the release of histamine.

Adapted from VCAA 2011 Exam 1 Section A Q6

SECTION B (26 MARKS)

Question 14 (6 MARKS)

The human immunodeficiency virus (HIV) is a pathogen that infects T helper cells. Scientists have discovered that 95% of infected T helper cells undergo a process called pyroptosis. During pyroptosis, the plasma membrane bursts, releasing cytokines.



Adapted from VCAA 2018 Northern Hemisphere Section B Q5

a Explain what is meant by the term 'pathogen' (1 MARK)

Adapted from VCAA 2014 Section B Q4a

b Is the HIV pathogen cellular or non-cellular? Justify your response. (2 MARKS)

Adapted from VCAA 2012 Exam 1 Section B Q7a

c Describe two functions of activated T helper cells, and outline two consequences of HIV that occur in relation to them. (3 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Section B Q5a

Question 15 (5 MARKS)

Plants have many important chemical and physical methods of defence against attack by pathogens and insects.

a Identify two examples of a physical method of defence in a plant. (2 MARKS)

Adapted from VCAA 2017 Section B Q2a

b Identify two mechanisms through which chemical barriers in plants help to protect against pathogens. (2 MARKS)

Adapted from VCAA 2018 Section B Q3a

c Explain why the innate immune system is so important in plants. (1 MARK)

Question 16 (4 MARKS)

Mast cells play an important role in the inflammatory response of humans.

a Name the part of the immune system to which these cells belong. (1 MARK)

Adapted from VCAA 2017 Section B Q4di

b State three changes that occur during an inflammatory response and their significance. (3 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q5bi

Question 17 (8 MARKS)

Research suggests that the microorganisms that normally live on the skin have a very complex and beneficial relationship with their hosts. *Staphylococcus epidermidis* is one of the most common species of bacteria on human skin. To investigate the possible beneficial role of this bacterium, scientists designed an experiment as follows.

Two groups of 50 mice were used. The mice in Group 1 had *S. epidermidis* applied to their skin. The mice in both Group 1 and Group 2 were infected with pathogenic bacteria. The mice were left for several days, and then scientists measured the levels of antigen-presenting cells (APCs) and cytotoxic T cells (T_c cells) in the skin of the mice from both groups. It was found that mice with *S. epidermidis* on their skin had higher levels of APCs and T_c cells and lower rates of pathogenic bacterial growth.

a Describe the role of cytotoxic T cells in an immune response. (2 MARKS)

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q6b

b Describe how antibodies and macrophages would have inhibited the spread of pathogenic bacteria in the mice. (2 MARKS)

Adapted from VCAA 2011 Exam 1 Section B Q5b

c State which group of mice served as the experimental group in this experiment. (1 MARK)

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q6dii

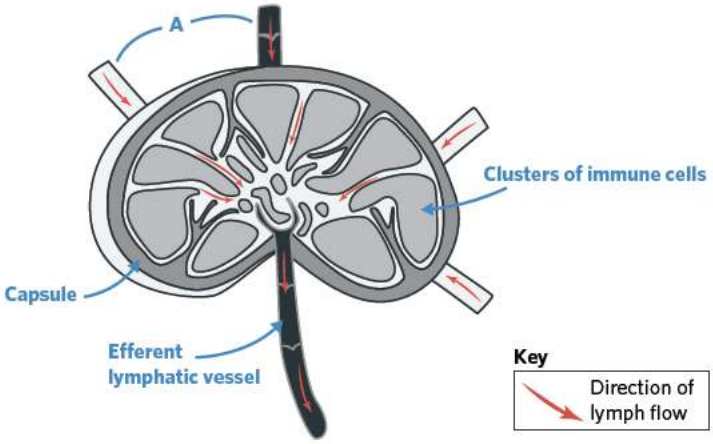
d Identify the independent and dependent variables in the experiment. (2 MARKS)

e One scientist accidentally placed a mouse from Group 1 with Group 2. Identify the type of error that has taken place. (1 MARK)

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q6

Question 18 (3 MARKS)

Consider the following diagram of a lymph node.



a Name and describe the role of the structures labelled A. (1 MARK)

b Name and describe one type of immune cell found within these clusters that plays a role in the adaptive immune response. (2 MARKS)

Adapted from VCAA 2015 Section B Q5

UNIT 3 AOS 2, CHAPTER 10

Immunity

10

10A How to become immune

10B When the immune system goes wrong

10C Antibodies to treat cancer

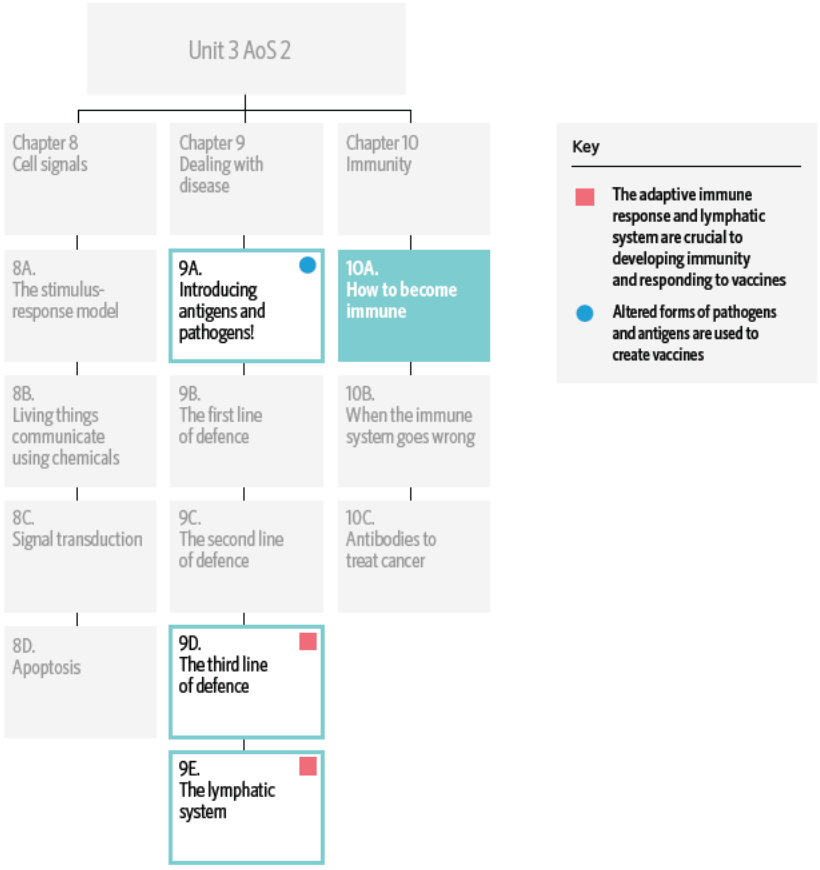
Key knowledge

- the difference between natural and artificial immunity, and active and passive strategies for acquiring immunity
- vaccination programs and their role in maintaining herd immunity for a particular disease in the human population
- the deficiencies and malfunctions of the immune system as a cause of human diseases including autoimmune diseases (illustrated by multiple sclerosis), immune deficiency diseases (illustrated by HIV), and allergic reactions (illustrated by reactions to pollen)
- the use of monoclonal antibodies in treating cancer

Image: Numstocker/Shutterstock.com

10A HOW TO BECOME IMMUNE

I got 99 problems but, thanks to a comprehensive vaccination schedule, dying from meningococcal disease ain't one.



In this lesson you will learn about the various ways we can create or acquire immunity (natural vs artificial, active vs passive). You will also learn about vaccines and how they can be used to achieve herd immunity.

Study design dot points

- the difference between natural and artificial immunity, and active and passive strategies for acquiring immunity
- vaccination programs and their role in maintaining herd immunity for a particular disease in the human population

Key knowledge units

Natural immunity	3.2.11.1
Artificial immunity	3.2.11.2
Herd immunity	3.2.12.1

Natural immunity 3.2.11.1

OVERVIEW

Natural immunity is immunity that is developed without any medical intervention. Natural active immunity occurs when a person becomes infected with a pathogen, and their adaptive immune system develops a long-lasting immunity to the disease. Natural passive immunity occurs when a person becomes immune after obtaining antibodies from another person (e.g. in milk during breastfeeding or across the placenta during foetal development).

THEORY DETAILS

The adaptive immune response attempts to provide an individual with protection – or 'immunity' – to a pathogen via the production of pathogen-specific antibodies. We can classify the type of immunity an individual has based on where the antibodies originated from. Immunity can be classified as either **natural** or **artificial**, and either **active** or **passive**.

This section will cover the two types of natural immunity: **natural active immunity** and **natural passive immunity**.

Natural active immunity

Natural active immunity is the classic example of your adaptive immune system doing its job when you're exposed to a pathogen. It occurs when an individual's immune system encounters a pathogen and mounts a response against it (Figure 1). This process is called 'natural' because it occurs without medical intervention, and is 'active' because the individual's own immune system is generating the antibodies in their system.

Natural passive immunity

Natural passive immunity occurs when an individual naturally acquires antibodies that their own immune system did not make. Importantly, in 'natural' immunity these antibodies have come from a *non-medical* source. The two examples of natural passive immunity you need to be aware of are:

1 Breastfeeding – human breast milk contains many nutrients and proteins essential for healthy growth and development, including different antibodies from the mother's immune system that she has acquired. Once ingested, these antibodies enter the baby's system and protect them against pathogens. This is important, as babies have poorly developed adaptive immune systems and aren't able to fully protect themselves against pathogens for the first few months of life (Figure 2a).

2 Placenta – during pregnancy, antibodies produced by the mother are able to cross the placenta and enter the foetus' bloodstream. These confer the child with protection during pregnancy and after it is born for a short period of time, helping to compensate for the baby's weak immune system (Figure 2b).

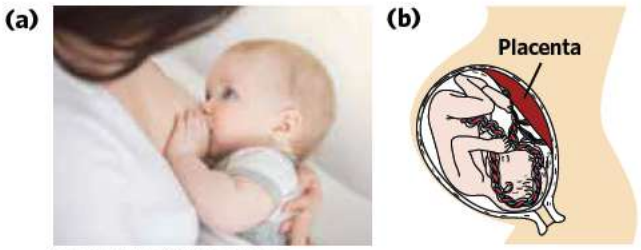


Image: UvGroup/Shutterstock.com

Figure 2 Natural passive immunity occurs after the transfer of antibodies from a mother to child **(a)** via the breast milk and **(b)** across the placenta.

natural immunity protection against a pathogen formed without medical intervention

artificial immunity protection against a pathogen as a result of a medical intervention. Also known as **induced immunity**

active immunity protection against a pathogen created by antibodies produced by an individual's own immune system

passive immunity protection against a pathogen conferred by externally produced antibodies

natural active immunity protection against a pathogen conferred by antibodies produced by an individual's own immune system without medical intervention

natural passive immunity protection against a pathogen conferred by antibodies produced by another individual's immune system without medical intervention (e.g. breastfeeding)

Image: Steve Buckley/Shutterstock.com

Figure 1 He may look miserable now but, once his immune system gets rid of the varicella-zoster virus causing his chicken pox, this guy will have natural active immunity against it!

lesson link If you're unfamiliar with how the adaptive immune system responds to pathogens, head to ***lesson 9D*** for a refresher!

Artificial immunity 3.2.11.2

OVERVIEW

Artificial immunity is immunity that is developed as a result of medical intervention. Artificial active immunity is generated after the injection of vaccines. Artificial passive immunity occurs when an individual receives an injection of antibodies.

THEORY DETAILS

In contrast to natural immunity, artificial immunity occurs when an individual has antibodies in their system due to some form of medical treatment or intervention. Like natural immunity, artificial immunity can be broken up into two types: **artificial active immunity** and **artificial passive immunity**.

Artificial active immunity

Artificial active immunity occurs when an individual's adaptive immune system produces antibodies against a pathogen that has been artificially introduced into the body. This is the basis of how **vaccines** work.

artificial active immunity protection conferred by antibodies produced by an individual's own immune system due to medical intervention (e.g. a vaccination)

artificial passive immunity protection conferred by externally produced antibodies injected as a medical intervention

vaccine a medical treatment containing antigens designed to stimulate an individual's immune system against a pathogen without causing disease

Vaccinations

One of the benefits of natural active immunity is that it generates long-lasting immunity due to the production of memory B and T cells. Unfortunately, in order to get this protection you have to go through all the nastiness of getting ill. Wouldn't it be great if there was some way to become immune without getting sick? The good news is that you can!

Vaccines are medical treatments that contain either weakened or deactivated forms of a pathogen such that the pathogen cannot cause disease or harm. They can also be comprised of structures that closely resemble pathogens (e.g. protein capsids). However, the body still recognises the artificially introduced antigens as foreign and can develop an adaptive immune response against them. Therefore, when the disease-causing pathogen is encountered again in the future, the body recognises the previously encountered antigen and is ready to quickly launch an immune response, meaning the pathogen is controlled before we get sick. There are four main types of vaccines. These are summarised in Table 1.

Table 1 Types of vaccines

Type of vaccine	Contents of vaccine	Example diseases
Attenuated	Pathogens that have been grown in a lab but have been altered to significantly reduce their **virulence**, meaning they are unlikely to cause disease or have side effects.	Measles Mumps Rubella Chickenpox
Inactivated	Pathogens that have been grown in a lab but have been 'killed' or destroyed so that they can't cause disease.	Influenza Polio Typhoid
Toxoid	Toxin produced by a pathogen that has been altered in a lab so that it can no longer cause disease.	Tetanus Diphtheria
Virus-like particle (VLP)	A protein capsid with antigens on the surface. These antigens are the same as those belonging to a pathogen.	HPV Hepatitis B

Because vaccines rely on the adaptive immune system to generate immunity, they often take days to weeks to confer immunity. It takes time for the complex adaptive immune processes to happen and for enough antibodies to be produced to create immunity – that's why it's worth getting prepared with vaccines before waiting for the real disease to come along!

Many vaccines require multiple doses to develop an adequate level of immunity. Vaccines for different diseases may require different numbers of doses at different times, the timing and number of which is known as a **vaccination program** or schedule. The first vaccination generates a **primary immune response**. This response creates a moderate level of antibodies and memory cells. The number of these antibodies and memory cells, however, dwindles over time.

As part of a vaccine program, a person may receive a second vaccination a few months after their first one. This second vaccination triggers the memory cells created by the first vaccine, resulting in a **secondary immune response**. This response occurs extremely quickly and results in the rapid creation of a larger number of antibodies and memory cells (Figure 3). Some diseases (such as diphtheria) may require up to six vaccinations before someone develops long-lasting immunity.

Another form of vaccination is a **booster vaccine** (or booster shot). Booster vaccines are given to people who have received a vaccination a long time ago. Whilst memory cells outlive plasma cells, they unfortunately die over time. As the number of memory cells decreases, a person's immunity to the disease will wane until they are once again susceptible to infection. Booster vaccines produce more memory B and T cells, increasing a person's immunity to an adequate level. It's important to note, however, that these booster shots are separate to vaccination programs that include multiple vaccinations. Rather than occurring as part of the initial program, they are given much later. For example, when an individual stands on a rusty nail they receive a booster of the tetanus toxoid vaccine to stimulate their immune system to create antibodies against the tetanus toxin.

virulence the potential of a pathogen to cause harm

vaccination program a series of vaccinations designed to confer an individual with immunity to a disease. Also known as a **vaccination schedule**

primary immune response the reaction of the immune system to an antigen it has not previously come into contact with

secondary immune response the reaction of the immune system to an antigen it has previously been exposed to

booster vaccine a vaccination given to a person after the completion of a vaccination program to boost their existing immunity against a disease. Also known as a **booster shot**

antivenom a medication containing antibodies that is used to treat people who have received a venomous bite or sting

Tip Whilst vaccines can be administered via injection or orally, VCAA has only asked about injected vaccines previously. Regardless of the route of administration, however, the underlying principles of vaccination apply to all vaccines.

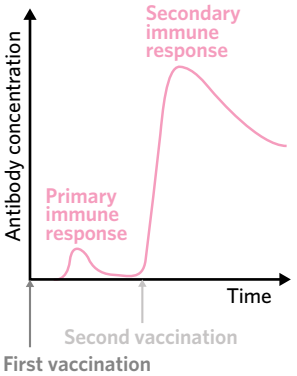


Figure 3 Vaccination programs are often comprised of more than one injection. Subsequent vaccinations create a faster response with an increased number of antibodies generated at a high rate.

Artificial passive immunity

Artificial passive immunity occurs when an individual's body gains antibodies to a pathogen that were introduced by medical intervention. When a person stands on a nail and receives a booster shot of the tetanus vaccine, they will also be given a dose of tetanus toxin antibodies. This is to protect them against tetanus whilst their immune system responds to the vaccine.

Antibodies can be used to treat a number of different conditions. For example, people who have been bitten by a snake are given an **antivenom** which contains antibodies designed to neutralise the venom. Antibody treatments immediately increase the number of antibodies in the blood, but over time these antibodies degrade and any conferred protection becomes less effective. Eventually, all the antibodies will have disappeared and that person will no longer be protected by them. Importantly, if someone is only given antibodies, they will never develop an active immunity to the disease because the antibodies do not produce the memory cells responsible for immunological memory (Figure 4).

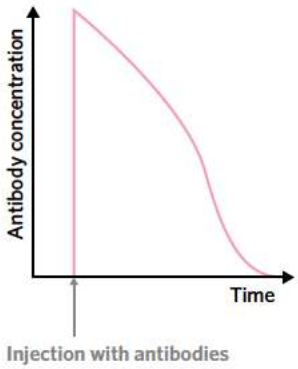


Figure 4 Injection with antibodies immediately increases antibody concentration. Antibody concentration decreases over time until there are no antibodies left.

Tip People can receive injections with antibodies (artificial passive immunity). Vaccines (artificial active immunity) can also be injections, however they do not contain antibodies – instead, they are comprised of antigens.

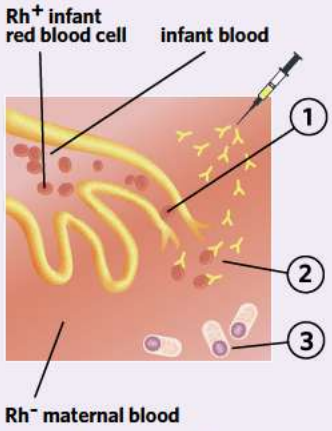
Case study

Treating haemolytic disease of the newborn

In lesson 9D you read a case study about haemolytic disease of the newborn (HDN), a disease in which anti-D antibodies are created in a Rhesus-negative mother after exposure to the Rhesus-positive blood of her foetus. These antibodies reside in the mother's blood for extended periods of time and can attack a future Rhesus-positive foetus.

We can prevent the formation of anti-D antibodies in the mother through the injection of artificially produced anti-D antibodies. These artificial anti-D antibodies circulate throughout the mother's body and destroy any of the foetus' Rhesus-positive blood cells before the mother's immune system can respond to them. In this way, the mother's immune system doesn't come into contact with any Rhesus-positive cells and therefore doesn't initiate an immune response.

The antibody used in anti-D injections is rare. In Australia, a man by the name of James Harrison was found many years ago to have this antibody naturally in his blood. Over the course of his life, he has donated over 1 100 times, helping protect more than 2 million babies in Australia. He gave his final donation in May 2018, donating for over 60 years even despite his fear of needles!



1. During birth, Rh+ foetal red blood cells leak into maternal blood
2. Injected anti-D antibodies destroy foetal Rh+ blood cells
3. Maternal B cells do not come into contact with Rh+ cells and therefore do not mount an adaptive response

Figure 5 Injected anti-D antibodies destroy the foetal Rhesus-positive blood cells before the blood cells stimulate the maternal immune system.

Herd immunity 3.2.12.1

OVERVIEW

Herd immunity refers to when the majority of people in a community are immune to a disease, helping to prevent the spread of a disease to those who haven't been vaccinated.

herd immunity protection conferred to non-immune individuals when a high percentage of the population is immune to the same disease. Herd immunity can often be achieved through high vaccination rates

THEORY DETAILS

Vaccines help protect individuals from getting a disease. Unfortunately, some people aren't able to receive vaccines or choose not to have them. For example, people with weakened immune systems can't get vaccinated against a disease, or some people may be allergic to certain components of the vaccine. It's not all doom and gloom though, as we can use **herd immunity** to prevent them from getting sick.

Herd immunity is immunity to a disease at a population level, and can help protect those most vulnerable to a disease. Pathogens need people to live in and to spread. But if a large proportion of a population is vaccinated against a disease (the 'magic number' is thought to be around 95% for most diseases), this pathogen cannot easily reproduce and spread throughout the population because not many people are susceptible to it. Therefore, the at-risk 5% do not become sick as they never encounter a person hosting the pathogen in the first place! (Figure 6).

Achieving herd immunity is an extremely important step in combatting disease. There will always be people who are not able to be vaccinated (e.g. babies or people with autoimmune diseases) or who choose not to vaccinate. The most effective way we can protect these people is through herd immunity.

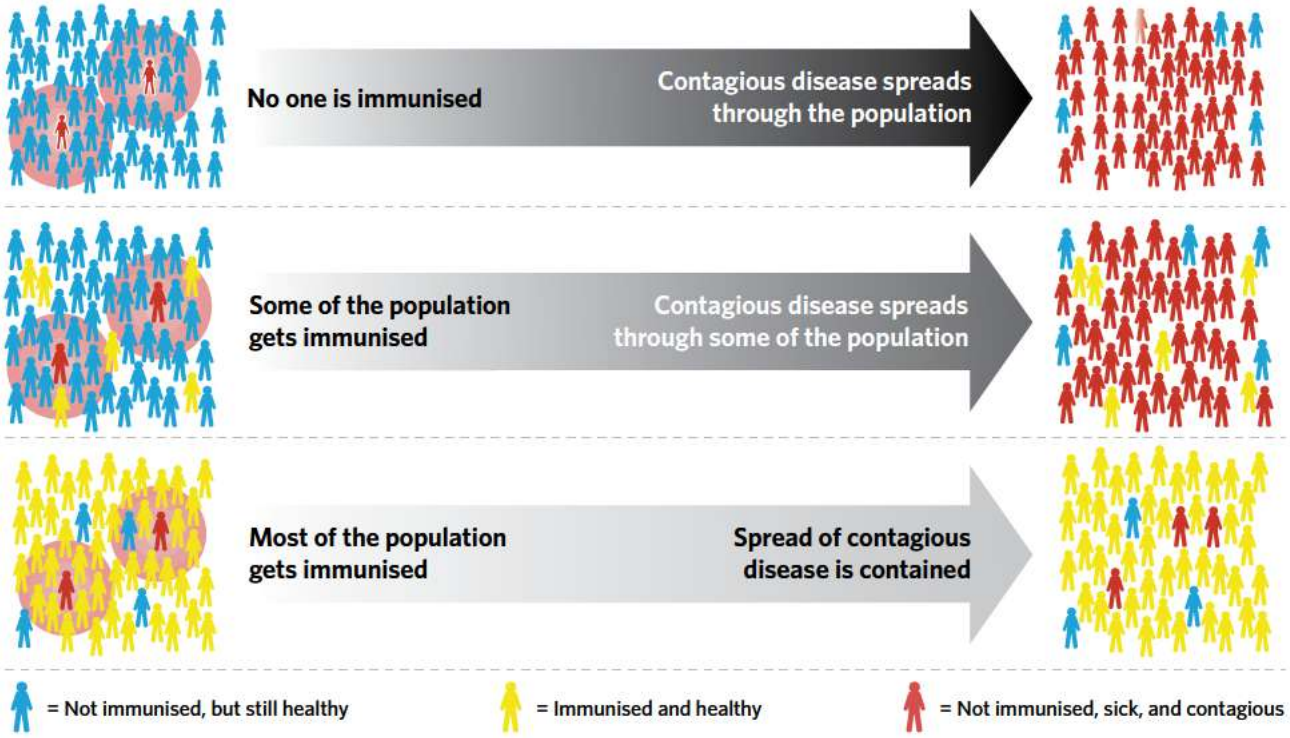


Figure 6 Herd immunity protects unvaccinated people by reducing the number of potential hosts and containing the spread of disease.

Theory summary

Immunity can be categorised based on the origin of the antibodies present in an individual (Table 2). Vaccinations are medical interventions containing non-disease-causing antigens and result in the formation of artificial active immunity. If a large proportion of a population is vaccinated against a disease, herd immunity is generated and protects those who are unvaccinated.

Table 2 Summary of types of immunity

	Medical intervention?	Source of antibodies	Example
Natural active immunity	✗	Individual's own immune system	Getting chicken pox and being immune to it afterwards
Natural passive immunity	✗	External source	Antibodies passing from mother to baby in breast milk or across the placenta
Artificial active immunity	✓	Individual's own immune system	Vaccines, such as against measles and polio
Artificial passive immunity	✓	External source	Being injected with antibodies, such as anti-D antibodies for Rhesus-negative mothers

10A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ type of immunity created via vaccination

b _____ the immunity achieved when over approximately 95% of the population has been vaccinated

c _____ protection against a disease facilitated by the injection of antibodies

d _____ immunity created when an individual gets sick and recovers by themselves

e _____ an injection designed to stimulate the immune system without causing disease

f _____ immunity given to a baby by the antibodies contained in breastmilk

g _____ a vaccination against a disease given to a person long after they complete the vaccination schedule for that disease

Question 2

Which of the following statements about immunity is false?

A Vaccinations result in natural active immunity.

B Recovery from infection likely results in natural active immunity.

C Antibodies crossing the placenta create natural passive immunity.

D Injection with antibodies against a pathogen creates artificial passive immunity.

Question 3

Which of the following statements about herd immunity is false?

A Booster shots support herd immunity.

B Herd immunity protects unvaccinated people.

C Herd immunity is created by injecting antibodies into unvaccinated people.

D Herd immunity can be achieved by vaccinating approximately 95% of people in a population.

Question 4

In the table, classify each of the following as either passive or active immunity.

I Vaccination

II Antibody injection

III Toxoid injection

IV Infant consumption of antibodies in breastmilk

V Injection of booster shot

	Passive immunity	Active immunity
A	II, IV	I, III, V
B	I, II, III, IV	V
C	IV, V	I, II, III
D	II, III, IV	I, V

Question 5

Fill in the blanks in the following sentences.

_____**I**_____is created when a high proportion of the population is vaccinated against a disease. It protects at-risk people because _____**II**_____. Another way to protect at-risk people is to give a _____**III**_____ to people who have previously received a vaccination against a disease. This treatment is needed because the number of _____**IV**_____ in the body decreases over time.

	I	II	III	IV
A	Herd immunity	the pathogen is killed directly by the vaccine	vaccine	antibodies
B	Active immunity	there are fewer potential hosts for the pathogen	vaccine	antibodies
C	Herd immunity	there are fewer potential hosts for the pathogen	booster shot	memory cells
D	Passive immunity	the pathogen is killed directly by the vaccine	booster shot	memory cells

Exam-style questions

Within lesson

Question 6 (1 MARK)

Australian marsupials, such as wallabies, kangaroos, wombats, and koalas, give birth to very underdeveloped young called joeys. Joeys spend many weeks in the pouch feeding on milk produced by mammary glands. This milk contains various antibodies.

The antibodies in the milk that are fed to the joey would be best described as

A artificially acquired, passive immunity.
B naturally acquired, passive immunity.
C artificially acquired, active immunity.
D naturally acquired, active immunity.

Adapted from VCAA 2017 Section B Q4c

Use the following information to answer Questions 7 and 8.

Haemolytic disease of the newborn (HDN) can occur if a Rhesus-negative mother is pregnant with a Rhesus-positive fetus. A treatment called immunoprophylaxis has reduced the incidence of newborn death due to HDN. In this treatment, the Rhesus-negative mother receives injections of RhD antibodies with her first Rhesus-positive pregnancy, and again at the birth.

Question 7 (1 MARK)

The injection of antibodies is used to achieve

A artificial (induced) and passive immunity.
B artificial (induced) and active immunity.
C natural and passive immunity.
D natural and active immunity.

Adapted from VCAA 2014 Section B Q5c

Question 8 (1 MARK)

The treatment of the mother with RhD antibodies would

A contain an inactive form of a pathogen.
B protect future pregnancies against HDN.
C stimulate an adaptive immune response.
D deliver RhD antibodies to the unborn foetus.

Question 9 (7 MARKS)

Pertussis (whooping cough) is a highly contagious respiratory infection caused by the bacteria *Bordetella pertussis*. The pertussis vaccine is offered as part of an immunisation program for children at two months, four months, six months, four years, and in Year 10 of secondary school.

a State the type of immunity formed by the vaccination. Justify your answer. (2 MARKS)

Adapted from VCAA 2013 Section B Q4a

b Adults who have previously been vaccinated against pertussis are advised to receive an extra vaccination if they are planning on coming into contact with newborn babies. This is because babies aren't able to receive the whooping cough vaccine until they are two months old.

i State the name of this type of vaccine, and explain why they are necessary. (3 MARKS)

Adapted from VCAA 2013 Section B Q4c

ii By encouraging high vaccination rates and booster shots every 10 years, governments are trying to achieve a specific type of immunity. Name this type of immunity and explain how it can protect babies who have not been vaccinated. (2 MARKS)

Adapted from VCAA 2018 Section B Q5b

Multiple lessons

Question 10 (1 MARK)

Vaccines usually take a number of weeks to become fully effective. This is because

A memory B cells are slow to respond.

B the inactivated pathogen requires time to multiply.

C it takes the innate immune system time to form memory B cells.

D the immune system needs time to produce enough antibodies to confer immunity.

Adapted from VCAA 2016 Section B Q5b

Question 11 (4 MARKS)

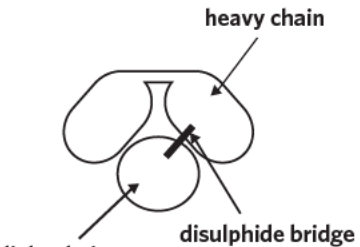
The toxin tetanospasmin is lethal even in extremely small amounts. A simplified representation of the structure of the toxin is shown.

A new preparation of the tetanus vaccine uses just the heavy chain segment of tetanospasmin.

a Identify the type of immunity created by this vaccination. (1 MARK)

b Identify where in the body the processes of clonal selection and B cell differentiation would take place after the vaccine had been administered. (1 MARK)

c Describe two mechanisms by which the antibodies created by the humoral response to the vaccination would prevent the toxin from harming the body. (2 MARKS)



Source: Dr AK Rana

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q11

Question 12 (9 MARKS)

Why do people not vaccinate?

By Hal Willaby

Published in *The Conversation* March 27th 2014

The National Health Performance Authority's report on childhood vaccination coverage released this morning shows immunisation rates have slightly increased in 2011-2012. But there are still some areas where coverage is below the national target.

The good news is that Australia has one of the highest vaccination rates in the world with over 90% of children fully immunised by age five. But there are areas where only 80% of five-year-olds are protected against preventable contagious disease.

So why are some children not immunised? There are two broad influences on timely uptake of routine childhood vaccines – access and acceptance.

Access is partly a structural problem, linked to barriers such as a lack of transport, limited clinic opening times, home-boundedness and, beyond that, to poverty and social exclusion. Generally speaking, we can address access problems by minimising these barriers.

The other factor impacting vaccine uptake is acceptance. This is the psychological orientation to vaccines influencing uptake; it's about attitudes, beliefs and concerns regarding vaccines, parenting, medicine generally, and a host of related matters. An individual's vaccine acceptance is the result of a certain composition of these, like a metaphorical DNA.

The public tends to hear a lot more about acceptance factors than they do about access. It's an easy formula for mass media to pit vaccination opponents against proponents, and parade examples of non-vaccinating parents. It excites emotion, leading to high click rates in online articles and crowded comments pages.

Nevertheless, the attention given to such parents is out of proportion to their actual numbers, and the likelihood of changing their minds. Vaccine refusers are a very small proportion in Australia – about 2% of parents make a values-based choice to forego all vaccines for their children.

A more interesting group is the 12% of parents who are at least somewhat supportive of vaccination, but fear both vaccination and non-vaccination could have negative outcomes for their child. About half of that 12% vaccinate fully, and the other half may delay or avoid certain vaccines but will have others.

Any action taken at the community level starts with acknowledging that parents want the best for their children regardless of their access to and acceptance of vaccines. When otherwise well-intentioned messages criticise what these parents view as healthy skepticism, the result can be a further distancing from timely uptake.

a The article states that Australia has one of the highest vaccination rates in the world with over 90% of children fully immunised by age five. How would not completing a vaccination schedule impact the immunity of a child against a disease? (2 MARKS)

b According to the article, what are the two factors influencing the uptake of vaccines in Australia? (1 MARK)

c What does the article suggest is the reason behind the stance of vaccine-refusing parents being so widely known? (1 MARK)

d Which group of parents would be the best target of extra efforts to increase vaccination rates in Australian children? Use evidence from the article to justify your response. (2 MARKS)

e Based on the information in the article, suggest three broad strategies for increasing vaccination rates amongst Australian children. (3 MARKS)

Key science skills

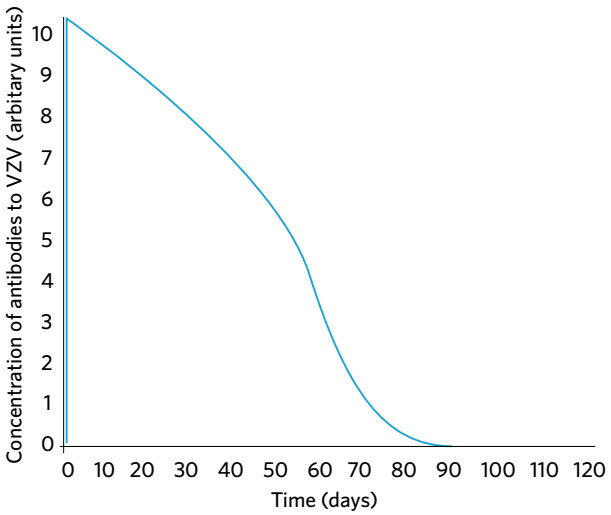
Question 13 (12 MARKS)

Chickenpox (varicella) is a highly contagious viral disease caused by the varicella-zoster virus (VZV). A vaccine against the disease became commercially available in 1984.

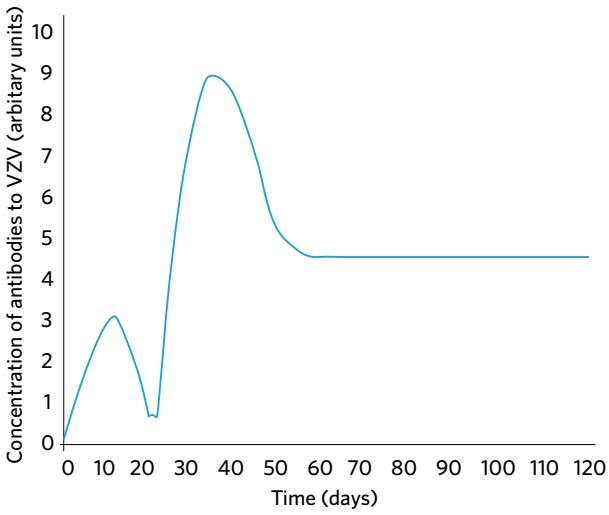
a What is a vaccine, and how can vaccines cause lifelong immunity? In your response, be sure to include information related to the humoral response. (3 MARKS)

Adapted from VCAA 2016 Section B Q5a

b A scientist wanted to compare the effects of two different injected medical interventions designed to prevent and/or treat chickenpox. To do so, she measured the antibody concentrations of two patients, Patient 1 and Patient 2. Patient 1 received intervention A, whereas Patient 2 received intervention B. Neither patient became ill during the 120 days of the experiment. The graphs show the scientist's findings over a 120-day period.



Adapted from VCAA 2015 Section A Q14



Adapted from VCAA 2017 Section A Q26

i Based on the information provided, identify the nature of each intervention and explain your response. (4 MARKS)

ii What occurred just after day 22 in intervention B, and why was this necessary? (2 MARKS)

Adapted from VCAA 2017 Section A Q26

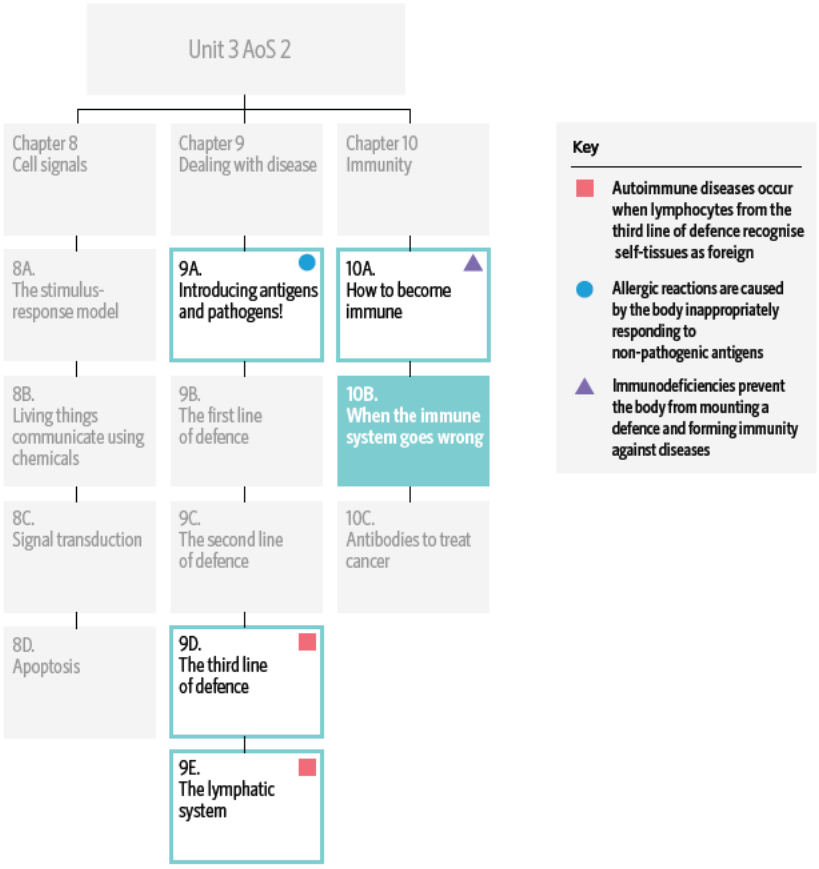
iii What type of immunity would be created by treatment A? (1 MARK)

c State whether a negative control was used in the experiment and identify what the control is/should be. (2 MARKS)

10B WHEN THE IMMUNE SYSTEM GOES WRONG

'I make mistakes, I am out of control and, at times, hard to handle. But if you can't handle me at my worst, then you sure as hell don't deserve me at my best.'

Marilyn Monroe (but also probably the immune system)



In this lesson you will learn about what can happen when the immune system doesn't function correctly. Specifically, you will learn about autoimmune diseases, immunodeficiency diseases, and allergic reactions.

Study design dot point

- the deficiencies and malfunctions of the immune system as a cause of human diseases including autoimmune diseases (illustrated by multiple sclerosis), immune deficiency diseases (illustrated by HIV), and allergic reactions (illustrated by reactions to pollen)

Key knowledge units

How autoimmune diseases work	3.2.13.1
How immune deficiency diseases work	3.2.13.2
How allergic reactions work	3.2.13.3

How autoimmune diseases work 3.2.13.1

OVERVIEW

Autoimmune diseases occur when the body's adaptive immune system recognises self-tissues as foreign and launches an immune response against them. An example of an autoimmune disease is multiple sclerosis, in which the myelin sheath surrounding nerve cells is broken down by T cells.

THEORY DETAILS

In lesson 9A you learned that cells of the body express major histocompatibility complex (MHC) proteins that mark these cells as 'self'. If a person's immune system is functioning normally, their lymphocytes should recognise these markers and not launch an attack against a cell expressing them. Sometimes, however, lymphocytes don't recognise these self-markers and end up attacking self-cells. When this occurs it can result in an **autoimmune disease**.

There are over 80 types of autoimmune diseases known and nearly every part of the body can be affected by them. Examples include rheumatoid arthritis, type 1 diabetes, and coeliac disease. The symptoms of autoimmune diseases are brought on by both B and T cells responding to self-tissues as if they were foreign.

autoimmune disease a disease in which an individual's immune system initiates an immune response against their own cells

autoantibodies antibodies directed against an organism's own tissues

autoreactive a cell that recognises a self-tissue as non-self

Tip We've presented the ways B cells and T cells cause autoimmune diseases separately here. In real life, however, autoimmune diseases are caused by both B and T cells responding to self cells and launching attacks against them. In the past, VCAA has tended to ask about the roles of T and B cells in autoimmune diseases separately.

lesson link Flip back to ***9D*** to brush up on the adaptive immune system if you're unclear about how it normally works.

B cells in autoimmune disease

The role B cells play in autoimmune diseases is similar to their role in the normal humoral response, however instead of the B cell responding to a pathogenic antigen they are responding to a self-antigen. Figure 1 summarises the process.

One hallmark feature of autoimmune diseases is the production of **autoantibodies** by plasma cells. Autoantibodies are antibodies that are directed against self-tissues and attack them. It is the destruction of these tissues that leads to the symptoms of autoimmune diseases.

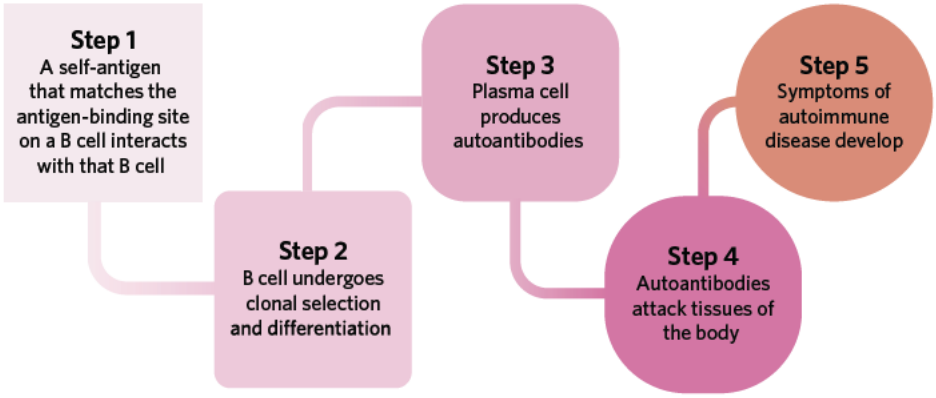


Figure 1 Summary of B cell involvement in autoimmune disease

T cells in autoimmune disease

Another hallmark feature of autoimmune disease is the presence of **autoreactive** helper T cells and cytotoxic T cells. These autoreactive lymphocytes have T cell receptors that bind with self-antigens rather than pathogenic antigens, and are driven by self-antigens to undergo the processes of clonal selection and differentiation (Figure 2).

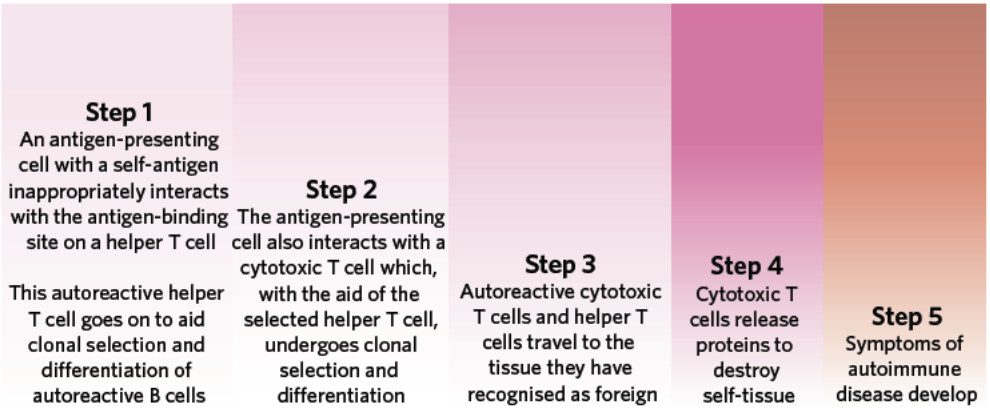


Figure 2 Summary of T cell involvement in autoimmune disease

Cause of autoimmune diseases

There are many different theories about how lymphocytes come to recognise self-tissues as foreign. Currently, it is thought to occur because of a combination of both genetics and environmental exposures. There are two theories that you should be aware of - the failure of clonal deletion, and the hygiene hypothesis.

Failure of clonal deletion

Clonal deletion is a process that occurs during the development and maturation of B and T lymphocytes. It involves the presentation of self-antigens to lymphocytes whilst they are still in the primary lymphoid tissues (bone marrow for B cells and the thymus for T cells). Any lymphocyte that responds to the self-antigen is destroyed, protecting the host against autoimmunity.

For unknown reasons, however, it seems that in individuals with autoimmune diseases this process does not occur as it should. As a result, their autoreactive lymphocytes are able to fully mature and launch an attack against self-tissues.

The hygiene hypothesis

Improvements to sanitation and hygiene over the past century have meant that children nowadays are exposed to far fewer antigens and pathogens when they're young. According to the **hygiene hypothesis**, this low exposure to non-self antigens results in an overactive immune system later in life that can cause autoimmune diseases to develop, as well as allergies and other inflammatory diseases.

Tip VCAA don't expect you to know about the causes of autoimmune diseases in detail. However, theories like the hygiene hypothesis frequently feature in questions about the immune system. When they are mentioned, the information you need to answer the question will be provided, however it might help to know a bit about them before the exam.

Management of autoimmune diseases

Just as there are a wide variety of autoimmune diseases, so too are there a number of different treatments. Two broad mechanisms of treating autoimmune diseases you should be familiar with are:

- filtration of autoantibodies from the blood. By removing autoantibodies from a patient's bloodstream the underlying tissue destruction causing a person's autoimmune disease should cease.
- immunosuppression. By deliberately reducing the activation and effectiveness of a person's immune system, their lymphocytes will be less able to recognise and attack self-tissues. Of course, if too much immunosuppression occurs the individual may develop an immune deficiency (see next section for more details).

Case study

Multiple sclerosis

You might have heard of, or even participated, in the MS Readathon while at school. But how much do you know about MS, the disease the event raises money for?

Multiple sclerosis (MS) is thought to be an autoimmune disease that attacks the nervous system. Before you learn about MS, though, let's take a closer look at how these cells, called **neurons**, work.

Structure and function of neurons

As you learned in 8B, neurons are one of the basic cells of the nervous system comprised of the brain, spinal cord, and peripheral nerves (Figure 3). Neurons communicate with other cells via electrical and chemical signals. They send electrical impulses from their cell body down their **axon**. The axon acts like an electrical wire, transmitting the signal along its length until it arrives at the axon terminals where it causes neurotransmitters to be released and diffuse across the **synapse** to interact with receptors on the receiving cell. (Figure 4).

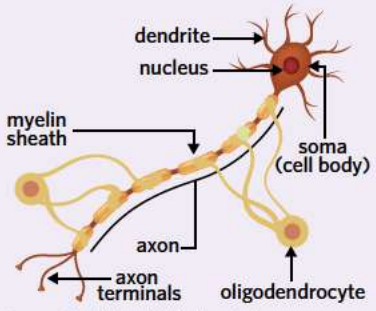


Image: gritsalak+karalak/Shutterstock.com

Figure 3 The structure of a neuron

clonal deletion the process by which autoreactive immature lymphocytes are normally destroyed. Occurs in the bone marrow for B cells and the thymus for T cells

hygiene hypothesis a theory that suggests autoimmune diseases arise through a lack of contact with foreign antigens during childhood

multiple sclerosis (MS) an autoimmune disease in which the myelin sheath surrounding axons in the nervous system is destroyed by the body's own immune cells

neuron a specialised cell that transmits electrical impulses in the nervous system

axon the long projection of a neuron along which an electrical signal is transmitted

synapse the junction between a neuron and a target cell where neurotransmitters cross

A second cell type in the nervous system, called an **oligodendrocyte**, supports the function of the axon by wrapping it in a **myelin sheath.** This sheath increases the speed of the electrical transmission down the length of the axon.

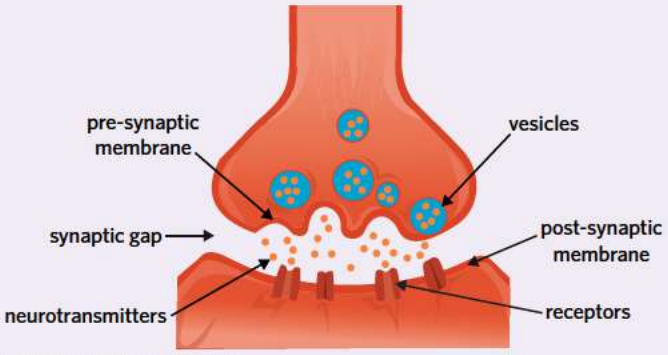


Image: Systemoff/Shutterstock.com

Figure 4 The structure of a synapse

Multiple sclerosis and the neuron

There are many theories as to how MS develops. One leading hypothesis is that MS is an autoimmune disease in which B and T cells recognise myelin as foreign and attack it. This process, known as **demyelination**, results in myelin being destroyed which slows down the speed of electrical conductivity down the axon (Figure 5). Oligodendrocytes are also destroyed by this process. Because neurons are responsible for muscle movement and sensory transmission, this results in MS patients experiencing a wide variety of symptoms, including muscle weakness, pain, vision loss, and impaired coordination.

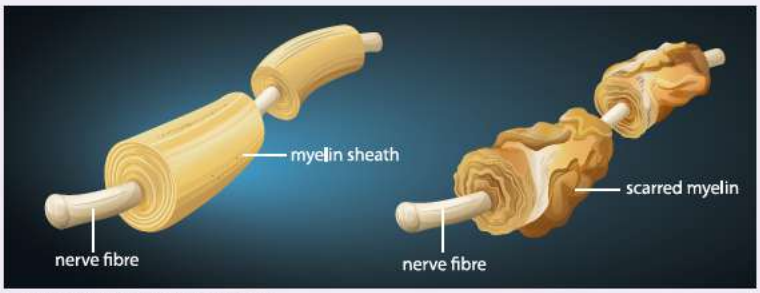


Image: BlueRingMedia/Shutterstock.com

Figure 5 Demyelination is the underlying disease process that causes the symptoms of multiple sclerosis.

oligodendrocyte a cell of the nervous system specialised to support the function of neurons

myelin sheath a layer of protein-rich fatty material that wraps around an axon, increasing the speed of electrical transmission in the axon

demyelination the disease process of multiple sclerosis in which the myelin sheath surrounding the axon is destroyed by the cells of the immune system

immune deficiency a state in which the immune system is no longer able to protect the body against infection or disease. Also known as an **immunodeficiency**

human immunodeficiency virus (HIV) a viral blood-borne infection that targets immune cells, particularly helper T cells, and destroys them, eventually leading to an acquired immunodeficiency

How immune deficiency diseases work 3.2.13.2

OVERVIEW

Immune deficiency diseases are conditions in which an individual's immune system does not function correctly. This can be due to a genetic condition or to a pathogen that they have acquired (e.g. HIV).

THEORY DETAILS

Immune deficiency (or immunodeficiency) is a state in which an individual's immune system is unable to combat pathogens effectively. As a result of this, people with an immunodeficiency are more susceptible to infections.

There are two types of immunodeficiency - primary and secondary. Primary immunodeficiencies originate within the immune system itself, and include genetic conditions that affect the functioning of the immune system (Figure 6). Additionally, as people age their thymus decreases in size. This results in a reduction in their production of T cells and can cause a reduced immune response in elderly people, resulting in a primary immunodeficiency.

Secondary immunodeficiencies, also known as acquired immunodeficiencies, occur when an external factor impacts the effectiveness of the immune system. For example, people receiving medical treatments such as chemotherapy might develop an immune deficiency as a side effect of their treatment. Secondary immunodeficiencies can also be caused by immune deficiency diseases. These diseases cause the immune system to no longer function properly. The example of an immune deficiency disease you need to be aware of for your exams is the **human immunodeficiency virus (HIV).**

Figure 6 David Vetter was born with severe combined immunodeficiency (SCID), a genetic condition that resulted in his adaptive immune system not functioning normally. He was known as the 'bubble boy' because he had to live in a sterile plastic bubble to prevent being exposed to pathogens.

acquired immunodeficiency syndrome (AIDS) a life-threatening condition caused by an untreated infection with the human immunodeficiency virus (HIV) in which an individual's immune system is no longer able to function normally

pyroptosis a highly programmed form of cell death initiated by the human immunodeficiency virus in helper T cells

Management of immunodeficiency

Given that there are many different factors that can cause immunodeficiency to arise there are a range of methods to manage the condition. For secondary immunodeficiencies, management includes:

- treating any underlying infection or disease that may be causing the immunodeficiency
- ceasing any medical interventions that may be causing the immunodeficiency.

For primary immunodeficiencies, the options for management are fewer, but include taking measures to prevent infection, including isolation of the affected individual and practising strict hygiene processes when in contact with them.

Case study

HIV

The human immunodeficiency virus (HIV) is a virus that causes HIV infection and, if left untreated, can over time cause the development of **acquired immunodeficiency syndrome (AIDS).** HIV infects macrophages and helper T cells, and destroys them via a number of different mechanisms, including:

- **pyroptosis** of infected T cells
- direct viral killing of infected T cells
- cytotoxic T cell-mediated destruction of helper T cells.

Over time the number of helper T cells in the body decreases. As a result, helper T cells are not available to bind to antigen-presenting cells to trigger the adaptive immune system. Furthermore, B and T cell differentiation will not be able to take place because helper T cells will not be present to stimulate it. This means the body becomes more susceptible to infections, and can become infected by pathogens that normally wouldn't pose a threat to a person with a functioning immune system (called opportunistic pathogens).

HIV is transmitted via the sharing of bodily fluids including blood, semen, vaginal secretions, and breast milk. Whilst there is currently no known cure for HIV, treatments such as antiretroviral drugs that prevent HIV from replicating have been developed. These drugs halt the destruction of helper T cells, thus preventing the development of AIDS.

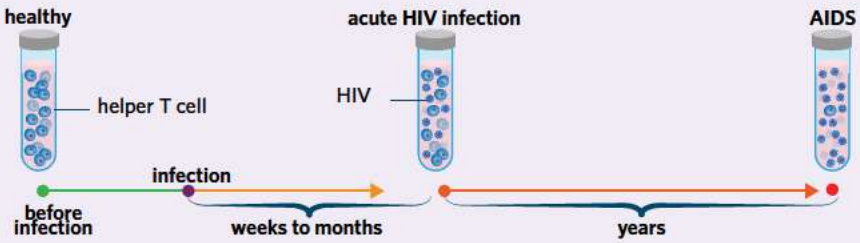


Image: VectorMine/Shutterstock.com

Figure 7 HIV destroys helper T cells, leading to the development of an immunodeficiency over time.

How allergic reactions work 3.2.13.3

allergen a non-pathogenic antigen that triggers an allergic reaction

allergic reaction an inappropriate immune response to a non-pathogenic antigen

allergy a cluster of syndromes experienced by a person who has had an allergic reaction

mast cell a type of leukocyte responsible for releasing histamine during allergic and inflammatory responses

OVERVIEW

Allergic reactions occur when the body's immune system is activated by a non-pathogenic antigen. They are initiated by histamine released from mast cells after IgE antibodies have bound to an antigen.

THEORY DETAILS

Back in lesson 9A the concept of **allergens** was introduced. Allergens are non-pathogenic antigens recognised by the immune system as foreign and result in an inappropriate immune response called an **allergic reaction**. Not only is this immune response unnecessary, but it also causes the unpleasant symptoms we know as **allergies**. These vary widely depending on the allergen and the body system affected, but can include an itchy rash, runny nose, sneezing, shortness of breath, and swelling (Figure 8).

How allergic reactions occur

There are two key processes involved in an allergic reaction - sensitisation, and re-exposure. Each of these are comprised of four steps, and are summarised in Figure 9.

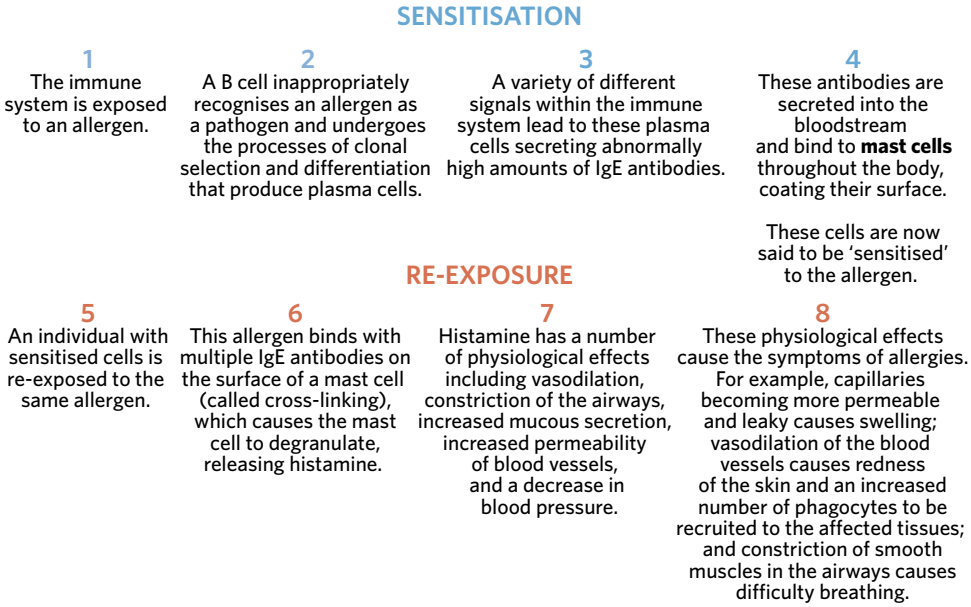


Figure 9 A breakdown of the two key processes involved in an allergic reaction

Image: saharrr/Shutterstock.com

Image: aoldman/Shutterstock.com

Figure 8 Allergic reactions can be **(a)** mild but extremely annoying like hay fever, or **(b)** serious and deadly like an anaphylactic reaction requiring treatment with an EpiPen.

Management of allergic reactions

Generally speaking, there are three key ways in which allergies can be managed:

hay fever an allergic reaction to pollen that causes inflammation of the nose resulting in itching, runny nose, sneezing, and swollen and watery eyes. Also known as **allergic rhinitis**

- Avoidance of allergens - for example, if a person has **hay fever** (see case study) and is allergic to pollen they could stay indoors or wear a face mask on days with a high pollen count
- Management of symptoms - for example, if a person experiences constriction of the smooth muscles in their airway they could use ventolin to relax these muscles and make breathing easier. If a person is having a severe allergic reaction, called anaphylaxis, they may need to inject themselves with adrenaline in the form of an EpiPen (Figure 8b). Adrenaline has the opposite effect of histamine in many areas throughout the body, and can help reverse the symptoms of anaphylaxis by constricting blood vessels and relaxing the muscles in the airways.
- Reduction of the allergic response - antihistamines are a medication that can be taken by those who experience allergies. These drugs work by binding to histamine receptors in the body, preventing histamine released by mast cells from interacting with them. Another way allergies can be reduced is by allergen immunotherapy, a treatment in which allergy sufferers are exposed to increasingly larger amounts of allergen either via injection or sublingual (dissolves under the tongue) tablets in an attempt to desensitise their immune system to an allergen.

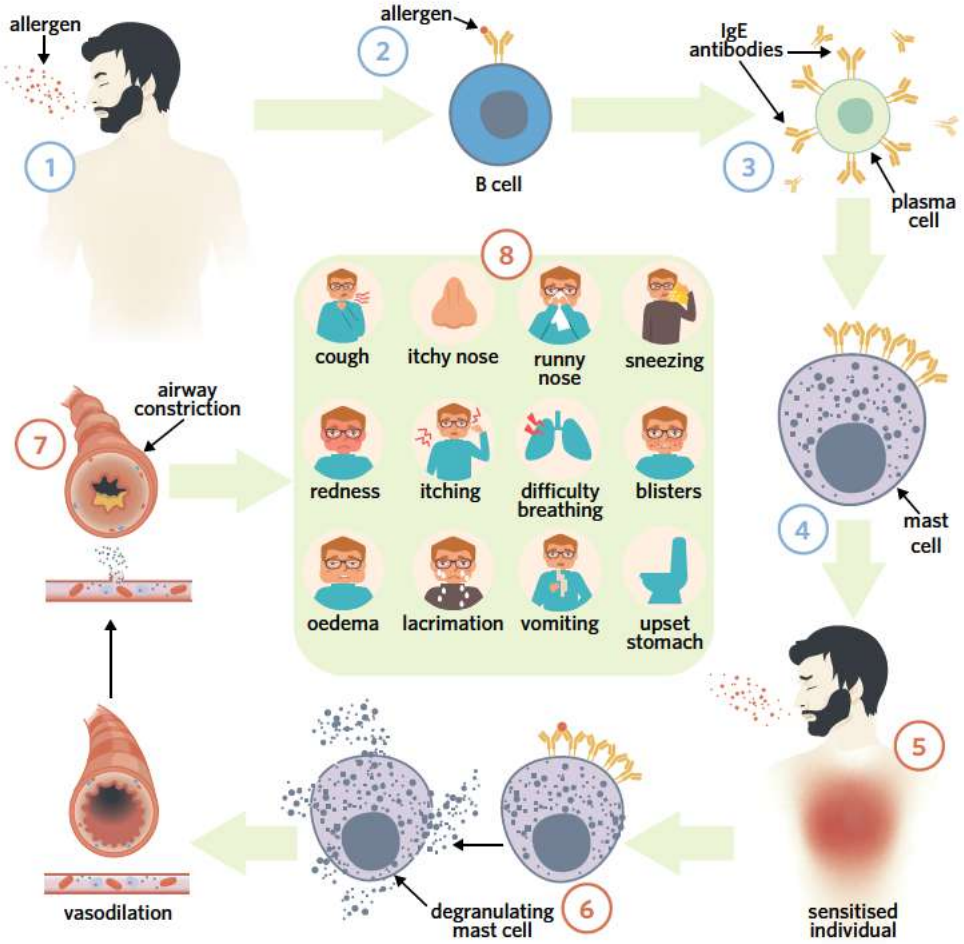


Figure 10 Summary of the allergic response illustrating the steps in Figure 9

Case study

Hay fever

Hay fever, also known as allergic rhinitis, is an allergic reaction caused by pollen. This is why it occurs mainly in spring, when pollen counts are high as plants start their next round of reproduction. The symptoms of hay fever are all caused by the release of histamine from mast cells and the physiological effects this causes. This process is summarised in Figure 11.

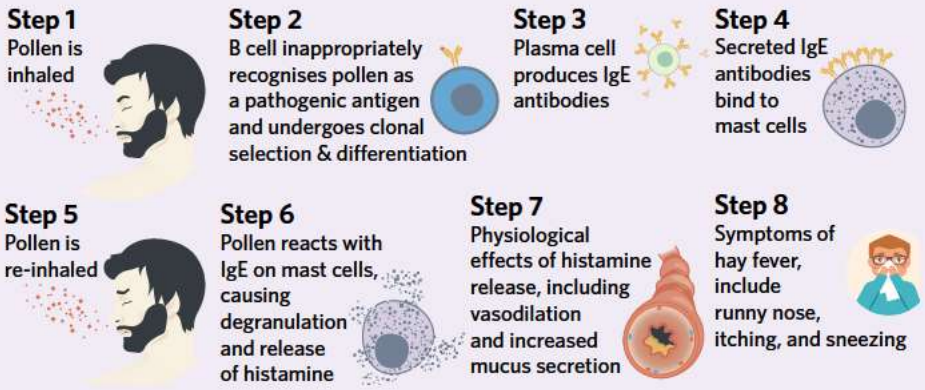


Figure 11 Summary of the allergic response causing hay fever

Theory summary

While the immune system is designed to protect us against diseases, sometimes things go wrong and it itself causes an individual to become unwell. Autoimmune diseases occur when autoreactive lymphocytes recognise tissues of the body as foreign and launch an attack against them. Immunodeficiency diseases are diseases that reduce the body's ability to defend itself against pathogens. Allergic reactions are IgE-mediated responses to non-pathogenic antigens called allergens.

10B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ proteins produced by plasma cells that respond to self-tissues
b _____ the pathogen that can lead to acquired immunodeficiency syndrome
c _____ class of antibody responsible for allergic reactions
d _____ the term given to lymphocytes that respond to the body's own tissues
e _____ the allergen that causes hay fever
f _____ the part of the body that is destroyed in patients with multiple sclerosis
g _____ state in which an individual's immune system is no longer functional

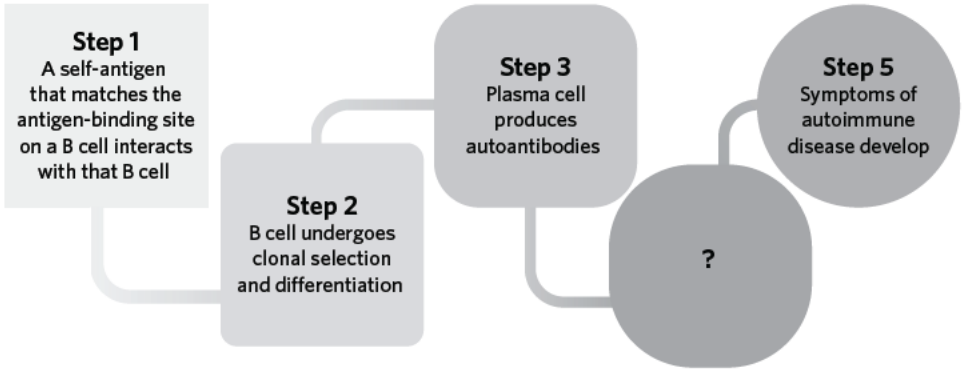
Question 2

Which of the following statements about autoimmune diseases is false?

A Autoreactive lymphocytes make an individual more susceptible to infection.
B Autoimmune diseases may be caused by an error in clonal deletion.
C Autoantibodies are a feature of some autoimmune diseases.
D Multiple sclerosis is thought to be an autoimmune disease.

Question 3

Which of the following options correctly describes the missing step in the diagram?



A Autoantibodies attack tissues of the body
B Autoantibodies induce pyroptosis of helper T cells
C Autoantibodies stimulate autoreactive lymphocytes
D Autoantibodies cause the release of histamine from mast cells

Question 4

Fill in the blanks in the following sentences.

The human immunodeficiency virus (HIV) can go on to cause ____**I**____. It does this by targeting ____**II**____ and destroying them via ____**III**____. This makes the body more susceptible to infection by ____**IV**____.

	I	II	III	IV
A	an autoimmune syndrome	lymphocytes	pyroptosis	allergens
B	an acquired immunodeficiency syndrome	cytotoxic T cells	apoptosis	opportunistic pathogens
C	an immunodeficiency	helper T cells	direct viral killing	allergens
D	an acquired immunodeficiency syndrome	helper T cells	pyroptosis	opportunistic pathogens

Question 5

Order the following steps in an allergic reaction.

1 Histamine is released

2 Abnormal amounts of IgE are produced by plasma cells

3 IgE binds with allergen, triggering degranulation of mast cells

4 B cells interact with an allergen

5 IgE binds to the surface of mast cells

A 4, 1, 5, 2, 3
B 3, 1, 4, 5, 2
C 4, 2, 5, 3, 1
D 5, 3, 1, 4, 2

Exam-style questions

Within lesson

Question 6 (1 MARK)

Allergic reactions are different from diseases caused by pathogens because in all allergies

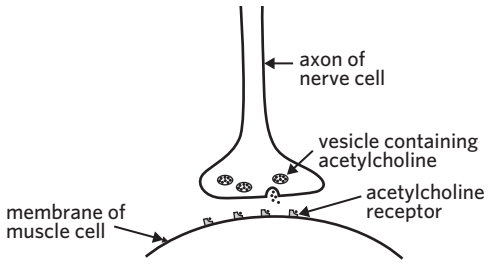
A certain self-tissues are not recognised as 'self' and this causes an immune response to the tissues.
B mast cells degranulate due to surface-bound IgE binding with an allergen.
C B cells are stimulated by allergens to produce large amounts of IgM.
D there are not enough lymphocytes to combat the allergen.

Adapted from VCAA 2015 Section A Q19

Use the following information to answer Questions 7 and 8.

Myasthenia gravis is a disease in which communication between a nerve and a muscle across a neuromuscular junction is disrupted by antibodies that bind to the acetylcholine receptor. The muscle cannot contract when this communication is disrupted.

The diagram shows a neuromuscular junction.



Question 7 (1 MARK)

Considering the information provided, myasthenia gravis is

A an allergic response.
B a pathogenic disease.
C an autoimmune disease.
D an immunodeficiency disease.

Adapted from VCAA 2016 Section A Q25

Question 8 (1 MARK)

Which one of the following could be a useful treatment for myasthenia gravis?

A Vaccination with an attenuated form of the myasthenia gravis pathogen in order to stimulate the adaptive immune system to generate antibodies against it.
B Repeated removal of the patient's blood and filtering of acetylcholine before returning the blood back to the patient's body.

C Increasing the amount of choline, a precursor to acetylcholine, obtained in the patient's diet.

D Suppression of the patient's immune system with immunosuppressants.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q15

Question 9 (5 MARKS)

Multiple sclerosis (MS) is an autoimmune disease. In sufferers of MS, the myelin coating of nerve cell axons is damaged. This damage results in poor transmission of nerve messages between the brain, the spinal cord, and the rest of the body. One aspect of MS diagnosis is imaging the brain to detect visible areas of demyelination, called plaques.

a Describe how autoreactive cells are developed in patients with MS, and explain how they lead to demyelination. (3 MARKS)

Adapted from VCAA 2011 Exam 1 Section B Q2b

b One of the primary symptoms of multiple sclerosis is weakening of the muscles. Describe a possible cause for this weakening. (2 MARKS)

Adapted from VCAA 2014 Section A Q10

Question 10 (6 MARKS)

In people with hay fever the inhalation of pollen causes an allergic reaction to take place. One of the primary symptoms of hay fever is a runny nose.

a Describe the sequence of events that would result in a runny nose in a sufferer of hay fever upon inhalation of pollen. (4 MARKS)

Adapted from VCAA 2011 Exam 1 Section B Q2b

b State two other specific physiological changes that occur as part of the allergic response and the resulting symptoms each one causes. (2 MARKS)

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q14

Multiple lessons

Use the following information to answer Questions 11 and 12.

The thymus is an important organ in the immune system. As humans grow older, there is a change in the weight of the thymus and an increase in the proportion of fat it contains.

Examine the table.

Age	At birth	10 years	20 years	30 years	60 years
Average weight of thymus (grams)	20	35	20	15	5

Question 11 (1 MARK)

Based on the information provided, it is reasonable to conclude that

A the production of metabolism-altering hormones will decrease.

B people have less need for an adaptive immune system as they age.

C as a person ages the number of mature B cells in their body decreases.

D a 60 year old will have a reduced cell-mediated immune response compared to a 20 year old.

Adapted from VCAA 2011 Exam 1 Section B Q2b

Question 12 (1 MARK)

The thymus plays an important role in the destruction of autoreactive lymphocytes. In doing so, it prevents the development of

A immunodeficiency diseases.

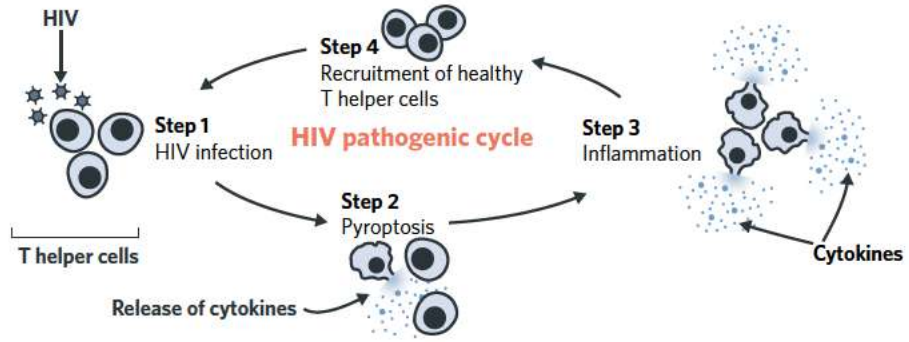
B autoimmune diseases.

C pathogenic infections.

D allergic reactions.

Question 13 (5 MARKS)

The human immunodeficiency virus (HIV) infects T helper cells. Scientists have discovered that 95% of infected T helper cells undergo a process called pyroptosis. During pyroptosis, the plasma membrane bursts, releasing cytokines. This release of cytokines results in constant inflammation.

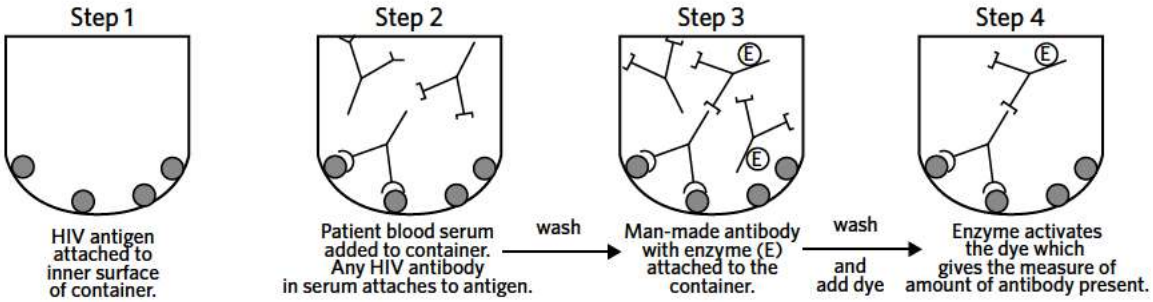


Source: Doitsh et al. (2014), as adapted by VCAA 2018 Northern Hemisphere Exam Section B Q5

a Explain, with reference to the adaptive immune system, how HIV could lead to the development of an immunodeficiency. (2 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q5a

b A diagnostic test for HIV infection includes the steps shown.



I State the cell type that would have produced the HIV antibodies seen in the patient's serum. (1 MARK)

II Identify and explain one way in which antibodies in the patient's serum could combat HIV. (2 MARKS)

Key science skills

Question 14 (5 MARKS)

Alopecia areata is a cell-mediated autoimmune disease that causes loss of body hair. Scientists wanted to study a treatment for alopecia areata using a cream called anthralin.

The scientists selected a breed of rat that develops alopecia areata at the age of four months. From 0-4 months of age, these rats had a normal coat of hair. Sixteen rats that had lost their hair were selected for the experiment and anthralin cream was applied to one half of each rat every day for 10 weeks.
The scientists hypothesised that if they applied the cream to one half of each of the 16 rats and left the other half untreated, they would only see the treated side regrow hair.

The results showed that all 16 rats regrew a full coat of hair on the treated half and remained hairless on the untreated half.

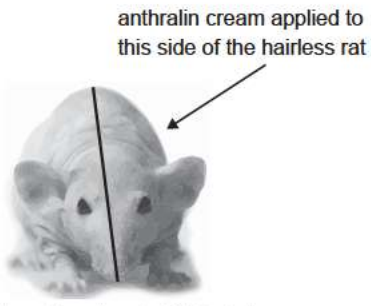


Image: Sergey Lavrentev/Shutterstock.com

a State whether a control was used in the experiment and identify what the control is/should be. (2 MARKS)

b At the cellular level, suggest what the scientists could expect to find in a tissue sample of the hairless skin from these rats as compared to the side with hair. (1 MARKS)

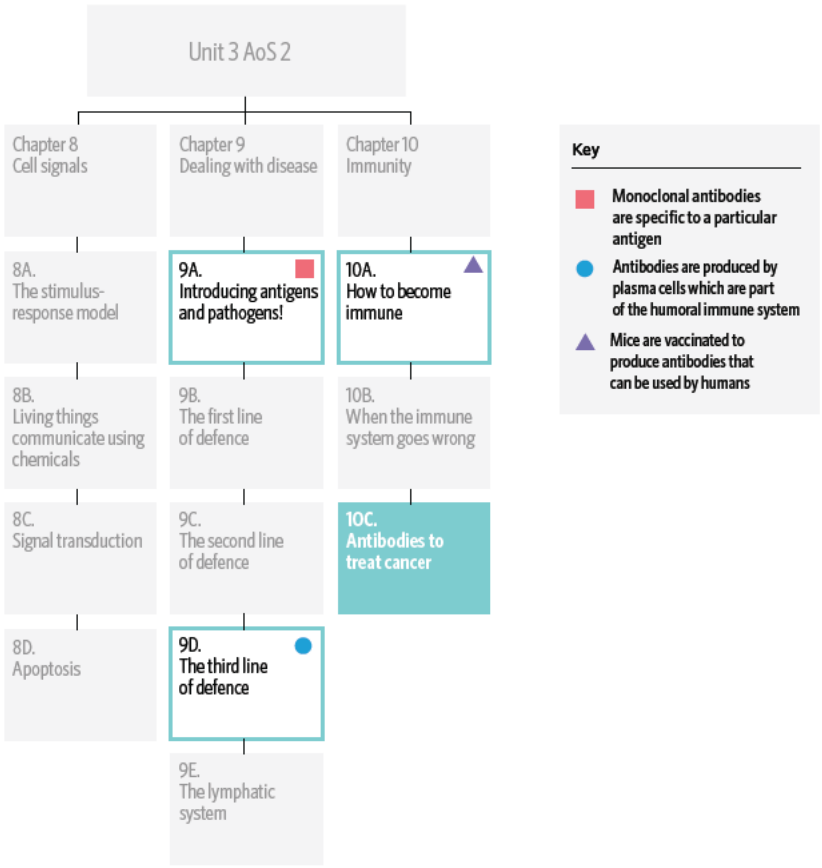
Adapted from VCAA 2017 Section A Q25

c Humans can also develop alopecia areata. The scientists wished to repeat their experiment using humans susceptible to developing alopecia areata.
What are two factors in the experimental design that scientists would have to control? (2 MARKS)

Adapted from VCAA 2011 Exam 1 Section B Q4e

10C ANTIBODIES TO TREAT CANCER

Are mice the key to better cancer treatments?



In this lesson you will learn how antibodies can be produced in a laboratory and then introduced into the human body to stage a specific attack on targeted cells to treat diseases such as cancer.

Study design dot point

- the use of monoclonal antibodies in treating cancer

Key knowledge units

How monoclonal antibody therapy works	3.2.14.1

How monoclonal antibody therapy works 3.2.14.1

OVERVIEW

Monoclonal antibodies are laboratory-made proteins that can be used to stage an immune-like attack on cancerous cells in the body.

THEORY DETAILS

What are monoclonal antibodies?

Monoclonal antibodies (mAbs) are one type of treatment for cancer (and other diseases). They can be used alongside or instead of existing chemotherapy and radiotherapy treatments and create a passive artificial immunity. Let's start by breaking down the term monoclonal antibodies.

You have already learned about **antibodies** in lesson 9D and their role in the body's immune response. They are protein molecules produced by plasma cells that contain two highly specific antigen-binding sites. **Monoclonal** refers to creating many identical copies of a single cell. In the context of mAbs, a fused **B lymphocyte** known as a **hybridoma** is cloned multiple times to produce a large yield of identical antibodies. Therefore, monoclonal antibodies are antibodies produced from a cloned hybridoma.

monoclonal antibodies (mAbs) identical laboratory-made antibodies produced by B cell clones

antibody a protein produced by plasma cells during the adaptive immune response that is specific to an antigen and combats pathogens in a variety of ways. Also known as **immunoglobulin**

monoclonal describes a clone of a cell formed asexually from a singular cell or organism

B lymphocyte a type of lymphocyte that plays an important role in humoral immunity and differentiates into plasma cells and B memory cells

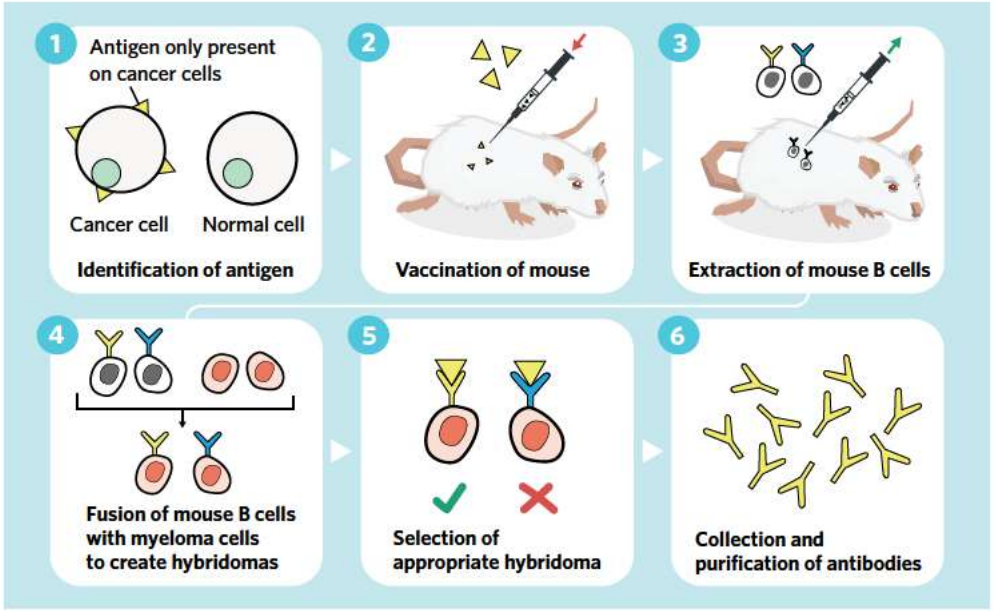
How are monoclonal antibodies produced?

To make monoclonal antibodies that can help fight cancer, scientists first need to identify and isolate an **antigen** that is present on cancer cells. These antigens are not necessarily exclusive to cancerous cells, however there are some antigens that are more frequently seen amongst cancerous cells than healthy cells. One example of such an antigen is the CA19-9 antigen in colorectal cancer. Once the antigen is selected, scientists vaccinate an animal, usually mice, with a weakened form of the antigen. As you learned in lesson 10A, a vaccination stimulates an immune response against the antigen and results in the selection and proliferation of a B lymphocyte that matches the antigen.

In lesson 9E, you learned that the spleen is a secondary lymphatic tissue where antigen-presenting cells interact with the adaptive immune system. Scientists extract the B lymphocytes that have been produced by the vaccination from the spleen of the mice.

The extracted B lymphocytes are fused with rapidly-dividing cancerous human plasma cells known as **myeloma cells**. The products of this fusion are called hybridomas. These tumour cells have the ability to grow indefinitely and replicate at a faster rate than normal antigen-producing cells.
From this, hybridomas can be screened so that only the cells relevant to the specific antigen remain. After screening, the hybridomas that produce the specific antibody can be cloned, which results in the mass production of these antibodies. The antibodies are then collected and purified before being administered to cancer patients (Figure 2).

Figure 2 The process of producing monoclonal antibodies



hybridoma the product of the fusion between a mouse's extracted B lymphocyte and a myeloma cell

antigen a substance that is recognised by the immune system as either foreign or self. A foreign antigen will trigger an immune response

myeloma cells rapidly-dividing cancerous plasma cells which are fused with extracted B cells from mice to produce hybridomas

lesson link In ***lesson 9D*** you can review what antibodies are and how they are produced through the humoral immune system.

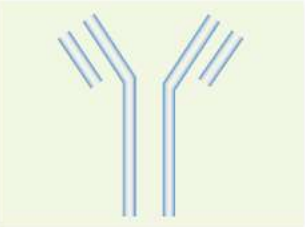


Figure 1 Basic structure of an antibody

How do monoclonal antibodies treat cancer?

Monoclonal antibodies can attach to a specific antigen expressed by cancer cells and initiate many different attacks depending on the makeup of the antibody. These include:

- identifying cancer cells as foreign so that immune system cells destroy them
- triggering apoptosis and destroying the cell membrane
- blocking cell growth by blocking the connection between a cancer cell and proteins that promote cell growth
- delivering radiation or chemotherapy treatment by exploiting their ability to connect with cancer cells.

Memory device

Image: black-sun/Shutterstock.com

Drug delivery
Identify cancer cells
Growth blocker
Apoptosis inducer

What are the limitations of monoclonal antibodies?

Monoclonal antibodies can be used to treat cancer and have less taxing side effects than radiotherapy and chemotherapy, however, the treatment is not always effective. Treating cancer with monoclonal antibodies is incredibly time-consuming and expensive. In addition, the antibodies produced are specific to a certain antigen, which means if a mutation occurs and changes the configuration of the antigen, the mAb is no longer effective.

Theory summary

Through the immunisation of mice and the extraction of produced B cells, scientists can stimulate the production of antibodies used for cancer treatment. The process to produce these antibodies is:

1 Identification of antigen
2 Vaccination of mouse
3 Extraction of mouse B cells
4 Fusion of mouse B cell with myeloma cells
5 Selection of appropriate hybridoma
6 Collection and purification of antibodies

These antibodies treat cancer though flagging the cancerous cells to the immune system, assisting in the delivery of drugs to target cells, preventing the growth of tumour cells through blocking growth proteins, and inducing apoptosis in cancerous cells.

10C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a rapidly reproducing plasma cell
b _____ a cell that is a fusion of a cancerous plasma cell and an extracted B lymphocyte from a mouse
c _____ protein molecules made in a laboratory by a hybridoma cell
d _____ proteins found on the surface of cells that identify them as self or non-self

Question 2

Which of the following correctly lists four treatments that monoclonal antibodies can initiate?

A	Flags cancer cells to the immune system	Delivers nutrients to healthy cells	Induces necrosis	Promotes growth of targeted cells
B	Induces apoptosis	Attacks any cancerous antigen in the body	Flags cancer cells to the immune system	Inhibits growth of targeted cells
C	Cuts off water supply to cancerous cells	Flags cancer cells to the immune system	Promotes growth of targeted cells	Induces necrosis
D	Targets a specific cancerous antigen in the body	Inhibits growth of targeted cells	Induces apoptosis	Flags cancer cells to the immune system

Question 3

Which of the following is false?

A mAbs are a fusion of a carbohydrate molecule and protein molecule.
B mAb production involves mice being immunised against an antigen.
C mAbs can flag cancerous cells to the body's immune system.
D mAbs can be used with chemotherapy treatments.

Question 4

Order the following steps for the production of monoclonal antibodies.

1 Fusion of mouse B cell with myeloma cell
2 Selection of appropriate hybridoma
3 Identification of antigen
4 Collection and purification of antibodies
5 Vaccination of mouse
6 Extraction of mouse B cells

A 5, 6, 1, 2, 4, 3
B 3, 5, 6, 1, 2, 4
C 3, 6, 5, 1, 2, 4
D 6, 5, 1, 2, 4, 3

Exam-style questions

Within lesson

Question 5 (1 MARK)

Monoclonal antibodies

A are lipid molecules.
B are produced by B memory cells.
C bind to the extracellular receptors of specific cells.
D all share the same universal active site that can bind to all cancerous cells.

Adapted from VCAA 2018 Section A Q24

Question 6 (1 MARK)

Monoclonal antibodies can be used to treat cancerous cells in the body.

Which of the following is not a role of monoclonal antibodies?

A Trigger cell lysis through necrosis.
B Initiate an immune response by flagging the cancerous cell to immune cells.
C Deliver treatments such as radiation or chemotherapy drugs directly to the site of cancerous cells.
D Prevent cell growth in the cancerous cell by blocking its connection to proteins that promote cell growth.

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q2c

Multiple lessons

Question 7 (10 MARKS)

Monoclonal antibodies: the invisible allies that changed the face of medicine

By Lara Marks

Published in *The Conversation* August 10th 2015

Monoclonal antibodies (mAbs) are tiny magic bullets that are quietly shaping the lives of millions of patients around the world. Produced in the lab, invisible to the naked eye, relatively few people are aware of these molecules' existence or where they came from. Yet monoclonal antibodies are contained in six out of ten of the world's bestselling drugs, helping to treat everything from cancer to heart disease to asthma.

In the years that have passed since 1975, mAb drugs have radically reshaped medicine and spawned a whole new industry. It is predicted that 70 mAb products will have reached the worldwide market by 2020, with combined sales of nearly $125bn.

Key to the success of mAb drugs are the dramatic changes they have brought to the treatment of cancer, helping in many cases to shift it away from being a terminal disease. mAbs can very specifically target cancer cells while avoiding healthy cells, and can also be used to harness the body's own immune system to fight cancer. In contrast, chemotherapy and radiotherapy can lead to debilitating effects on an individual's health, as there is not a high-cell specificity, meaning cancer cells are targeted with less direction.

mAbs have also radically altered the treatment of inflammatory and autoimmune disorders like rheumatoid arthritis and multiple sclerosis, moving away from merely relieving symptoms to targeting and disrupting their cause.

Aside from cancer and autoimmune disorders, mAbs are being used to treat over 50 other major diseases. Applications include treatment for heart disease, allergic conditions such as asthma, and prevention of organ rejection after transplants. mAbs are also under investigation for the treatment of central nervous disorders such as Alzheimer's disease, metabolic diseases like diabetes, and the prevention of migraines. More recently they were explored as a means to combat Ebola, the virus disease that ravaged West Africa in 2014.

a What is meant by the term 'autoimmune disorder'? (1 MARK)

b Do monoclonal antibodies cause less severe side effects than chemotherapy?
Support your response with evidence from the article. (2 MARKS)

c Identify the type of immunity created by mAbs. (1 MARK)

d Describe one way that mAbs can affect cancerous cells that does not require the use of other drugs. (2 MARKS)

e The article discusses the potential applications of mAbs including 'treatment for heart disease, allergic conditions such as asthma, and prevention of organ rejection after transplants'.

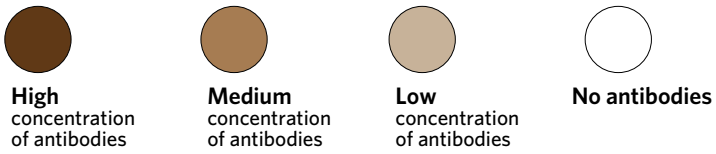
i State whether the mAbs used to treat cancerous cells would be identical to the mAbs used for these future potential applications. Justify your response. (2 MARKS)

ii Describe the potential role of mAbs in drug delivery for these applications. (2 MARKS)

Key science skills

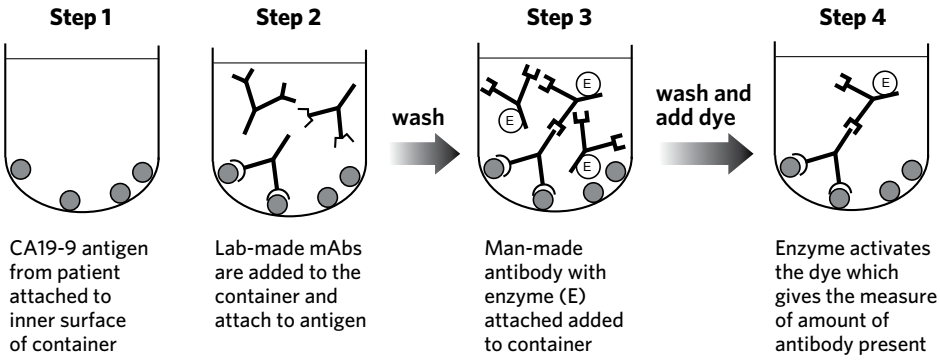
Question 8 (8 MARKS)

Scientists use a test called ELISA to identify whether antibodies are present in a solution. If antibodies are present, the solution changes colour.



Using monoclonal antibodies in an ELISA test, scientists can detect the presence of colorectal cancer by detecting the amount of the antigen CA19-9 in a patient's sample. If cancerous cells are present in the sample, mAbs will attach to CA19-9 antigen and cause a colour change. If cancerous cells are not present, the mAbs will be washed out.

The ELISA process is as follows:



Once the ELISA procedure is completed, the colour change can be observed.

The scientists used samples from five different individuals and displayed the results in the table.

Sample	Concentration
1	High
2	Nil
3	Low
4	Medium
5	Medium

a Identify and explain an uncontrolled factor that may have affected the results. (2 MARKS)

b The scientists used additional samples that were known as the positive and negative control. These samples are not shown in the table.

i Define the purpose of a positive and negative control. (2 MARKS)

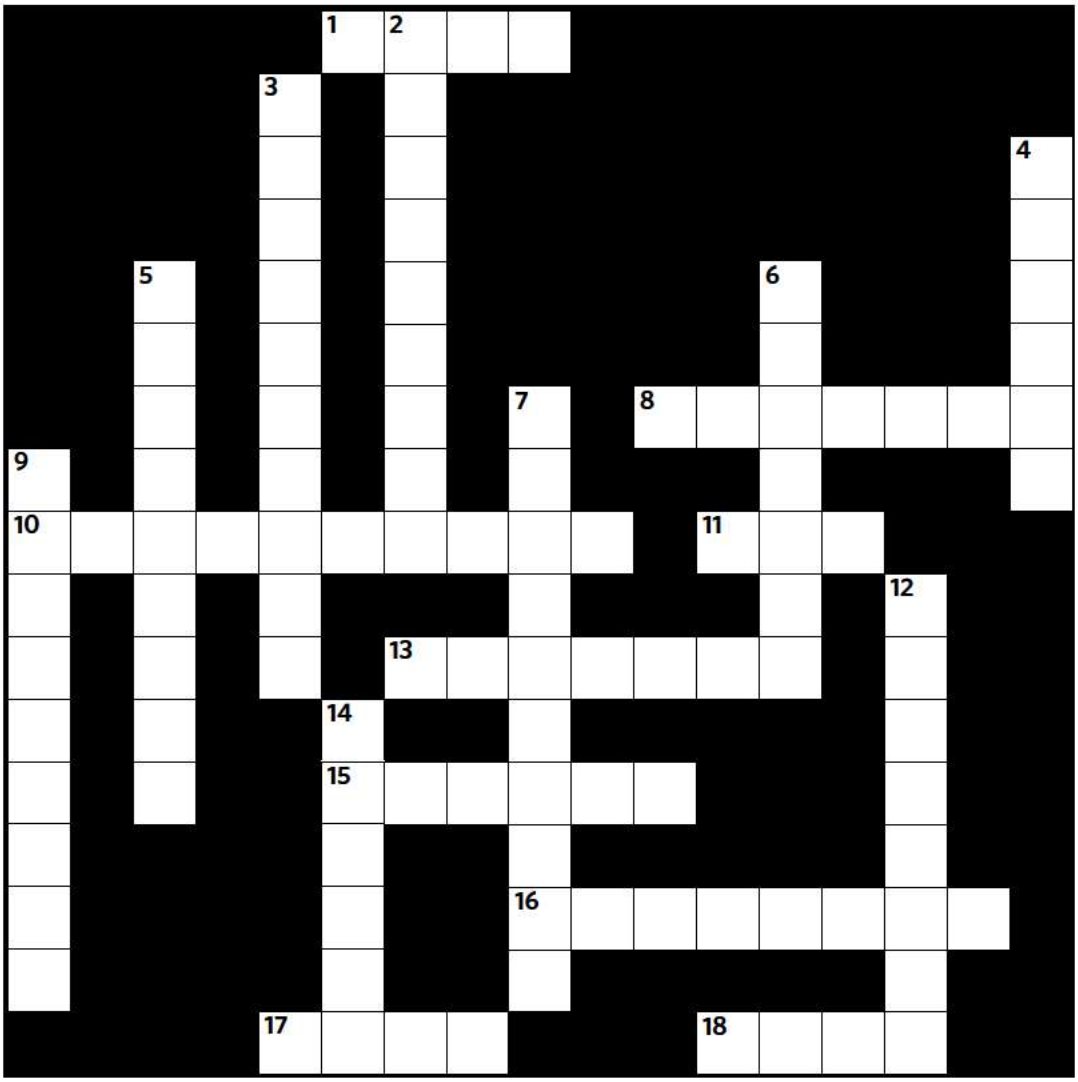
ii Identify what is in each control sample and explain the predicted colour of the samples. (2 MARKS)

c Explain one way that monoclonal antibodies can be used to treat cancer in humans. (2 MARKS)

Adapted from VCAA 2012 Exam 1 Section A Q24

ACTIVITIES

Immunity crossword



ACROSS

1. _____ cells release histamine during an allergic response.

8. When a pathogen causes harm to an organism, we call this a pathogenic _____.

10. _____ diseases occur when the immune system attacks 'self-cells'.

11. A virus which infects and causes the destruction of helper T cells.

13. Contains antigens that can cause an immune response but rarely cause disease.

15. B _____ cells can remember a specific pathogen for years after first exposure.

16. A relatively harmless antigen that can cause the release of histamine by mast cells.

17. By encouraging high vaccination rates, governments are attempting to achieve _____ immunity.

18. A disease caused by the HIV virus. A symptom of this disease is an extremely weak immune system.

DOWN

2. An injection which contains antibodies specific to either a venom or toxin.

3. This type of immunity can be induced by the injection of antigens.

4. A disease caused by the uncontrolled replication of cells.

5. _____ T cells can kill target cells by initiating apoptosis or by punching holes in the plasma membrane.

6. When antibodies are obtained from an external source.

7. _____ antibodies can be used to deliver drugs to certain cells with extremely high specificity.

9. Immunity via breastfeeding and natural exposure to antigens are both examples of _____ acquired immunity.

12. Some drugs _____ the immune system, and can be used to treat individuals suffering from autoimmune diseases.

14. By producing pathogen-specific immune cells, a person can become _____ to a disease.

Crossword answers

1. mast; 2. antivenom; 3. artificial; 4. cancer; 5. cytotoxic; 6. passive; 7. monoclonal; 8. disease; 9. naturally; 10. autoimmune; 11. HIV; 12. suppress; 13. vaccine; 14. immune; 15. memory; 16. allergen; 17. herd; 18. AIDS

Monoclonal antibodies

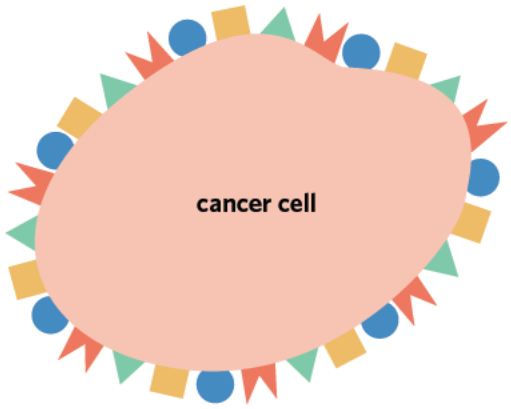
1 Create an annotated flow chart representing one of the following scenarios. Refer to the mode of action of drugs involving the use of a monoclonal antibody drug therapy.

   a Due to their high replication rate and significant energy demands, cancerous tumours often form blood vessels to support their growth. Some monoclonal antibodies can prevent the formation of these blood vessels.

   b Some monoclonal antibodies can trigger specific cells within the immune system to attack cancerous cells.

   c Cancerous cells often produce growth factor proteins that tell other cancerous cells to grow and divide. Some monoclonal antibodies can block the reception of these proteins.

2 Design a monoclonal antibody that could be used to deliver cancer-fighting drugs directly to a cancerous cell from a patient suffering from lung cancer. Show this antibody interacting with the cancerous cell. A diagram of one of these cancerous cells is shown.



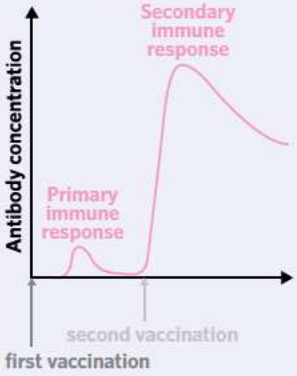
CHAPTER SUMMARY

When things go right

	Medical Intervention?	Source of antibodies	Example
Natural active immunity	✗	Individual's own immune system	Getting chicken pox and being immune to it afterwards
Natural passive immunity	✗	External source	Antibodies passing from mother to baby in breast milk or across the placenta
Artificialactive immunity	✓	Individual's own immune system	Vaccines, such as against measles and polio
Artificial passive immunity	✓	External source	Being injected with antibodies, such as monoclonal antibodies

10A

Vaccinations

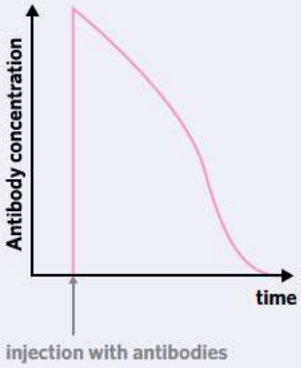


- Injections containing weakened/deactivated pathogens that don't cause disease but stimulate an adaptive immune response
- Often given as a series of injections called a vaccination program/schedule
- Booster shots are given after completion of a vaccination program to boost immunity

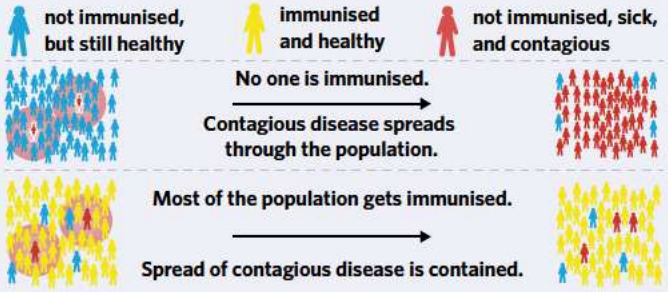
10C

Monoclonal antibodies can be used to treat cancer.
They are produced by:

1. Identification of antigen
2. Vaccination of mouse
3. Extraction of mouse B cells
4. Fusion of mouse B cells with myeloma cells
5. Selection of appropriate hybridoma
6. Collection and purification of antibodies



10A



Herd immunity is achieved when 95% of the population is vaccinated against a disease. It protects people who are unable/choose not to receive a vaccination by reducing the number of potential hosts of a pathogen.

When things go wrong

Autoimmune diseases

- Adaptive immune system recognises self-tissues as non-self and launches an attack against them
- Characterised by the presence of autoantibodies and autoreactive T cells

example

Multiple sclerosis

- Destruction of oligodendrocytes and myelin sheath surrounding axons by autoreactive T lymphocytes and autoantibodies

Immune deficiency diseases

- Conditions in which an individual's immune system no longer functions correctly, making them more susceptible to disease

example

HIV

- The human immunodeficiency virus (HIV) destroys immune cells, particularly helper T cells
- Due to destruction of helper T cells, the adaptive immune response no longer functions correctly
- If this occurs, the patient is said to have an acquired immunodeficiency syndrome (AIDS)

Allergic reactions

- Sensitisation - B cells inappropriately respond to an allergen and secrete a high amount of IgE which goes on to bind to mast cells
- Re-exposure - allergen cross-links with IgE on the surface of mast cells, causing the release of histamine

example

Hay fever

- Caused by pollen
- Pollen is inhaled and cross-links with IgE on the surface of mast cells, causing the release of histamine
- Histamine causes a number of physiological changes that result in the symptoms of hay fever (e.g. runny nose, sneezing)

CHAPTER REVIEW QUESTIONS

SECTION A (15 MARKS)

Question 1 (1 MARK)

The incidence of disorders associated with a malfunctioning immune system, including autoimmune disorders and hypersensitive allergic responses, appears to have increased in recent years.

Autoimmune diseases are different from allergic responses because in all autoimmune diseases

A the immune system recognises and responds to an invading pathogen.

B histamine is released from mast cells to cause an inflammatory response.

C the immune system is weakened, which increases the chance of pathogenic infection.

D the immune system recognises self-tissues as foreign and initiates an immune response.

Adapted from VCAA 2015 Section A Q19

Question 2 (1 MARK)

Chronic lymphocytic leukemia is a cancer that can affect the production and development of white blood cells. Individuals suffering from chronic lymphocytic leukemia often have a weakened immune response and as a result are far more vulnerable to pathogenic attack.

Chronic lymphocytic leukemia is an example of

A an allergic reaction.

B a pathogenic attack.

C an autoimmune disease.

D an immunodeficiency disease.

Adapted from VCAA 2018 Section A Q16

Question 3 (1 MARK)

Rubella is a virus that causes a highly contagious infectious disease. When infected with rubella, humans initially produce IgM antibodies and then IgG antibodies. IgM antibodies do not cross the placenta.

Tests for the presence of IgM and IgG antibodies are carried out on a newborn baby if the mother has been diagnosed with a rubella infection during pregnancy. The results for the tests carried out on four newborn babies before they had been fed are shown in the table.

	Antibodies for the rubella virus found in the baby's blood
Baby 1	none
Baby 2	IgG
Baby 3	IgG
Baby 4	IgM & IgG

Using your knowledge and the information given, it would be correct to conclude that

A the mother of baby 1 has never produced IgG antibodies in response to the rubella virus.

B baby 3 was exposed to the rubella virus during fetal development.

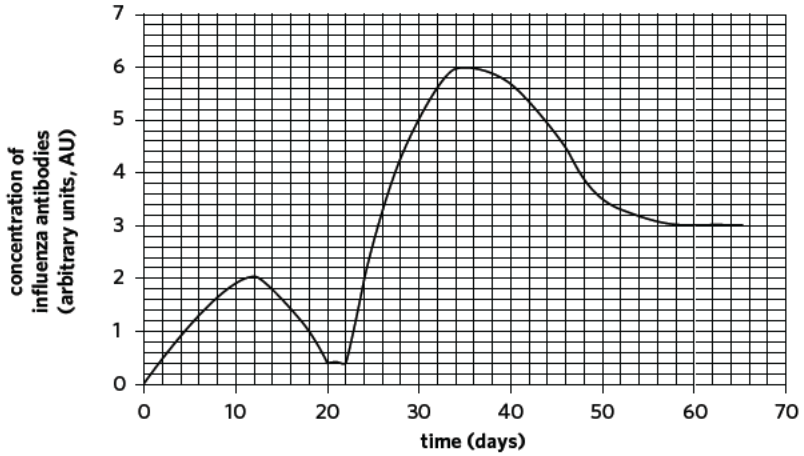
C baby 4 has been injected with the rubella vaccine.

D baby 2 has innate immunity to the rubella virus.

Adapted from VCAA 2012 Exam 1 Section A Q18

Question 4 (1 MARK)

A daily blood sample was obtained from an individual who received a single vaccination against a particular strain of the influenza virus. The individual had no prior exposure to this strain of influenza. The graph shows the concentration of antibodies present in the individual's blood for this strain of influenza over a period of 65 days.



Which one of the following conclusions can be made using this data?

A The patient received the influenza vaccination on day 12.

B B memory cells were present in the patient's blood on day 22.

C The influenza virus produced the most antibodies on day 34 of the treatment.

D More of the influenza virus would be present within the blood on day 30 compared to day 12.

Adapted from VCAA 2017 Section A Q26

Question 5 (1 MARK)

People that have been infected with one or more different respiratory viruses develop antibodies in response to each kind of virus in their blood.

The blood of four patients was tested to diagnose which viruses each patient had previously been infected with. The results are shown in the table.

	Antibody to			
Blood from	Rhinovirus	Influenza A	Influenza B	RSV
Brenda	0	++	++	++
Nathan	++	0	0	++
Stacy	++	0	0	0
Jacqueline	0	++	++	0

Key:
++ agglutination
0 no agglutination

From the information in the table it is reasonable to infer that

A Brenda and Jacqueline have each been infected with the same set of viruses.

B Brenda has a stronger immune response to the RSV virus than Nathan.

C Stacy has been exposed to the fewest number of different viruses.

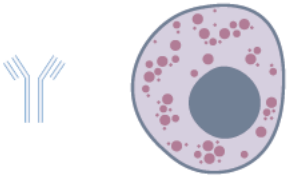
D Nathan has never been infected with the Rhinovirus.

Adapted from VCAA 2011 Exam 1 Section A Q24

Use the following information to answer Questions 6 and 7.

Allergic reactions are potentially life-threatening reactions to typically non-damaging substances. Two key components of an allergic reaction are the IgE antibodies which are produced by B lymphocytes, and the responses of cell X. Cell X releases cytokines for cell-cell signalling and histamine which can cause localised swelling, dilation of blood vessels, and itchiness.

IgE antibody **cell X**



Question 6 (1 MARK)

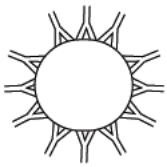
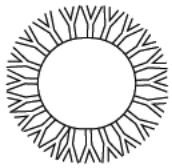
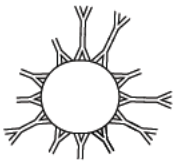
Cell X is an example of a

A B lymphocyte.
B T helper cell.
C phagocyte.
D mast cell.

Question 7 (1 MARK)

The IgE antibody interacts with cell X.

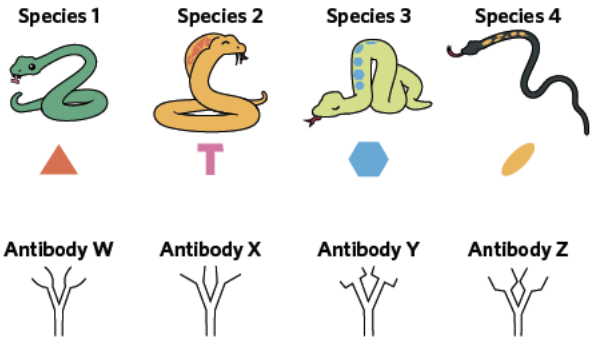
Which of the following diagrams correctly shows the interaction between the IgE antibody and cell X?

A 
B 
C 
D 

Use the following information to answer Questions 8 and 9.

A park ranger was admitted to a hospital and requesting treatment for a snake bite. The ranger urgently required a dose of antivenom. Luckily, the ranger managed to capture and bring the snake with them into the hospital. To decide which antivenom to prescribe, doctors analyse the given chart with the four most common major venomous snake species in the area. Beneath each species is a diagram of their toxin. The four antibodies present in each antivenom are also shown. Due to a design flaw, the antibodies have been mixed up.

After examining the captured snake, the doctors decided it belonged to species 1 and administered an antivenom containing one of the antibodies W–Z.



Question 8 (1 MARK)

Which antibody would be found in the antivenom?

A Antibody W
B Antibody X
C Antibody Y
D Antibody Z

Question 9 (1 MARK)

After being injected with the antivenom, the ranger's condition quickly improved. This is because antivenom serum

A provided a passive and natural immunity.
B provided an active and induced (artificial) immunity.
C introduced antibodies which bound to and deactivated the snake venom.
D triggered the park ranger's immune system to mount an immune response against the venom.

Adapted from VCAA 2016 Section A Q23

Question 10 (1 MARK)

Monoclonal antibodies can be produced and used to treat different types of cancers. Which one of the following is a correct statement about monoclonal antibodies?

A Monoclonal antibodies are naturally produced in response to invading pathogens.

B The same monoclonal antibody can be used to treat all types of cancers.

C A monoclonal antibody will always initiate apoptosis in the target cell.

D Monoclonal antibodies contain two identical antigen recognition sites.

Adapted from VCAA 2018 Section A Q24

Question 11 (1 MARK)

Scientists are currently developing a vaccine to combat the Ebola virus. When developing a vaccine, scientists use a weakened form of the Ebola virus, which is injected into the patient.

Scientists use a weakened form of the virus because

A it is difficult to isolate healthy samples of the Ebola virus.

B there is less chance to initiate an immune response in the patient.

C healthy samples of the Ebola virus cannot survive in humans.

D there is less chance to cause disease in the patient.

Question 12 (1 MARK)

A doctor was consulting with a mother who had recently given birth. The doctor explained that breastfeeding would not protect her child against infections after breastfeeding stops. This is because the type of immunity achieved by breastfeeding is an example of

A active and natural immunity.

B passive and natural immunity.

C active and induced (artificial) immunity.

D passive and induced (artificial) immunity.

Adapted from VCAA 2016 Section A Q23

Use the following information to answer Questions 13 and 14.

Scientists are investigating factors that increase the likelihood of developing certain human diseases. Recently, the 'hygiene theory' has been considered a possible factor. This theory proposes that if a child's environment is overly hygienic and does not allow sufficient exposure to a wide range of non-self antigens, an overactive immune system will result later in life.

Multiple sclerosis (MS) is one of many studied human diseases. In sufferers of MS, the myelin coating of nerve cell axons can be recognised and damaged by an overactive immune system. This damage results in poor transmission of nerve messages between the brain, the spinal cord, and the rest of the body. One aspect of MS diagnosis is imaging the brain to detect visible areas of demyelination, called plaques.

A recent study tested for the presence of antibodies to the bacteria that cause stomach ulcers, *Helicobacter pylori*, in the blood of 550 MS patients and 299 healthy people. Both groups of people had the same proportion of each gender and were of similar age. Exposure to *H. pylori* usually occurs by the age of two years. The results of the antibody testing showed that the rate of *H. pylori* infection was 30% lower in the women with MS than in the healthy women or healthy men.

Question 13 (1 MARK)

The findings of this study are consistent with the suggestion that

A women with MS are less likely to have been exposed to the *H. pylori* bacteria in early childhood when compared to healthy women.

B *H. pylori* degrades the myelin sheath in individuals affected by multiple sclerosis.

C the symptoms of multiple sclerosis first present themselves early in life.

D women are much more likely to suffer from MS than men.

Adapted from VCAA 2017 Section A Q25

Question 14 (1 MARK)

Considering the information, multiple sclerosis is

A an allergic response.

B an infectious disease.

C an autoimmune disease.

D an immunodeficiency disease.

Adapted from VCAA 2016 Section A Q25

Question 15 (1 MARK)

Lupus is a condition that results in the increased secretion of antibodies that attach themselves to healthy cells in a patient's body. The accumulation of these antibodies causes inflammation, joint pain, rash, fatigue, and fever.

Which one of the following could be a useful treatment for lupus?

A Injecting signalling molecules which have been designed to initiate apoptosis in the lupus-causing pathogen.

B Achieving lupus vaccination rates which are high enough to support herd immunity.

C Administration of drugs which suppress the patient's immune response.

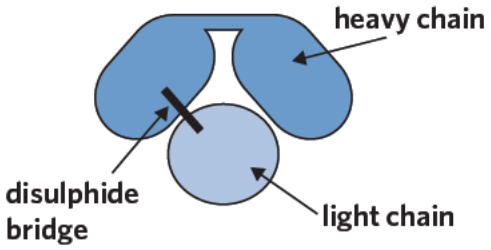
D Injection of hypersensitive mast cells into the bloodstream.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q15

SECTION B (25 MARKS)

Question 16 (8 MARKS)

The bacterium *Clostridium tetani* is capable of producing the toxin tetanospasmin which is lethal even in extremely small amounts. A simplified representation of the structure of the toxin is shown in the diagram.



A new preparation of the tetanus vaccine uses just the heavy chain segment of tetanospasmin to cause an immune response. When injected by itself, the heavy chain of the toxin tetanospasmin is unable to damage the host.

a What is a vaccine? (1 MARK)

Adapted from VCAA 2016 Section B Q5a

b In an experimental trial, scientists injected sheep with the new vaccine. After 10 days, they withdrew blood from the sheep and mixed it with *C. tetani* that had been suspended in sterilised water. The scientists noted the almost immediate agglutination in the mixture after antibodies interacted with the tetanospasmin toxin.

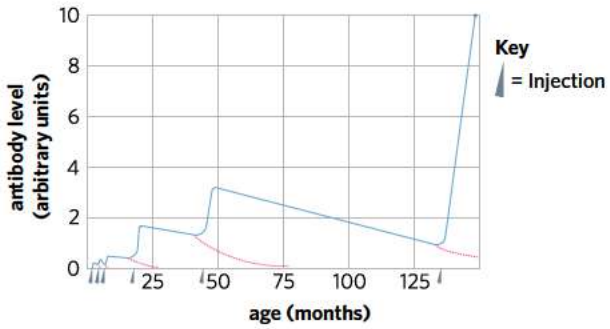
i Identify where the antibodies bind to the tetanospasmin toxin. (1 MARK)

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q11

ii Explain how the binding of antibodies provides immunity to the tetanospasmin toxin. (2 MARKS)

Adapted from VCAA 2014 Section B Q4cii

c The tetanus vaccination schedule for children includes multiple doses of the vaccine over several years of a child's life. The blue line on the graph shows the antibody levels of a child if the vaccination is given at the appropriate times, whilst the pink lines show what happens to the antitoxin levels if it is not administered according to the schedule.



i How many doses of the vaccine does each vaccination schedule require? Justify your answer. (1 MARK)

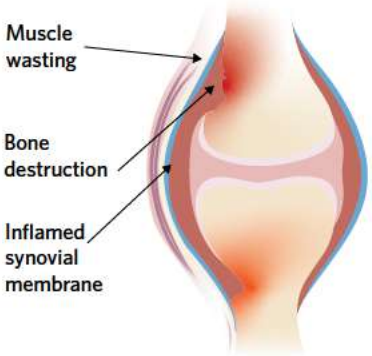
ii Children are not considered to be immune to the *C. tetani* bacterium until the vaccination schedule is complete. Explain how the vaccination schedule enables a longer-lasting immunity to the toxin tetanospasmin than a single vaccination. (3 MARKS)

Adapted from VCAA 2015 Section B Q4a

Question 17 (6 MARKS)

Rheumatoid arthritis is an autoimmune disease characterised by inflammation and degradation of joints. Autoantibodies can be found in the blood of patients suffering from rheumatoid arthritis. The joint of an individual suffering from rheumatoid arthritis is shown.

Rheumatoid arthritis joint



a Explain the role autoantibodies play in the inflammation and degradation of joints. (1 MARK)

Adapted from VCAA 2013 Section B Q5a

b Two keen biology students, Sasha and Andy, were discussing whether rheumatoid arthritis is due to a malfunction in the humoral or cell-mediated immune systems, or both. Explain how these two immune responses are different. (2 MARKS)

Adapted from VCAA 2015 Section B Q4b

c The symptoms of rheumatoid arthritis typically present between the ages of 30 and 55 whereas other autoimmune diseases, such as type 1 diabetes, generally appear in childhood. Suggest why some autoimmune diseases vary in the timing of the initial onset of symptoms. (3 MARKS)

Question 18 (11 MARKS)

Whooping cough is a highly contagious disease caused by an infection from the bacterium *Bordetella pertussis*. It is typically transmitted through coughing or sneezing. Whooping cough can be prevented by immunisation with the whooping cough vaccine. Individuals younger than two months old cannot receive the whooping cough vaccine.

a It is recommended that adults get the whooping cough vaccine every 10 years, especially if they spend large amounts of time around children. Identify this type of vaccine and explain why it is necessary. (2 MARKS)

Adapted from VCAA 2013 Section B Q4c

b Name the two different cell types that are important in providing lifelong immunity. (2 MARKS)

Adapted from VCAA 2016 Section B Q5c

c Explain how immunising a person against a disease reduces their chances of contracting a particular disease. (3 MARKS)

d Despite being unable to receive the whooping cough vaccine, individuals under the age of two can still be protected from the whooping cough disease in a number of ways. Pregnant mothers are able to receive the vaccine which provides the infant with an immunity to the disease, and herd immunity also serves to protect susceptible infants.

i Is the infant's immunity to whooping cough from the mother's vaccination an active or passive form of protection against a disease? Justify your answer. (2 MARKS)

Adapted from VCAA 2013 Section B Q4a

ii Describe what herd immunity is and explain how it can protect unvaccinated infants from whooping cough. (2 MARKS)

Adapted from VCAA 2018 Section B Q5b

UNIT

4 How does life change and respond to challenges over time?

In this unit students consider the continual change and challenges to which life on Earth has been subjected. They investigate the relatedness between species and the impact of various change events on a population's gene pool. The accumulation of changes over time is considered as a mechanism for biological evolution by natural selection that leads to the rise of new species. Students examine change in life forms using evidence from palaeontology, biogeography, developmental biology, and structural morphology. They explore how technological developments in the fields of comparative genomics, molecular homology, and bioinformatics have resulted in evidence of change through measurements of relatedness between species.

Students examine the structural and cognitive trends in the human fossil record and the interrelationships between human biological and cultural evolution. The biological consequences, and social and ethical implications, of manipulating the DNA molecule and applying biotechnologies is explored for both the individual and the species.

Image: Microgen/Shutterstock.com

UNIT 4

AOS1

How are species related?

In this area of study students focus on changes to genetic material over time and the evidence for biological evolution. They investigate how changes to genetic material lead to new species through the process of natural selection as a mechanism for evolution. Students examine how evolutionary biology and the relatedness of species is based upon the accumulation of evidence. They learn how interpretations of evidence can change in the light of new evidence as a result of technological advances, particularly in molecular biology. The human fossil record is explored to identify the major biological and cognitive trends that have led to a complex interrelationship between biology and culture.

Outcome 1

On completion of this unit the student should be able to analyse evidence for evolutionary change, explain how relatedness between species is determined, and elaborate on the consequences of biological change in human evolution.

Image: Josh Anon/Shutterstock.com

UNIT 4 AOS 1, CHAPTER 11

How species evolve

11

11A Mutations

11B Natural selection

11C Gene flow and drift

11D Speciation

11E Artificial selection

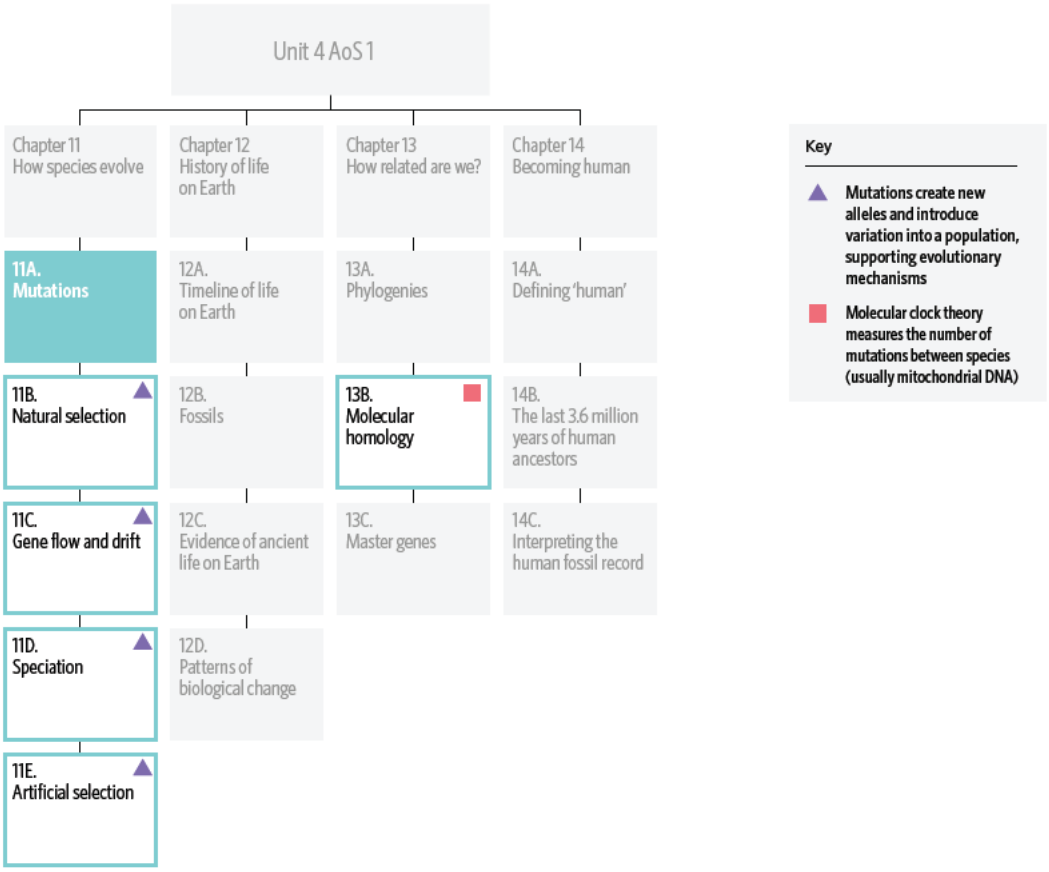
Key knowledge

- the qualitative treatment of the causes of changing allele frequencies in a population's gene pool including types of mutations (point, frameshift, block) as a source of new alleles, chromosomal abnormalities (aneuploidy and polyploidy), environmental selection pressures on phenotypes as the mechanism for natural selection, gene flow, and genetic drift (bottleneck and founder effects), and the biological consequences of such changes in terms of increased or reduced genetic diversity
- processes of evolution including through the action of mutations and different selection pressures on a fragmented population and subsequent isolating mechanisms (allopatric speciation) that prevent gene flow
- the manipulation of gene pools through selective breeding programs

Image: Ian Kennedy/Shutterstock.com

11A MUTATIONS

You share 99.9% of your DNA with every other person in the world. So why do we all look so different? One reason is mutations.



In this lesson you will learn how mutations affect the gene pool. To do this, you will explore point, frameshift, block, and chromosomal mutations and their respective consequences.

Study design dot point

- the qualitative treatment of the causes of changing allele frequencies in a population's gene pool including types of mutations (point, frameshift, block) as a source of new alleles, chromosomal abnormalities (aneuploidy and polyploidy), environmental selection pressures on phenotypes as the mechanism for natural selection, gene flow, and genetic drift (bottleneck and founder effects), and the biological consequences of such changes in terms of increased or reduced genetic diversity

Key knowledge units

Point, frameshift, and block mutations (Types of mutations)	4.1.1.1.1
Chromosomal abnormalities (Types of mutations)	4.1.1.1.2
The effect of mutations on allele frequencies	4.1.1.2

Point, frameshift, and block mutations 4.1.1.1.1

OVERVIEW

Mutations are responsible for introducing new alleles into a population via changes to the DNA. There are three types of mutations: point, frameshift, and block mutations. These involve the substitution, addition, or deletion of bases or blocks of DNA.

THEORY DETAILS

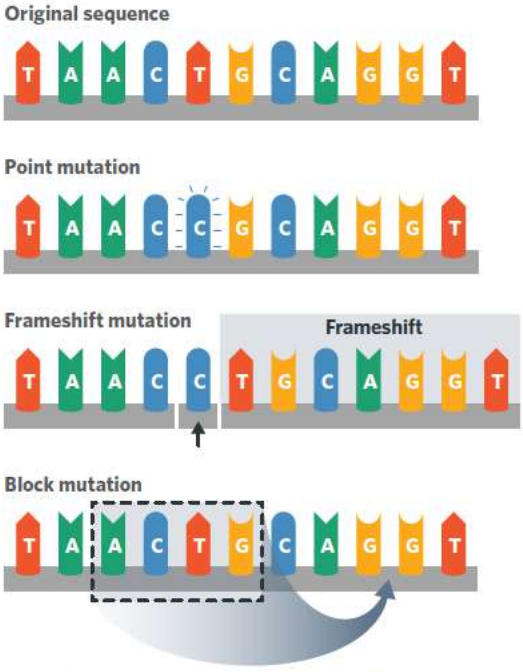


Figure 1 The three types of mutations that affect genes

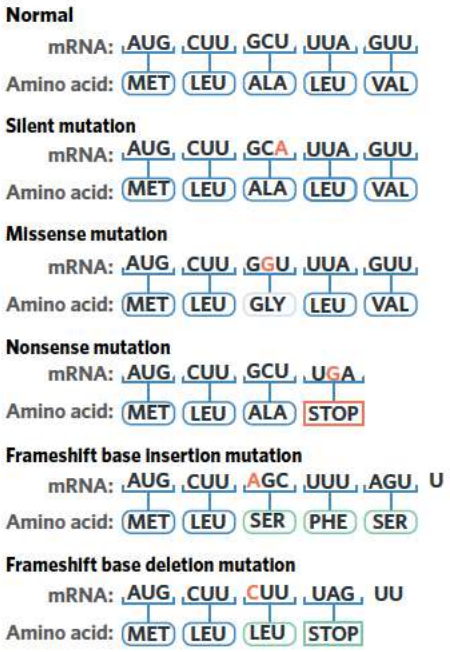


Figure 2 Different point and frameshift mutations in the DNA, and their subsequent effects on the mRNA and polypeptide chain

Point mutations

Point mutations describe changes to one nucleotide in a gene. These modifications can include the substitution of a base which can be further broken down into silent, missense, and **nonsense mutations** depending on their effect. Technically, the addition or deletion of a single nucleotide is also a point mutation, however, this is better described as a frameshift mutation (explained later in the lesson).

Silent substitution mutations

Silent mutations occur all the time but have very little effect. This is because most amino acids are encoded by multiple codons (you should remember from Unit 3 that this is called redundancy in the genetic code). Essentially, silent mutations occur when a nucleotide substitution changes the codon, but has no effect on the corresponding amino acid and causes no change to the polypeptide.

Missense substitution mutations

Missense mutations involve substituting a nucleotide which results in the substitution of a corresponding amino acid, altering the primary structure of the polypeptide. This in turn affects the folding of the polypeptide and could affect the function of the entire protein.

point mutation a mutation that alters one nucleotide

nonsense mutation a mutation in which a nucleotide is substituted for another, changing the codon to a stop codon, ceasing transcription on the gene. Therefore, there is an effect on protein structure

silent mutation a mutation in which a nucleotide is substituted for another, changing the codon, while coding for the same amino acid. Therefore, there is no effect on protein structure

missense mutation a mutation in which a nucleotide is substituted for another, changing the codon and coding for a different amino acid. Therefore, there is an effect on protein structure

Memory device An easy way to remember the three types of point mutations is that silence does no harm, missense causes mischief and nonsense causes no function.

Case study

Sickle cell anaemia is a genetic disease that causes a deformity in red blood cells. Whilst normal red blood cells take a flattened disk-like shape, sickle cells are shaped like crescents, increasing their length and decreasing their width (Figure 3).

Red blood cells are responsible for carrying oxygen to the cells in the body. Due to reduced total volume and surface area, sickle cells are unable to carry oxygen as efficiently as normal red blood cells. Additionally, the sickle cell shape causes the cell to get caught in the capillaries, reducing total blood flow.

Sickle cell anaemia arose through a single missense substitution mutation (Figure 4).

Figure 3 An image displaying normal and sickle red blood cells

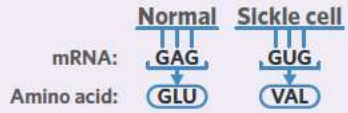


Figure 4 The missense mutation that causes sickle cell anaemia

Nonsense substitution mutations

Nonsense mutations are generally considered the most dangerous substitution mutation, as they prematurely end the transcription of a gene. Nonsense mutations occur by substituting a nucleotide that causes the affected codon to become a stop codon. Therefore, the gene will not be completely transcribed, resulting in a polypeptide that is too short to function as intended.

Frameshift mutations

Frameshift mutations involve the addition or deletion of one or two nucleotides, which alters the **reading frame** of all the following nucleotides. The reading frame is how DNA or RNA is divided into triplets or codons respectively. Since the reading frame is shifted in frameshift mutations, all following amino acids are affected and can cause major disruptions to the structure and function of a protein.

Figure 5 Frameshift mutations change the reading frames. The possible reading frames are demonstrated by the blue, red, and green lines. If the first A in the gene above was deleted, the reading frame would shift from blue to red.

Frameshift mutations are either **base insertion mutations** or **base deletion mutations** and can both involve one or two nucleotides (Figure 2).

frameshift mutations a mutation that involves the insertion or deletion of one or two nucleotides, affecting every codon from that point forward

reading frame the order in which nucleotide triplets or codons are divided into a consecutive, non-overlapping sequence

base insertion mutation when a nucleotide is added to a gene, affecting every codon from that point forward

base deletion mutation when a nucleotide is removed from a gene, affecting every codon from that point forward

Tip Singular nucleotide frameshift mutations can be considered point mutations, whereas frameshift mutations that involve adding or removing two nucleotides cannot.

Block mutations

Block mutations involve altering the structure of a chromosome by inserting, deleting, or swapping a cluster of nucleotides, potentially involving multiple genes. These mutations usually occur during the process of meiosis.

The four types of block mutations include:

1. Deletion mutation – when a section of DNA is removed from a chromosome, shortening the DNA.
2. Duplication mutation – when a section of DNA is replicated, lengthening the DNA.
3. Inversion mutation – when a section of DNA has its sequence reversed.
4. Translocation mutation – when two sections of DNA on different chromosomes switch places.

block mutations a mutation that affects a large chunk of DNA, or an entire gene

aneuploidy when a cell or organism varies in the usual number of chromosomes in its genome by the addition or loss of a chromosome

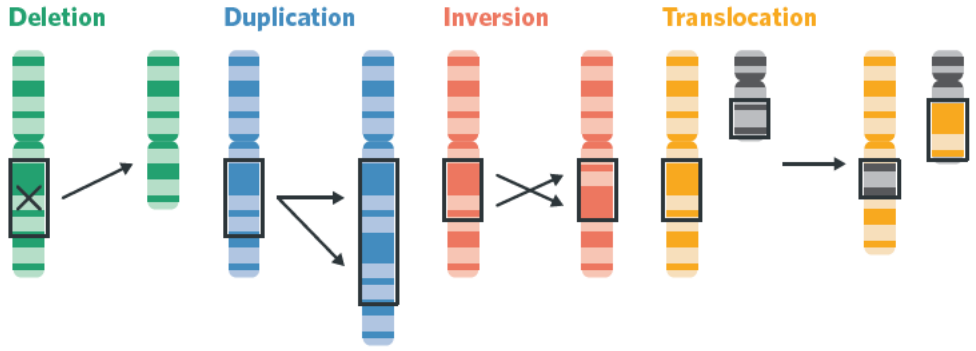


Figure 6 A diagram that summarises the types of block mutations

Chromosomal abnormalities 4.1.1.1.2

OVERVIEW

Genomes can also change by losing or gaining a chromosome or sets of chromosomes. These mutations are known as chromosomal abnormalities and can be further categorised as aneuploidy or polyploidy.

THEORY DETAILS

Aneuploidy

Aneuploidy is a condition that describes the absence of a chromosome or the presence of an additional chromosome. These mutations can be seen in an individual's karyotype and usually stem from issues during meiosis.

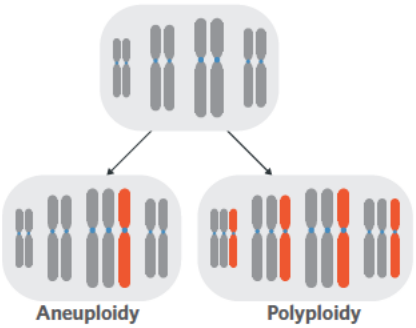


Figure 7 Aneuploidy and polyploidy mutations

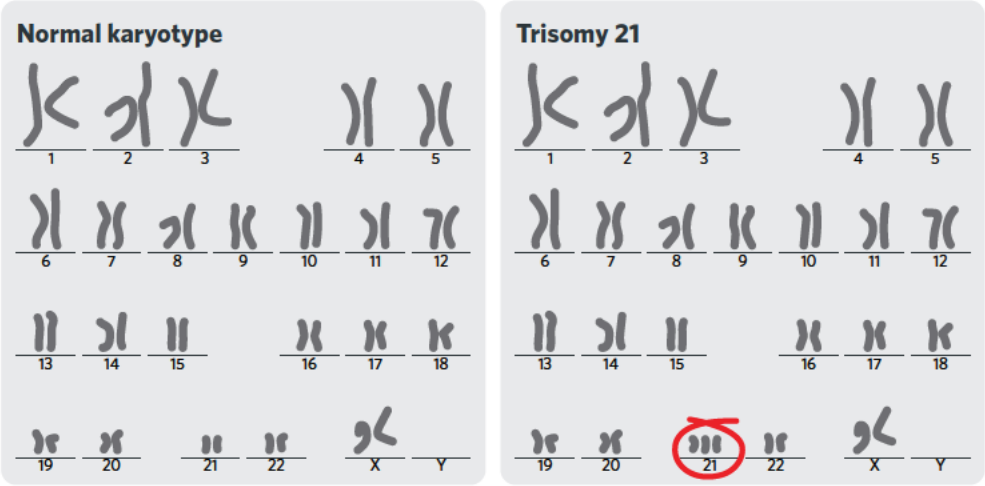


Figure 8 A comparison between a normal karyotype and a sufferer of Down syndrome

Table 1 A table of different aneuploidy conditions

Condition	Mutation	Incidence rate (approx.)	Common symptoms
Down syndrome	Trisomy 21	1 : 1000	Decreased muscle tone, short neck, flattened facial profile and upward slanting eyes
Edwards syndrome	Trisomy 18	1 : 2500	Very small weight, small head, long and underdeveloped fingers
Klinefelter syndrome	XXY	1 : 650	Typically tall, infertile, enlarged breast tissue. Only affects phenotypic males
Turner syndrome	X0	1 : 2000	Typically infertile, short height and fused neck and head. Only affects phenotypic females

Polyploidy

Polyploidy is the condition where an individual has more than two sets of chromosomes. Humans, like most eukaryotes, are diploid (2n). For us, an additional set of chromosomes in an embryo is fatal. Likewise, humans cannot survive as haploid (n) organisms.

polyploidy when an organism contains additional sets of each chromosome in its genome.

It is quite common for other organisms, such as plants, to thrive with additional sets of chromosomes. Some advantages of this include increased size and hardness in fruit. However, these individuals are usually unable to reproduce sexually.

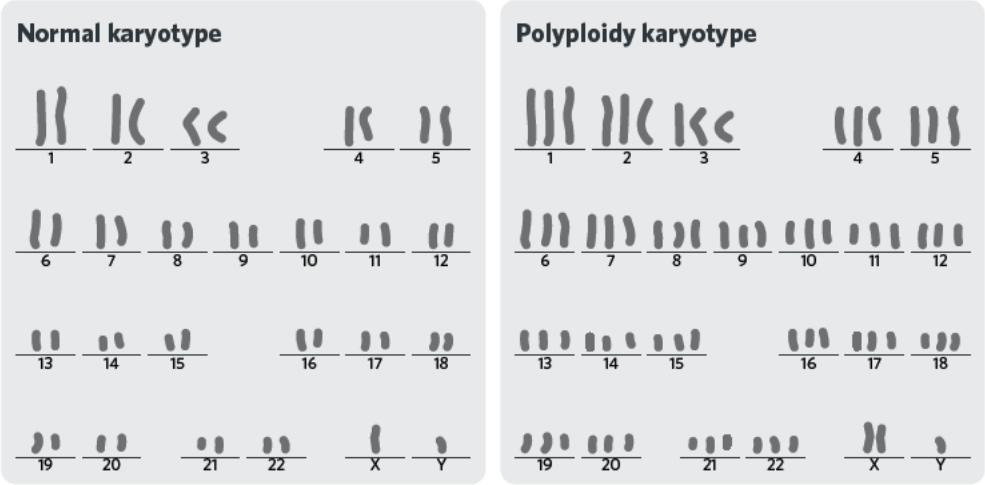


Figure 9 A comparison between a normal karyotype and polyploidy karyotype

The effect of mutations on allele frequencies 4.1.1.2

OVERVIEW

Mutations introduce new alleles into a population and this increases genetic diversity.

THEORY DETAILS

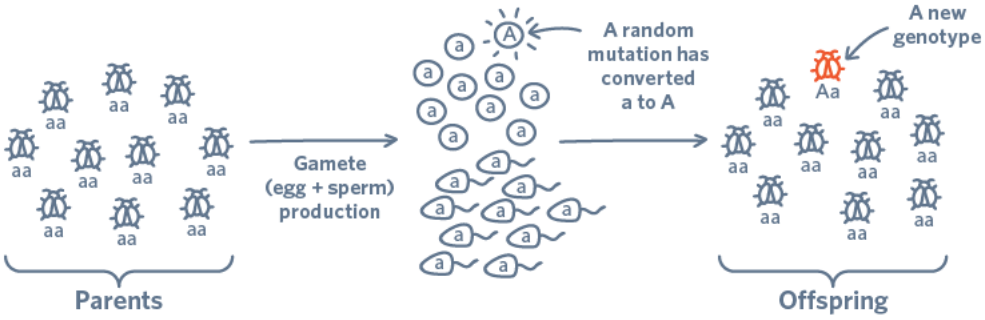


Figure 10 The effect of a single mutation on the gene pool

Mutations to DNA can be induced by an agent known as a **mutagen**. An example of a mutagen is UV radiation, which causes mutations in skin cells that can lead to cancer. Mutations can also be spontaneous and unexplainable. A mutation can be categorised as beneficial, neutral, or **deleterious**, depending on the mutation's overall effect on individual fitness.

Figure 10 shows how a mutation in a single beetle can create a completely new **allele** in a population. For this to occur, the mutation must occur in an individual's **germline cells** (or gametes). If a mutation is not heritable, it has occurred in a **somatic cell** (cells that cannot undergo meiosis). Therefore, somatic mutations are not passed down to future offspring.

Theory summary

Mutations can be as small as the substitution of a base or as large as the addition of an entire set of chromosomes. However, they both share the similarity of increasing the genetic variation in a population. Mutations are a key source of genetic variation and are an important process in evolution.

mutagens agents that can cause mutations in DNA

deleterious alleles that have an overall negative effect on individual fitness when expressed

alleles variants of a gene

allele frequency the proportion of certain alleles in a gene pool

gene pool all the genes in a population

germline cell cells involved in the generation of gametes in eukaryotes

phenotype the physical or biochemical characteristics of an organism, resulting from expression of a gene (or set of genes) and interaction with the environment

somatic cell any cell in an organism that is not a germline cell

11A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ is a type of mutation that involves changing one nucleotide for another

b _____ the addition of a single nucleotide

c _____ different variations of a gene

d _____ having extra sets of chromosomes

e _____ a physical or chemical substance that can encourage a mutation to occur

f _____ when a nucleotide change results in a codon corresponding to a different amino acid

g _____ a mutation that can involve an entire gene or parts of a gene

h _____ a cell that will undergo meiosis

i _____ missing a single chromosome

Question 2

Which of the following is false?

A Nonsense mutations result in the affected codon becoming a stop codon.

B Missense mutations result in the affected codon coding for a different amino acid.

C Silent mutations result in the affected codon coding for the same amino acid.

D Point mutations involve the substitution or addition of multiple nucleotides.

Question 3

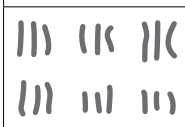
Complete the following table.

Normal DNA	5′-G-A-T-A-C-T-C-A-G-T-3′
X	5′-G-**C-T-C-A-G-T**-A-T-A-3′
Point mutation in DNA	**Y**
Z	5′-G-A-**T**-T-A-C-T-C-A-G-T-3′

	X	Y	Z
A	Frameshift mutation	5′-G-A-T-A-C-**A-**C-A-G-T-3′	Block mutation
B	Missense mutation	5′-G-A-T-A-C-**U-**C-A-G-T-3′	Frameshift mutation
C	Block mutation	5′-G-A-T-A-C-**A-**C-A-G-T-3′	Frameshift mutation
D	Nonsense mutation	5′-G-A-T-A-C-**U-**C-A-G-T-3′	Block mutation

Question 4

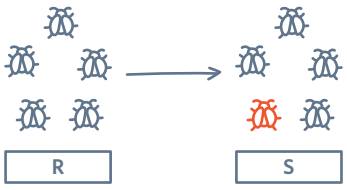
Complete the following table.

K	L	M
		

	K	L	M
A	Diploid	Polyploid	Triploid
B	Triploid	Diploid	Haploid
C	Polyploid	Diploid	Aneuploid
D	Aneuploid	Polyploid	Diploid

Question 5

Fill in the blanks.



	R	S
A	Lower genetic diversity	Higher genetic diversity
B	Higher genetic diversity	Lower genetic diversity
C	Same genetic diversity	Same genetic diversity
D	Different species	Different species

Question 6

Which of the following are all true about mutations?

A	Mutations assist in increasing genetic diversity	By changing the genetic code, the phenotype of individuals change	Mutations in somatic cells will be passed down to future offspring	Mutagens cause mutations
B	By changing the genetic code, the phenotype of individuals change	Mutagens help prevent mutations from occurring	Aneuploid individuals are either missing or have an additional chromosome	Missense mutations create STOP codons
C	Mutations in germline cells will be passed down to future offspring	Missense mutations code for a different amino acid	Mutations assist in decreasing genetic diversity	Mutagens help prevent mutations from occurring
D	Aneuploid individuals are either missing or have an additional chromosome	Mutations in germline cells will be passed down to future offspring	Missense mutations code for a different amino acid	Mutations assist in increasing genetic diversity

Question 7

Classify the following either as point, frameshift, block, or chromosomal mutations.

I The substitution of a nucleotide for another without changing the corresponding amino acid.

II The removal of a singular nucleotide.

III The deletion of multiple codons.

IV The duplication of an entire set of chromosomes.

V The deletion of an entire gene.

VI Mutating a codon to become a stop codon early in the chain without adding or deleting any nucleotides.

VII The relocation of a gene to a different chromosome.

VIII Having an additional chromosome 21.

IX A mutation that affects the reading frame.

	Point mutations	**Frameshift mutations**	**Block mutations**	**Chromosomal abnormalities**
A	I, II, VI, IX	II, III	V	IV, VII, VIII
B	I, II, VI	II, IX	III, V, VII	IV, VIII
C	I, II	II, III, VI	V, VII, IX	IV, VIII
D	I, II, VI	II, III, IX	V, VII, VIII	IV

Exam-style questions

Within lesson

Question 8 (1 MARK)

Sufferers of Down syndrome are aneuploid.

This means that their cells have

A multiple extra sets of chromosomes.

B one extra set of chromosomes.

C an additional singular chromosome.

D multiple nuclei.

Adapted from VCAA 2017 Sample Section A Q24

Question 9 (1 MARK)

The following information shows the chromosome number in root tip cells from a range of plants.

Species	Common name	Chromosome number
Arabis holboellii	Rockcress	14 or 21 or 28
Nasturtium spp.	Flowery peppery goodness	32 or 64
Vitis vinifera	Common grapevine	38 or 57 or 76
Viola spp.	Violets	12 or 24 or 36 or 48

Each species has been affected by which type of mutation?

A Aneuploidy
B Polyploidy
C Block mutation
D Random Chromosome Number Disease

Adapted from VCAA 2012 Exam 2 Section A Q5

Question 10 (1 MARK)

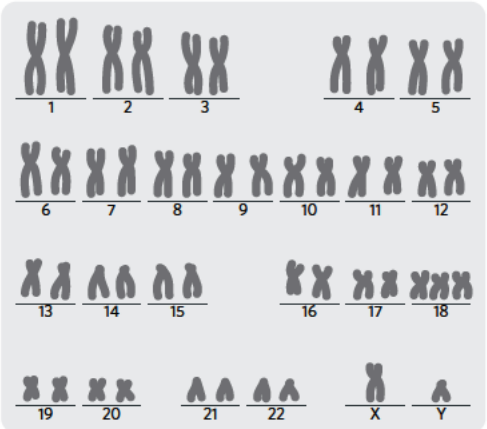
Which of the following does not outline how natural variation can exist between individuals within a population?

A Mutations create new alleles.
B Different allele combinations arise in sexual reproduction.
C Individuals adapt their DNA to an environmental pressure.
D Changes in chromosome number may change phenotypes.

Adapted from VCAA 2018 Section B Q7a

Question 11 (3 MARKS)

The karyotype shows a sufferer of Edwards syndrome.



Newborn babies that suffer from Edwards syndrome rarely survive longer than 12 months. This occurs from mistakes in the formation of the egg or sperm and results in difficulties in feeding and breathing, as well as abnormal amounts of growth.

a From the information, what issue occurs in the genome to cause Edwards syndrome? (1 MARK)

b Name the type of chromosomal abnormality and briefly explain how this might have occurred. (2 MARKS)

Adapted from VCAA 2014 Section B Q9b

Question 12 (4 MARKS)

Second letter

First letter	U	C	A	G	Third letter
U	UUU, UUC: phe UUA, UUG: leu	UCU, UCC, UCA, UCG: ser	UAU, UAC: tyr UAA: STOP UAG: STOP	UGU, UGC: cys UGA: STOP UGG: trp	U C A G
C	CUU, CUC, CUA, CUG: leu	CCU, CCC, CCA, CCG: pro	CAU, CAC: his CAA, CAG: gln	CGU, CGC, CGA, CGG: arg	U C A G
A	AUU, AUC, AUA: ile AUG: met	ACU, ACC, ACA, ACG: thr	AAU, AAC: asn AAA, AAG: lys	AGU, AGC: ser AGA, AGG: arg	U C A G
G	GUU, GUC, GUA, GUG: val	GCU, GCC, GCA, GCG: ala	GAU, GAC: asp GAA, GAG: glu	GGU, GGC, GGA, GGG: gly	U C A G

Consider the following sequence of six amino acids that make up part of a polypeptide.

------ [val] ------ [lys] ------ [gly] ------ [arg] ------ [val] ------ [leu] ------

A mutation within the gene coding for this sequence of six amino acids resulted in the following six amino acids in the same position

------ [val] ------ [lys] ------ [gly] ------ [arg] ------ [ala] ------ [leu] ------

a Explain how a mutation caused this change in amino acid sequence. (2 MARKS)

b Explain the consequences if a nucleotide in the *lys* codon was removed. How would this affect the overall structure of the protein? (2 MARKS)

Adapted from VCAA 2018 Section A Q20 and Q21

Multiple lessons

Question 13 (1 MARK)

A repressor molecule is unable to bind to the operator region of the *lac* operon due to a mutation. Identify where the mutation could occur.

A Regulatory gene

B Promoter region

C *lacZ* structural gene

D *lacY* structural gene

Question 14 (3 MARKS)

In populations of fruit flies, there are individuals that are resistant to the effects of insecticides. Insecticide-resistant fruit flies arose as a result of a mutation. In normal insecticide-susceptible fruit flies, a specific section of mRNA has the corresponding anticodon CGA, whereas in the insecticide-resistant fruit flies, the sequence is AGA which codes for a different amino acid.

a Considering the anticodon of the insecticide-resistant fruit flies, what is the corresponding sequence of nucleotides on the individual's DNA? (1 MARK)

b Identify the type of point mutation that has occurred in the fruit flies' DNA and suggest which type of cells it occurred in. (2 MARKS)

Adapted from VCAA 2014 Section A Q22

Question 15 (4 MARKS)

Consider the template strand of a hypothetical gene, shown. The exons are in bold type.

3′ **TAC GTA** CCG **AAA TAC GTT** CTT GAC **TAT ATC** 5′

The DNA triplet TAC indicates START and codes for the amino acid methionine that remains in the polypeptide. The DNA triplets ATC, ATT and ACT code for a STOP instruction.

a Outline the sequence of the transcribed pre-mRNA that is corresponding to the template strand. Write pre-mRNA from 5′ to 3′. (1 MARK)

b How many amino acids would be present in the polypeptide expressed by this gene? (1 MARK)

c An allele for this gene codes for a polypeptide with only four amino acids. This is caused by a mutation in one of the exons. This mutation is a result of one nucleotide change. By referring to the original sequence, identify the nucleotide change that must have occurred to bring about this shorter polypeptide. Justify your answer. (2 MARKS)

Adapted from VCAA 2015 Section B Q8a

Key science skills

Question 16 (6 MARKS)

Scientists are exploring the effects of different strengths of UV radiation on mice. Cancer can be caused by mutations in the tumour suppressor gene which is responsible for slowing the rate of cell division and repairing DNA errors to prevent tumours from forming. To measure the effect of each radiation level, scientists measured the number of mutations in the tumour suppressor gene of skin cells in each mouse.

a What are the independent and dependent variables in the experiment? (2 MARKS)

b State a hypothesis for this experiment. (1 MARK)

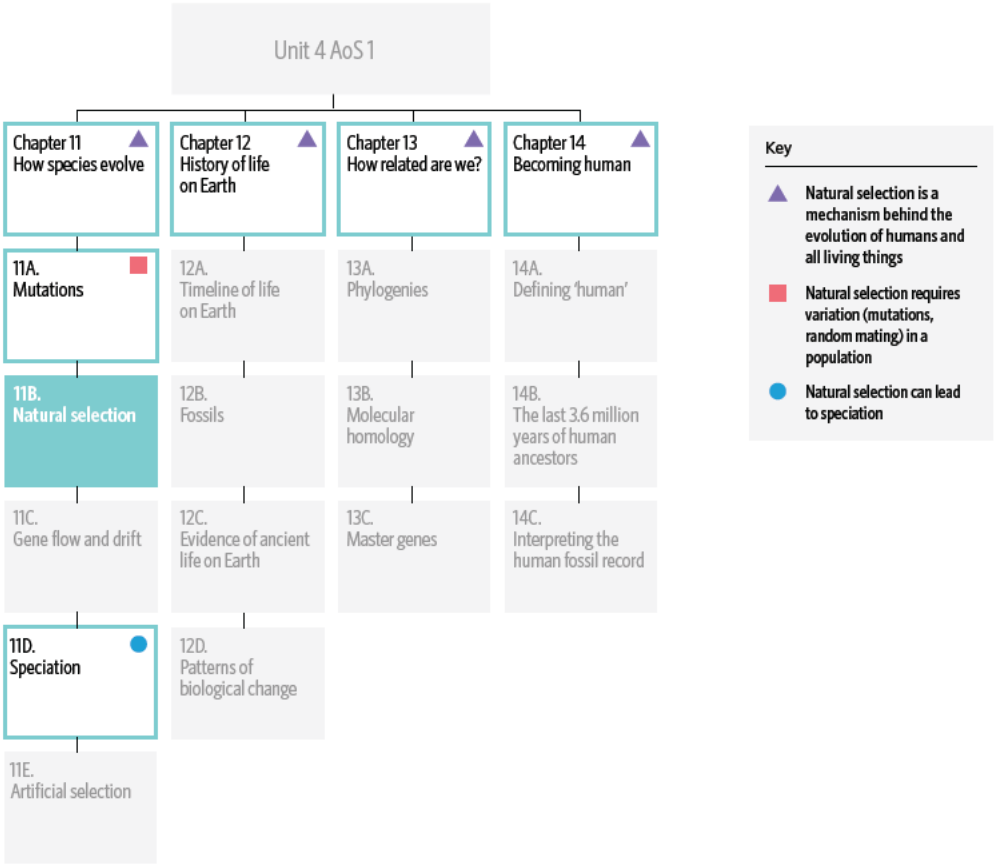
c What is the general term for substances, such as UV radiation, that cause mutations? (1 MARK)

d Identify **one** possible uncontrolled variable in this experiment and explain the potential effect. (2 MARKS)

Adapted from VCAA 2017 Northern Hemisphere Section B Q11b

11B NATURAL SELECTION

In the mid-nineteenth century two naturalists, Charles Darwin and Alfred Russel Wallace, independently conceived and described a mechanism for evolution: natural selection. The process of natural selection helps explain how species, over generations, adapt to their environment.



In this lesson you will learn how species change as they adapt to selection pressures through the process of natural selection.

Study design dot point

- the qualitative treatment of the causes of changing allele frequencies in a population's gene pool including types of mutations (point, frameshift, block) as a source of new alleles, chromosomal abnormalities (aneuploidy and polyploidy), environmental selection pressures on phenotypes as the mechanism for natural selection, gene flow, and genetic drift (bottleneck and founder effects), and the biological consequences of such changes in terms of increased or reduced genetic diversity

Key knowledge units

Natural selection	4.1.1.3
The effect of natural selection on allele frequencies	4.1.1.4

Natural selection 4.1.1.3

OVERVIEW

Natural selection is a mechanism for evolution in which the individuals best adapted to the selection pressures in their environment survive and pass on their alleles.

THEORY DETAILS

Natural selection occurs via the following steps:

1. There is physical, biochemical, or behavioural variation in phenotypes between individuals in a **population**.
2. This variation is **heritable**.
3. A specific selection pressure exists that causes a **struggle** for survival. Some individuals survive and reproduce better, as they have an **advantageous phenotype** that helps them overcome the selection pressure.
4. Organisms with the 'fitter' - or advantageous - phenotype pass their alleles onto the next generation. This changes the **allele frequencies** in the population as the trait becomes more common.

An overview of natural selection can be summarised in Table 1, using the peppered moth case study as an example.

Figure 1 Peppered moths

population a group of organisms of the same species living in the same area

heritable transmissible from parent to offspring (i.e. encoded in genes)

struggle (for survival) the battle for organisms to survive and reproduce in their environment, caused by selection pressures and limited resources

advantageous phenotype a biochemical, physical, or behavioural trait that increases an individual's fitness in its local environment

allele frequency the proportion of certain alleles in a gene pool

disadvantageous phenotype a biochemical, physical, or behavioural trait that lowers an individual's fitness in its local environment

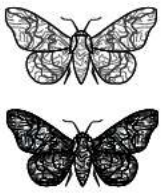
offspring children of a parent

competition an interaction between organisms in which both are harmed when trying to use the same limited resource. Can exist within or between species

fitness a measure of how well an organism survives and reproduces in its environment

gene a section of DNA that carries the code to make a protein

Table 1 Summary of the process of natural selection, using the example of peppered moths

Requirement for natural selection	What this means	Example - image	Example – explanation
1 Variation	Individuals in a population vary genetically. This leads to phenotypic differences.		One species of moth has two genetic variants: black and white.
2 Heritability	These traits - whether advantageous or **disadvantageous** for survival and reproduction - can be passed on from parents to **offspring**.		Body colour is heritable - parents with white body colour are likely to have offspring with white body colour, while parents with black body colour are likely to have offspring with black body colour.
3 Selection pressure and struggle	The struggle is caused by a selection pressure. That is, a factor that impacts an organism's ability to reproduce and survive. For example, environmental (e.g. predation, temperature increase, limited resources) or population factors (e.g. excess offspring and high **competition**)		The industrial revolution occurs, and there is an increase of soot in the air. This settles on trees, making the trees black. White moths become very visible, so birds prey heavily on white moths. The birds determine who lives and who dies, so the birds are the selection pressure.
4 Fitness	Individuals with phenotypes that make them fitter under the local selection pressures reproduce more successfully, and pass on the **genes** for the advantageous traits to their offspring.		The frequency of the allele for the black phenotype increases in the population, as they are camouflaged from predators. The frequency of the allele for the white phenotype decreases.

Case study

Charles Darwin was one of the key scientists behind the theory of evolution by natural selection – and there are often VCE exam questions that ask students to apply their knowledge to his studies. In 1835 on the Galápagos Islands west of Ecuador, Darwin observed that ground finches comprised several species, each with a unique beak shape. He noticed that these finches closely resembled another finch species on the South American mainland.

Darwin imagined that the island species might be descendants of the original mainland species. Upon further study, he realised that each finch's varied beak shape helped the birds acquire a specific type of food. For example, seed-eating finches had stronger, thicker beaks for breaking seeds, and insect-eating finches had spear-like beaks for stabbing their prey.

Darwin realised that natural selection had occurred, and that the selection pressure driving change in phenotype was food type.

1. Variation: there was variation in beak shape among the ancestral population of mainland finches.
2. Heritability: this variation was heritable.

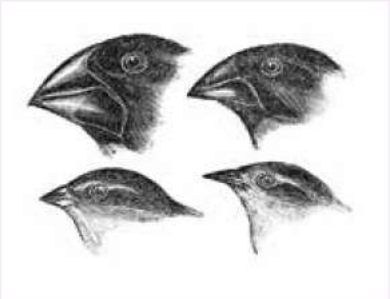


Figure 2 Finches from the Galápagos Archipelago

3. Struggle: upon migration to the Galápagos Islands, the food available for the finches (the selection pressure) was different compared to the mainland, and even different between islands. Some finches with specific beak shapes were better at effectively finding and consuming Galápagos Island food types.
4. Fitness: the finches that had beak shapes that could most effectively consume the available food survived and reproduced more successfully. Their offspring inherited the parents' beak shape, and over generations separate species with beak shapes specialised to the food type on their island evolved.

Case study

Cane toads are an invasive pest in Australia. They are poisonous, and most native animals that eat cane toads die. However, research by Ben Phillips from the University of Melbourne suggests that the red-bellied black snake has evolved to deal with cane toads. Compared to red-bellied black snakes that live in uninfested areas, red bellies that live in Queensland alongside cane toads are longer, rarely eat the toads, and if they do eat them they are less impacted by the poison.

1. Variation: there is variation in red-bellied black snake length and behavioural response to cane toads and in their susceptibility to toad poison.
2. Heritability: this variation is heritable.
3. Struggle: the cane toads provide the selection pressure that causes a struggle for survival among red-bellied black snakes.
4. Fitness: snakes that avoid eating the toads, or are less affected by their poison, survive and produce more offspring. These advantageous traits are passed onto the next generation.

Tip Students can struggle to answer short answer questions on natural selection. The trick is that most questions are just asking you to explain the process of natural selection in the given scenario. Start by saying which trait is 1) variable, stating that this trait is 2) heritable, identifying the 3) selection pressure and explaining how this affects 4) fitness and phenotype of individuals over generations.

The effect of natural selection on allele frequencies 4.1.1.4

OVERVIEW

Natural selection can reduce the genetic diversity in a gene pool as only the fittest individuals with alleles that code for advantageous phenotypes survive and reproduce.

THEORY DETAILS

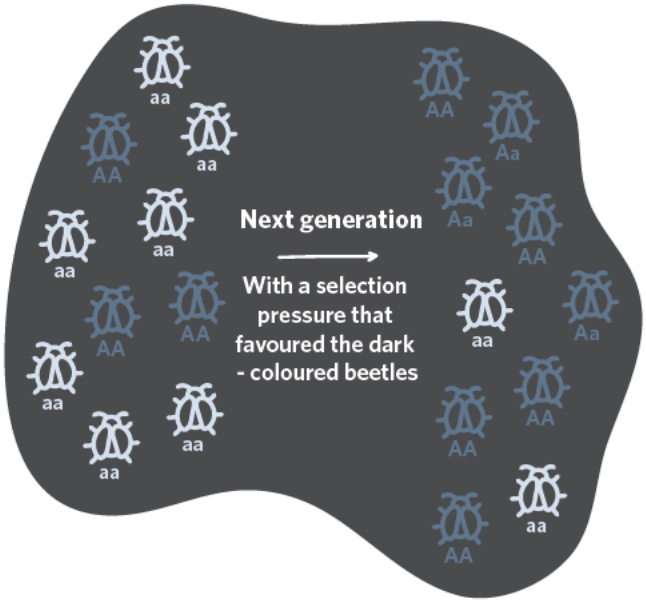


Figure 3 The change in allele frequencies of a beetle population affected by natural selection

Ultimately, **natural selection** drives the adaptation of a population to its local **selection pressures**. It is important to note that:

- The selection pressure determines which phenotypes make organisms 'fitter' and, consequently, which traits will be better represented in the next generation.
  - For example, in plants, if light is limited larger leaves may be selected for over smaller leaves as large-leaved plants can absorb more light. However, if herbivory imposes a greater pressure, plants with spiky, unpalatable leaves may become more common.
- As advantageous traits become more common in the population, the genetic makeup (or allele frequencies) of the population also changes. Therefore, **evolution** occurs.
  - The alleles that code for advantageous traits will become more common, whilst the alleles that code for disadvantageous traits will become less frequent.
- Species with large amounts of **genetic variation** are less likely to go extinct.
  - This is because a species with more variation in alleles has a higher chance of possessing a favourable genetic trait that will help it survive if a new selection pressure arises.
  - A good example of this is disease resistance. Populations with more diverse gene pools also have greater diversity in their immune systems. This generally makes them more tolerant of individual disease outbreaks.
  - Low genetic variation can also cause problems for species, as inbreeding is more likely to occur. Inbreeding can lead to a high prevalence of disadvantageous alleles.
  - Small populations are more likely to have low genetic variation than large populations, so small populations have a higher risk of extinction.

natural selection organisms that are better adapted to their local environmental selection pressures are more likely to survive and pass on their genes

selection pressure a factor in the environment (e.g. limited resources, deforestation, changing temperature, predation) that impacts an individual's ability to survive and reproduce. It causes a struggle for survival

evolution the change in the genetic makeup of a population over successive generations

genetic variation the differences in DNA sequences between individuals

Theory summary

Natural selection is a mechanism for evolution in which individuals best adapted to their environment are more reproductively successful and pass on their genes. The selection pressure determines which phenotype makes organisms fitter. As the fit trait becomes more common in the population, the allele frequencies in the population change.

11B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the environmental factor that is limited or changing that means some organisms in a population are fitter than others

b _____ the measure that represents how well you survive and reproduce

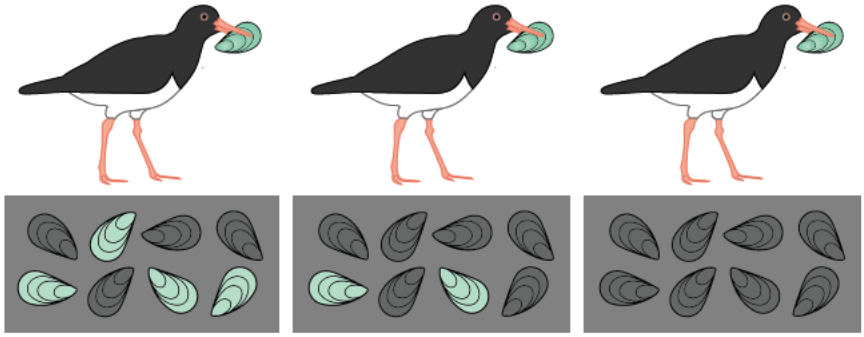
c _____ the set of characteristics of an individual resulting from the interaction of its genotype with the environment

d _____ differences in genetic information between individuals

e _____ competition between organisms for resources

Question 2

In the image, identify the selection pressure, the population that selection is acting against, the advantageous phenotype, and the trait that is heritable.



Generations later...

	Selection pressure	Population that selection is acting against	Advantageous phenotype	Heritable gene
A	Lack of shelter	The mollusc population	Green shell	Grey shell
B	Being a green mollusc	The green individuals in the mollusc population	Grey shell	Green shell
C	Oyster catcher	The grey individuals in the mollusc population	Grey shell	Grey shell
D	Predators	The mollusc population	Grey shell	Colour of shell

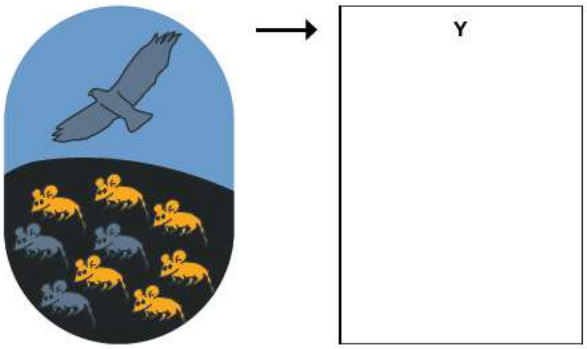
Question 3

What belongs in the spaces W, X, Y, and Z in the table?

Step in natural selection	What this means
1 Variation	**W**
2 **X**	These traits - whether advantageous or disadvantageous for survival or reproduction – can be passed on from parents to offspring.
3 Struggle	**Y**
4 **Z**	Individuals with phenotypes that make them fitter under local selection pressures have more offspring and pass on the genes for the advantageous traits.

	W	X	Y	Z
A	There is a struggle for survival, with some variants more successful	Variation	Only the fittest organisms survive and pass on their traits	Some individuals are fitter than others
B	There are differences between individuals in a population	Heritable	Selection pressures lead to individuals battling to survive	Fitness
C	Traits can be passed on from parent to offspring.	Selection pressure	External factors that affect an organism's ability to reproduce and survive mean some organisms are fitter than others	Heritable
D	Individuals in a population are different genetically and phenotypically	Heritable	External factors that affect an organism's ability to reproduce and survive mean some organisms are fitter than others	Organisms with adventurous traits have more offspring

Question 4



Identify which image resembles Y according to the theory of natural selection. Note the grey mice are harder for the birds to see.

A


B


C


D


Question 5

Which of the following is false?

A Only small populations have low genetic diversity.

B Advantageous alleles increase genetic fitness.

C A selection pressure acts upon a population, increasing the difficulty of survival.

D For natural selection to occur, advantageous traits must be hereditary.

Exam-style questions

Within lesson

Question 6 (1 MARK)

In 1954, copper waste in the Finniss River killed numerous fish. This caused various species in the area to die out. However, one species, the black-banded rainbow fish, increased in numbers. The black-banded rainbow fish have modified gills that enable the fish to filter and remove the copper before it enters their body.

With respect to the black-banded rainbow fish it is reasonable to conclude that

A there was more genetic variation in the black-banded rainbow fish population than in the populations of other fish species.

B the copper in the river caused a mutation in the black-banded rainbow fish that helped them survive.

C the ability of black-banded rainbow fish gills to remove copper already existed in 1954.

D the populations of other fish in the river were small even before the copper waste spill.

Question 7 (1 MARK)

The 200th anniversary of the birth of Charles Darwin was celebrated in 2009. In the development of his ideas on evolution, Darwin did not propose that

A all members of a species have an equal chance of survival.

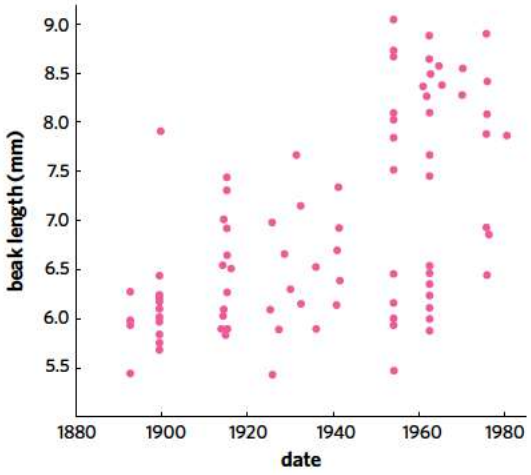
B individuals in a population have different chances of reproductive success.

C offspring look more like their parents than they do unrelated individuals of the same species.

D selection pressures determine advantageous phenotypes.

Question 8 (1 MARK)

The soapberry bug *(Jadera haematoloma)* uses its long beak to penetrate the fleshy fruit of plants to feed on the seeds at the centre. The bug feeds on the native soapberry tree. The bug also feeds on the fruit of the introduced golden rain tree. Investigators measured the average beak length of the soapberry bug over eighty years. The results are shown in the graph.



From this information it would be reasonable to conclude that

A the diameter of the golden rain tree seed acted as a selection pressure on beak length.

B the population of soapberry bugs increased over the eighty years.

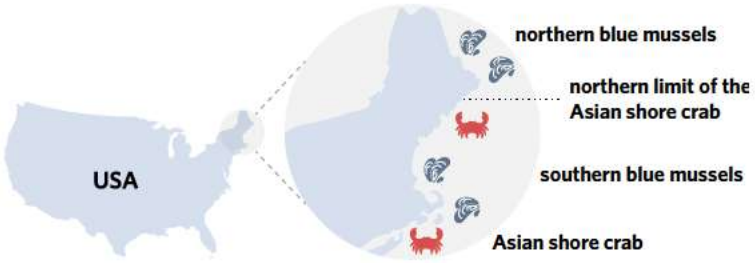
C the response of the soapberry tree to predation by soapberry bugs was to grow harder fruit.

D soapberry bugs with longer beaks survive and reproduce more than soapberry bugs with shorter beaks.

Adapted from VCAA 2011 Exam 2 Section B Q19

Question 9 (5 MARKS)

The blue mussel, *Mytilus edulis*, lives along the northeastern coastline of the USA. A species of Asian shore crab, *Hemigrapsus sanguineus*, was accidentally introduced into the area about 15 years ago. As shown in the image, the Asian shore crab has only migrated to the southern half of the total area inhabited by the blue mussel.



The Asian shore crab feeds off the blue mussels. The thinner the mussel shell, the easier it is for the crab to crush and eat the mussel. In recent times, scientists have observed that the overall population of the southern blue mussel has a thicker shell than that of the northern blue mussel. This contrasts with 15 years earlier when there was no difference in the range of shell thickness in northern and southern blue mussel populations.

a Explain how the population of southern blue mussels has developed thicker shells. (3 MARKS)

b Assume that the Asian shore crab migrates past the northern limit line into the northern blue mussel area. What would you expect to happen to the shell thickness of the northern blue mussels over time? Explain your reasoning. (2 MARKS)

Adapted from VCAA 2010 Exam 2 Section B Q4

Multiple lessons

Question 10 (1 MARK)

Nearly one million people die every year from bacterial infections that cannot be treated with antibiotics because the bacteria have changed in a way that prevents the antibiotic from working. The rise in incidence of antibiotic-resistant bacteria is due to

A these bacteria having acquired immunity to antibiotics.

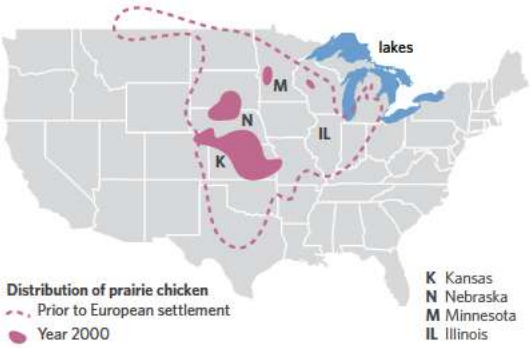
B the overuse of antibiotics causing mutations in bacteria.

C the introduction of selectively bred, antibiotic-resistant bacteria.

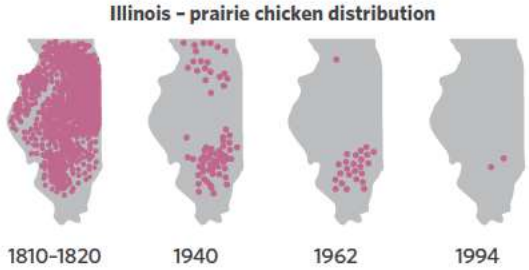
D antibiotic-resistant phenotypes being favoured through natural selection.

Question 11 (10 MARKS)

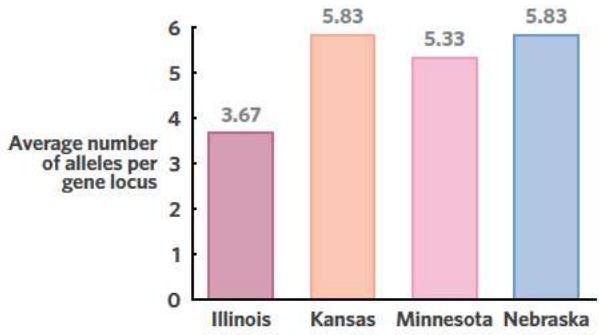
The prairie chicken (*Tympanuchus cupido pinnatus*) is a grassland bird native to North America. A prairie chicken spends its entire life within several kilometres of its birthplace. Prior to European settlement, prairie chickens numbered in the millions across the Midwest of the USA. As a result of the grasslands being replaced by plant food crops, the distribution of the prairie chickens has diminished, as shown in the map.



By 1994, Kansas, Nebraska, and Minnesota still supported large and widespread populations; however, in the state of Illinois, the number of prairie chickens fell to less than fifty individuals located in two separate geographical areas, as shown in the image.



Representative samples of prairie chickens from the four states were selected for testing. Each prairie chicken had six gene loci tested. The average number of alleles at each gene locus for each prairie chicken group is shown in the graph.



a Define allele frequencies. (1 MARK)

b Consider the graph and maps of prairie chicken distribution.

- **i** What do these results mean for the future of the Illinois birds? (2 MARKS)
- **ii** The Illinois and Minnesotan populations are close to each other. Why do they have different average numbers of alleles per gene locus? (1 MARK)

c Measures were taken in the 1990s to prevent the prairie chicken from dying out completely.

- **i** Why were the Illinois prairie chickens at greater risk of extinction compared to the prairie chickens from other states? (2 MARKS)
- **ii** Describe one measure that could be used to increase the average number of alleles per gene locus for Illinois prairie chickens. (1 MARK)

d How might natural selection have prevented prairie chickens from becoming extinct when humans replaced grasslands with food crops? (3 MARKS)

Adapted from VCAA 2011 Exam 2 Section B Q6

Key science skills

Question 12 (9 MARKS)

Menna read that Tasmanian devils are dying much younger than they have historically, due to widespread devil facial tumour disease. Devil facial tumour disease is an infectious cancer spread by biting, and primarily affects adults (> 2 years old). It causes death within months of initial infection.

Menna thought that it was possible that, to counter early death, Tasmanian devils may be becoming sexually mature and reproductively active at a younger age. She compared the age of sexual maturity of Tasmanian Devils in 1983, before the population was infected (n = 87:61 males:females), to the age of sexual maturity of Tasmanian Devils in 2006, after the population was infected (n = 21:33 males:females).

Menna found that the number of females breeding before the age of one increased from 0–12.5 % before the disease entered the population, to 13.3–83.3 % after the disease spread.

a What was Menna's hypothesis? (1 MARK)

b What is meant by 'n = 87:61 males:females'? (1 MARK)

c Identify:

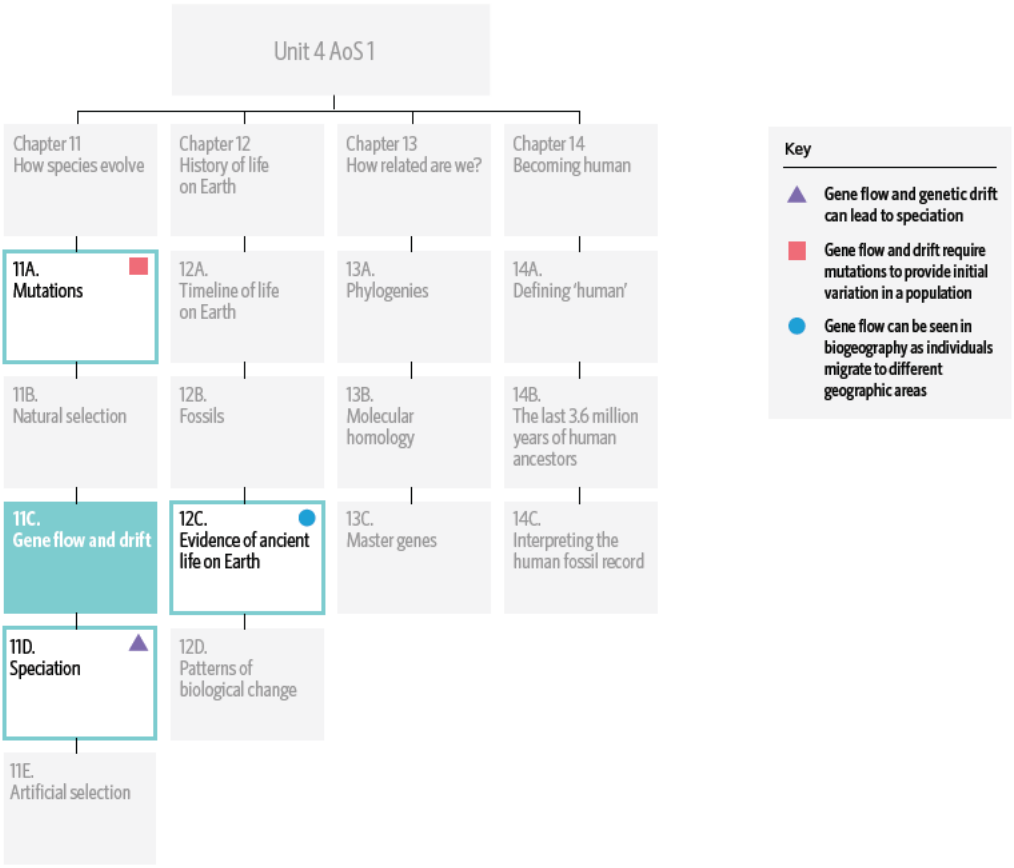
- **i** the independent variable. (1 MARK)
- **ii** the dependent variable. (1 MARK)

d Name two factors that Menna should have controlled and explain how they could have affected the validity of her results. (4 MARKS)

e What conclusion can Menna draw from her results? (1 MARK)

11C GENE FLOW AND DRIFT

Like waves on the ocean, the gene pool is continuously fluctuating due to random genetic drift and migrations.



In this lesson you will learn about the process and consequences of gene flow and genetic drift.

Study design dot point

- the qualitative treatment of the causes of changing allele frequencies in a population's gene pool including types of mutations (point, frameshift, block) as a source of new alleles, chromosomal abnormalities (aneuploidy and polyploidy), environmental selection pressures on phenotypes as the mechanism for natural selection, gene flow, and genetic drift (bottleneck and founder effects), and the biological consequences of such changes in terms of increased or reduced genetic diversity

Key knowledge units	
Gene flow	4.1.1.5
The effect of gene flow on allele frequencies	4.1.1.6
Genetic drift	4.1.1.7
The effect of genetic drift on allele frequencies	4.1.1.8

Gene flow 4.1.1.5

OVERVIEW

Gene flow is the introduction or removal of alleles from a population due to migration.

THEORY DETAILS

When individuals in a **population** enter or exit, they bring with them their **alleles**. This means that populations in different geographic locations can exchange genes through reproduction after individuals migrate.

gene flow the flow of alleles in and out of a population due to the migration of individuals

population a group of individuals of the same species living in the same location

alleles variants of a gene

Migration can occur because populations are physically close together, or due to external forces such as the clearing of a geographical barrier between populations. The migration into and out of a population is known as **immigration** and **emigration** respectively.

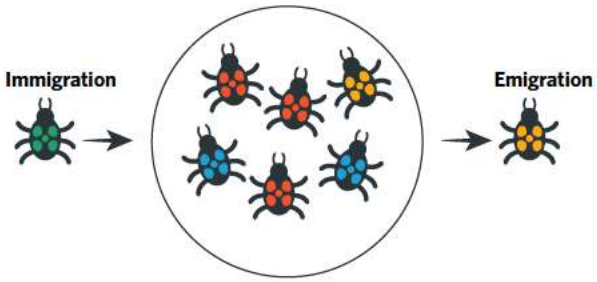


Figure 1 Gene flow in a beetle population

The effect of gene flow on allele frequencies 4.1.1.6

OVERVIEW

Gene flow can introduce or remove alleles from a population. Therefore, it can increase or decrease genetic variation.

THEORY DETAILS

Immigration and emigration can both affect **allele frequencies**. As new alleles are brought into a population, immigration increases genetic diversity in a population. This increase is more noticeable in smaller populations since they have fewer alleles to begin with. In larger populations, the new alleles may barely affect the **gene pool**. Emigration essentially removes alleles from a population, which can decrease genetic diversity in small gene pools, however larger populations tend to be unaffected.

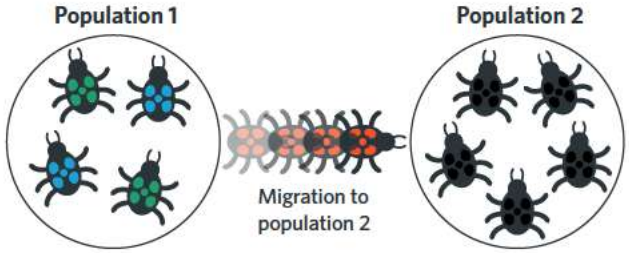


Figure 2 The effect of gene flow on a beetle population. Because Population 1 is small, the emigration of the beetle with red spots removes the red spot allele from the gene pool and reduces genetic variation. The immigration of this beetle into Population 2 introduces a brand new allele, increasing genetic variation in this population.

Genetic drift 4.1.1.7

OVERVIEW

Genetic drift is the change in a population's allele frequencies due to random occurrences. These random occurrences most often result in genetic drift taking place via either the bottleneck effect or the founder effect.

THEORY DETAILS

In response to random events allele frequencies may change drastically and affect the overall population diversity. This is known as **genetic drift**. The effect of genetic drift is seen more clearly in smaller populations and usually occurs by two methods:

- **Bottleneck effect** - when a large portion of a population is wiped out by a random event (such as natural disasters or overhunting).
- **Founder effect** - when a small group of individuals colonise a new population.

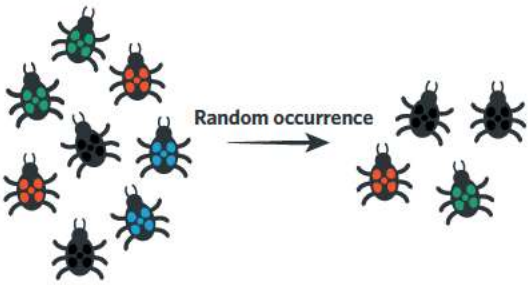


Figure 3 Beetle population affected by genetic drift. The population's genetic variation is reduced, as it has lost the blue allele from the gene pool.

immigration the movement into a population

emigration the movement out of a population

allele frequency the proportion of certain alleles in a gene pool

gene pool all the genes in a population

phenotype the physical or biochemical characteristics of an organism, resulting from expression of a gene (or set of genes) and interaction with the environment

genetic drift the dramatic change in allele frequencies due to a chance event

bottleneck effect the reduction in genetic diversity that occurs when a large proportion of a population is removed due to a chance event

founder effect the reduction in genetic diversity that occurs when a population is derived from a small group of colonising ancestors

Bottleneck effect

Random events - like natural disasters and oil spills - can dramatically decrease population size. The loss of so many individuals in a population means many unique alleles are lost. A *bottleneck effect* occurs because the new population has lower genetic diversity than the pre-disaster population.

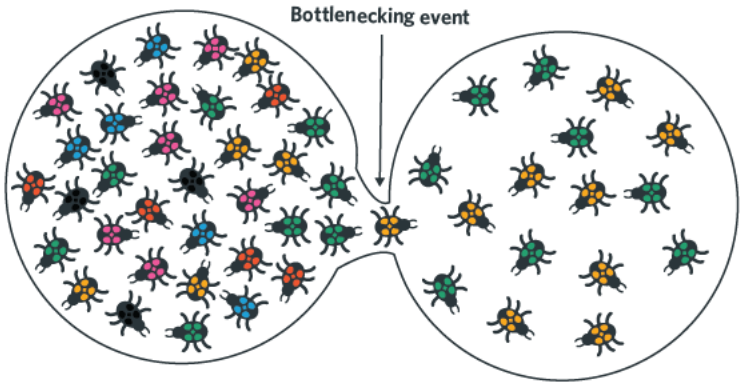


Figure 4 Bottleneck effect displayed in a beetle population

Founder effect

The founder effect occurs when a small number of individuals colonise a new region and start a new population. The founding group's gene pool is small and so the genetic diversity of the new founder population is also small. Therefore, the founder population's gene pool is unrepresentative of the original population.

Think of a population of beetles of many different colours.

If ten green beetles left their original multicoloured population to form a new population, it would not mirror the initial gene pool. This means the genetic diversity of the new population is significantly lower than the original and is an example of a founder effect. However, if the original beetles were all green, it will still resemble the initial gene pool and thereby has not altered the genetic diversity so it is not an example of a founder effect.

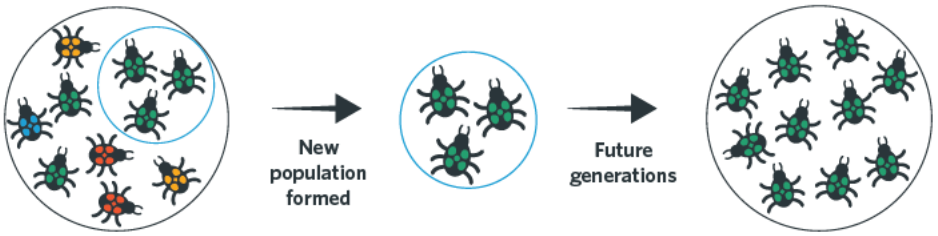


Figure 5 Founder effect displayed in a beetle population

The effect of genetic drift on allele frequencies 4.1.1.8

OVERVIEW

The founder and bottleneck effects both decrease genetic diversity in a population.

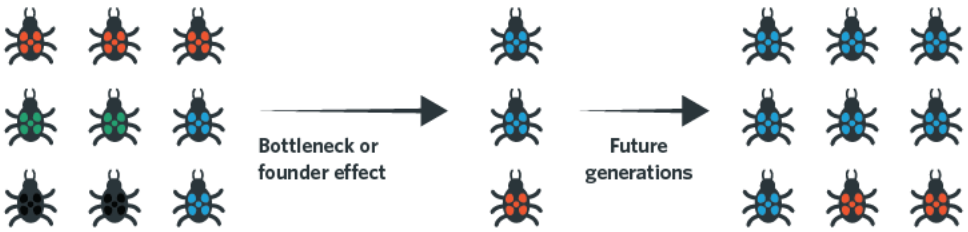


Figure 6 The effect of genetic drift on a beetle population. Both bottlenecks and founder effects reduce genetic variation in future generations.

THEORY DETAILS

Genetic drift reduces genetic variation in a population. In the case of the bottleneck effect, the gene pool is reduced due to a random occurrence. As for the founder effect, only a small selection of the original population's alleles are represented in the founders' genes. Reducing genetic variation has two major risks:

1 **Inbreeding** – this keeps harmful alleles in the gene pool.

2 Lower adaptive potential – populations affected by bottlenecks and small founding groups are vulnerable to new selection pressures that could challenge and potentially wipe out the entire population.

inbreeding sexual reproduction between two related individuals

Once again, the effects of genetic drift are more apparent in small populations, as inbreeding and a lower adaptive potential can cause greater negative effects. However, these negative effects of chance are lessened on larger populations. For example, if a population is comprised of ten beetles, and a given beetle died by chance before it sexually reproduces, all of its genes will be lost from the gene pool. This equates to losing 10% of the population's gene pool. However, if there were a population of 100 beetles and one died by chance, only 1% of the gene pool is lost. This demonstrates that the impacts of random events are reduced in large populations.

Theory summary

Gene flow and genetic drift are processes that result in the genetic diversity of a population changing. Whilst genetic drift only decreases the gene pool of a population, the effects of gene flow can both increase and decrease genetic variation.

11C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ migration of individuals into a population

b _____ movement of alleles into and out of a population

c _____ type of genetic drift where a random occurrence drastically reduces a population's size and gene pool

d _____ mating within a related population

e _____ when a few individuals from a population colonise a new area of land and create a very different gene pool

Question 2

Which of the following statements is false?

A Genetic drift occurs independently of an individual's genetic fitness.

B Emigration increases the genetic variation in a population.

C Bottleneck effect occurs through the drastic reduction in population size, then repopulating with a limited gene pool.

D Founder effect involves a species colonising a new area of land.

Question 3

Complete the following table.

Cause	Type of genetic drift
Volcanic eruption kills the majority of a population	**X**
Y	Bottleneck effect
Small group migrates to another island	**Z**

	X	Y	Z
A	Bottleneck effect	Meteor impact	Bottleneck effect
B	Natural selection	Flood	Founder effect

C	Founder effect	Cyclone	Bottleneck effect
D	Bottleneck effect	Bushfire	Founder effect

Question 4

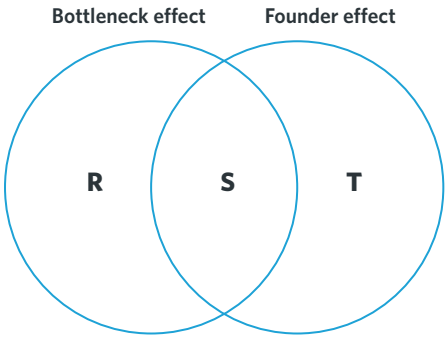
Complete the following table.

Event	Effect on genetic variation
Bottleneck effect	**K**
L	Increase
Founder effect	**M**
N	Decrease

	K	L	M	N
A	Decrease	Immigration	Decrease	Emigration
B	Increase	Immigration	Increase	Emigration
C	Decrease	Emigration	Decrease	Immigration
D	Decrease	Emigration	Increase	Immigration

Question 5

Complete the Venn diagram.



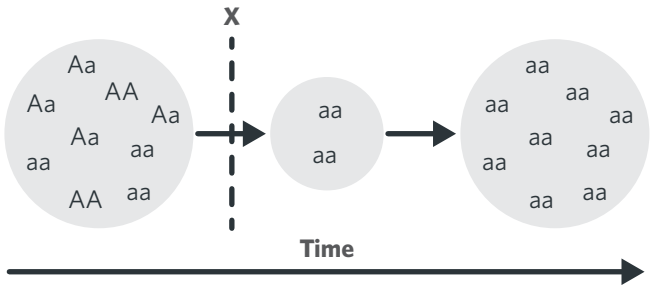
	R	S	T
A	Can occur through a natural disaster	Increased genetic diversity	Occurs when a population is drastically reduced
B	Can occur through human intervention	Increased genetic diversity	Can occur through a natural disaster
C	Occurs when a population is drastically reduced	Decreased genetic diversity	Occurs when a founding population is not representative of the population from which they originated
D	Can occur through a natural disaster	Decreased genetic diversity	Occurs when a founding population is representative of the population from which they originated

Exam-style questions

Within lesson

Question 6 (1 MARK)

Consider the diagram that models changes in allele frequencies for one trait in a population over two generations. The original population is shown on the left.



If event X is a natural disaster, then the diagram models

A founder effect.

B bottleneck effect.

C gene flow.

D random mating.

Adapted from VCAA 2014 Section A Q33

Question 7 (1 MARK)

Northern elephant seals, *Mirounga angustirostris*, were nearly hunted to extinction in the 1890s, with only about 20 individuals left at the end of the century. The population has now grown to more than 120 000. In the 1890s, southern elephant seals, *Mirounga leonina*, were not as severely hunted and currently there are estimated to be 600 000 southern elephant seals.

Which of the following statements is not true?

A Southern elephant seals would have a greater genetic diversity compared to northern elephant seals.

B Northern elephant seals evolved as a result of the bottleneck effect.

C Northern elephant seals would have experienced greater genetic drift than southern elephant seals.

D Southern elephant seals evolved as a result of the bottleneck effect.

Adapted from VCAA 2015 Section A Q40

Question 8 (4 MARKS)

Populations of a particular species can experience events that alter their genetic diversity.

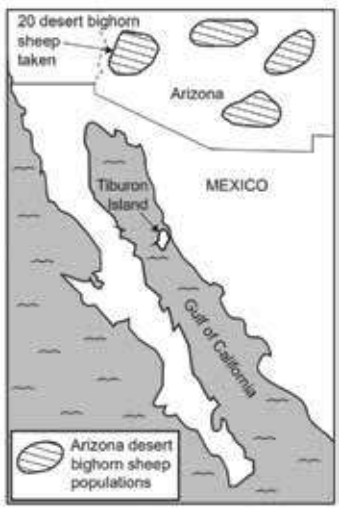
a Explain how the genetic diversity of a population is affected by a natural event such as gene flow. (2 MARKS)

b Identify whether the amount of gene flow increases or decreases as the distance between two populations increases. Justify your answer. (2 MARKS)

Multiple lessons

Question 9 (1 MARK)

Tiburon is an isolated island off the coast of Mexico. Desert bighorn sheep became extinct on this island hundreds of years ago. In 1975, 20 desert bighorn sheep were taken from a population in the American state of Arizona (shown on the map) and were re-introduced to Tiburon Island. By 1999, the population of desert bighorn sheep on Tiburon Island had risen to 650.



The allele frequency of the desert bighorn sheep on Tiburon Island was influenced by

A natural selection.

B founder effect.

C bottleneck effect.

D gene flow.

Adapted from VCAA 2016 Section A Q37

Question 10 (3 MARKS)

Populations of the lizard species *Anolis sagrei* are found on the many islands of the Bahamas. There is natural variation between the phenotypes of individuals within each population.

In 2004, a hurricane completely wiped out the populations of *A. sagrei* lizards on seven of the smaller islands. Scientists randomly chose seven males and seven females from a remaining population on a large island. They introduced one male and one female to each of the seven smaller islands. Over the next three years, the scientists noted that the size of the populations increased on each of the seven smaller islands. The scientists measured the genetic diversity within each of the populations and found there was lower genetic diversity in each new population compared with the population on the large island.

a Explain, with reference to genetic drift, why there is a lower genetic diversity on the smaller islands. (2 MARKS)

b With reference to selection pressures, explain the importance of genetic diversity in a population. (1 MARK)

Adapted from VCAA 2018 Section B Q7b

Question 11 (7 MARKS)

Burrunan dolphins are found only in Port Phillip Bay and the Gippsland Lakes in Victoria. There are only 150 burrunan dolphins alive today. The Port Phillip Bay population is very isolated and rarely mixes with dolphins outside the bay. Port Phillip Bay is impacted by the human population and industry of Melbourne and surrounding towns and is used heavily for recreation, fishing, and shipping.

a It has been concluded that the remaining dolphins survived based on luck, as events such as ships hitting and killing individuals are completely random. Given this, explain whether the impact of the human population is an example of natural selection or genetic drift. (2 MARKS)

b Explain whether gene flow would impact the dolphin population. (2 MARKS)

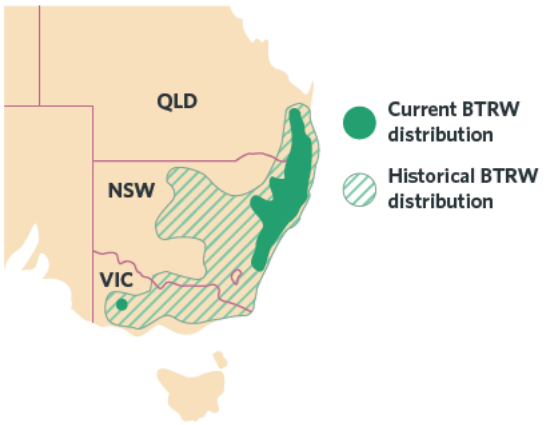
c Four healthy individuals from the dolphin population (two male, two female) were taken into captivity and bred intensively over several generations in order to dramatically increase the population size of dolphins. Outline an issue with such a breeding program, referring to the genetic diversity and fitness of the future population. (3 MARKS)

Adapted from VCAA 2018 Section B Q9e

Key science skills

Question 12 (8 MARKS)

The brush-tailed rock-wallaby, *Petrogale penicillata*, was an abundant species across southeastern Australia, however now faces extinction. Currently, the rock-wallaby is restricted to two populations: one larger population along the east coast spanning Queensland and New South Wales, and one smaller population in western Victoria. To explain the decrease in the rock-wallaby population, scientists have been investigating the distance between colonies of the species to determine the effect of gene flow on a population's viability.



Source: adapted from Department of Environment & Climate Change (2008)

The scientists hypothesise that if the amount of genetic flow between two populations is dependent upon the distance between rock-wallaby colonies, then the greater the distance, the lower the amount of gene flow that would occur.

a State the independent and dependent variable. (2 MARKS)

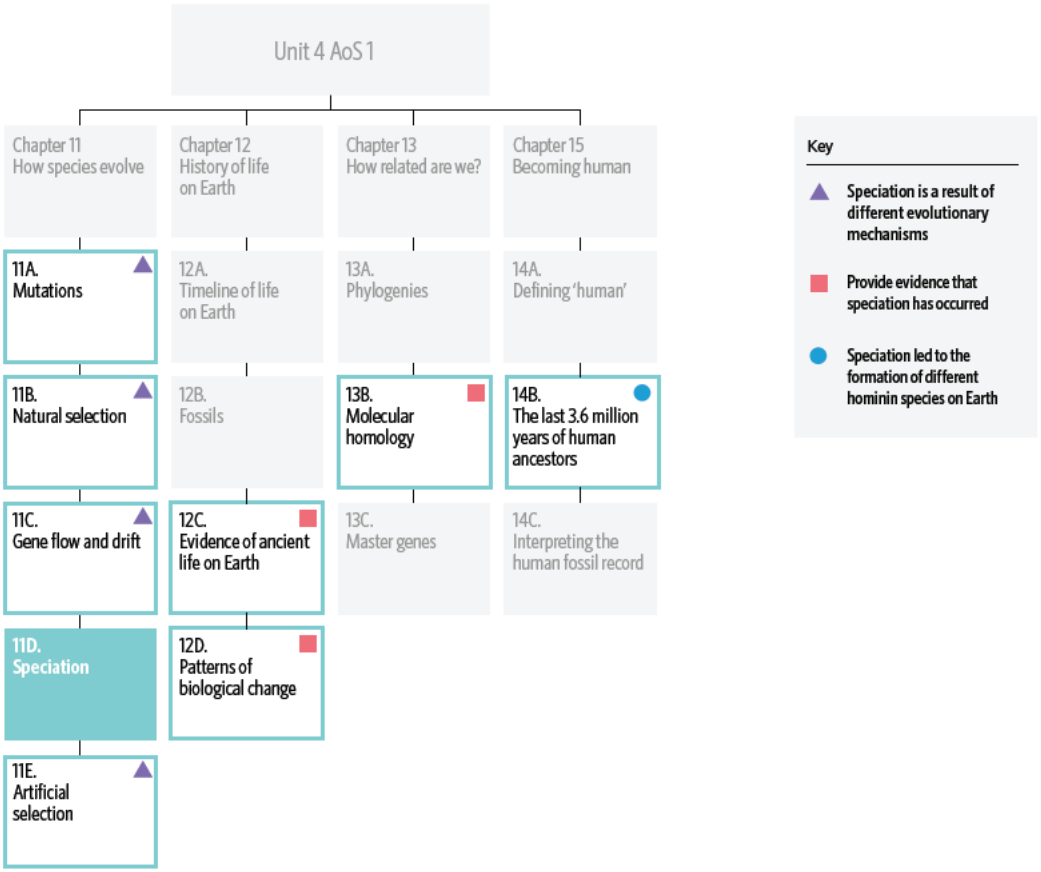
b Explain how gene flow can increase genetic diversity. (2 MARKS)

c Outline why genetic variation is important for a population. (2 MARKS)

d By referring to the map, suggest a reason why scientists could conclude that the rock-wallabies were not affected by the founder effect. (2 MARKS)

11D SPECIATION

You have learned about all of these evolutionary processes, but how are new species actually created?



In this lesson you will learn how new species evolve through allopatric speciation.

Study design dot point

- processes of evolution including through the action of mutations and different selection pressures on a fragmented population and subsequent isolating mechanisms (allopatric speciation) that prevent gene flow

Key knowledge unit

Speciation	4.1.2.1

Speciation 4.1.2.1

OVERVIEW

Speciation is the process by which populations genetically diverge until they become different species.

THEORY DETAILS

Throughout this chapter you have learned about different evolutionary processes such as mutations, natural selection, genetic drift, and gene flow. Speciation occurs when genetic differences accumulate through these processes until a new **species** is formed.

Individuals can be distinguished as different species if they cannot breed to produce **viable** and **fertile** offspring. Other methods that indicate whether two individuals are of the same species include comparing their amino acid sequences, DNA sequences, or structural features.

species a group of individuals who are able to breed with each other and produce viable and fertile offspring

viable able to survive

fertile having the ability to produce offspring

Speciation can be categorised as **allopatric speciation** or **sympatric speciation.** Allopatric speciation requires a **geographic barrier**, such as the formation of a mountain range or an ocean splitting a population. The barrier isolates the populations from each other, leading to genetic divergence and the creation of new species.

In contrast, sympatric speciation occurs within the same geographic area where different selection pressures act on different phenotypes within a population, causing individuals with certain phenotypes to diverge from others and form a new species.

The North American apple maggot fly is a great example of sympatric speciation. Their original host plant was the hawthorn tree, but after European settlement and the introduction of apple trees, the maggot flies began to use apples as a host. Due to close proximity, individuals that were born in an apple were more likely to breed with other apple-born individuals, and the same applied to hawthorn flies. Over time, the two groups generated distinct mutations despite the fact that there was no geographic barrier preventing gene flow. Finally, the two groups became separate species and could no longer breed to produce viable and fertile offspring.

allopatric speciation the geographic separation of a population from a parent population resulting in the evolution of a new species

sympatric speciation the divergence of a species from an original species without the presence of a geographical barrier

geographic barrier a physical factor that prevents gene flow, and thereby stops two populations from breeding together

Image: Randy Bjorklund/Shutterstock.com

Figure 1 Photograph of an apple maggot fly

Tip VCAA will only assess allopatric speciation as it is the only process of speciation stated in the study design.

Allopatric Speciation

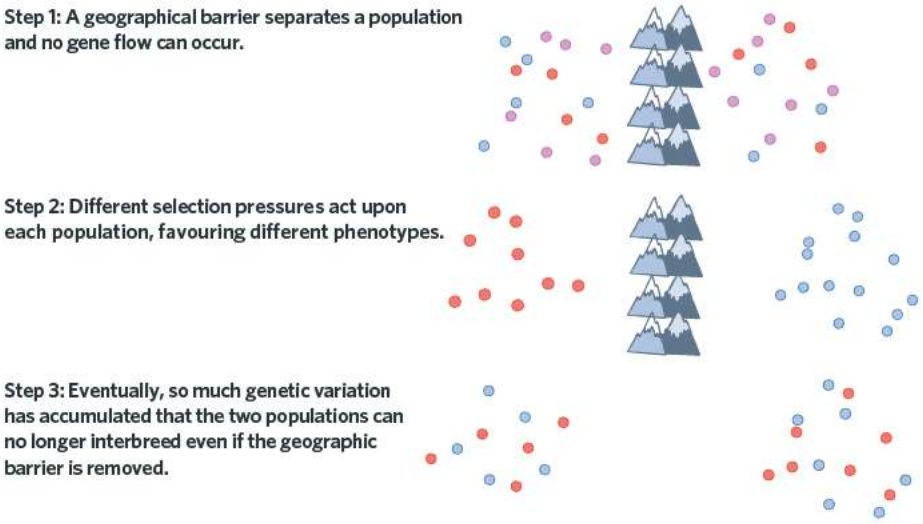


Figure 2 The process of allopatric speciation

The process of allopatric speciation follows the steps below:

1. Initially a population (or populations) of the same species becomes isolated by a geographical barrier.
2. The isolated populations are exposed to different selective pressures.
3. Over time, sufficient differences accumulate in the two populations until they form new species.

Tip These three steps are what VCAA look for when they ask you to describe the process of allopatric speciation, with each point tending to equal one mark.

Once these steps have occurred, the two populations could be reunited and would be unable to interbreed to produce viable and fertile offspring.

An example of allopatric speciation occurred with a snapping shrimp population.

1. The population was separated by the Isthmus of Panama, a stretch of land in Central America that formed around 3 million years ago.
2. Populations either side of the land mass were subject to different selection pressures.
3. Over time, differences accumulated and new species formed.

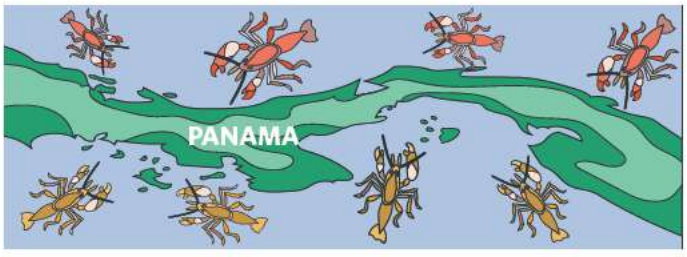


Figure 3 Map showing geographic barrier separating snapping shrimp population

A population has a greater chance of undergoing allopatric speciation if there is already a large amount of genetic variation prior to the appearance of the geographic barrier. This provides the species with a greater ability to survive the differing selection pressures created by their new environment.

Isolating mechanisms

Different species cannot produce fertile and viable offspring because there are mechanisms that inhibit reproduction from occurring normally. These can be classified as either pre- or post-reproductive isolating mechanisms and are listed.

Pre-reproductive isolating mechanisms

- Geographical - individuals may be too far away within or between populations.
- Ecological - individuals may inhabit different ecological niches and not interact.
- Temporal - the time of the day or year when individuals are ready to breed may differ.
- Behavioural - the type of mating behaviours, such as a mating call, of individuals may vary.
- Structural - the physical characteristics of individuals may drastically vary which would make breeding impossible. For example, a Great Dane, and a Chihuahua cannot breed due to their size despite both being the same species.

Post-reproductive isolating mechanisms

- Gamete mortality - the sperm may be unable to penetrate the ovum for fertilisation.
- Zygote mortality - fertilisation may occur and a zygote may be formed, however it will not survive.
- Hybrid sterility - a viable offspring may be formed and may survive until adulthood, however, this offspring will not be fertile.

Tip These isolating mechanisms are unlikely to be assessed but help your understanding of what prevents a viable and fertile offspring from forming.

Theory summary

Allopatric speciation involves the separation of a population by a geographic barrier. This reproductively isolates the populations on either side of the barrier preventing gene flow, until enough genetic differences accumulate that the populations become distinct species. Remember that a species is defined as individuals that can interbreed and produce viable and fertile offspring.

11D QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the formation of a new species in the same geographic area

b _____ the formation of a new species separated by a geographic barrier

c _____ an organism that can survive

d _____ an organism that can produce offspring

e _____ a physical factor dividing a population

f _____ population that can interbreed and produce viable and fertile offspring

Question 2

Which of the following statements is false?

A Speciation is a result of different selection pressures affecting a species.

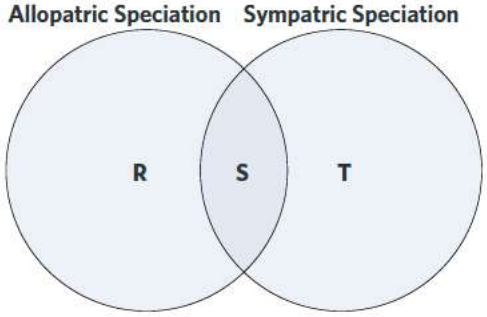
B Mutations that are involved in speciation create variation between the original and newly formed species.

C Sympatric speciation does not involve different selection pressures affecting a population.

D The process of natural selection is part of allopatric speciation due to the presence of multiple selection pressures.

Question 3

Fill in the blanks in the Venn diagram.



	R	S	T
A	No geographic barrier	Different selection pressures	Mutations occur in population
B	Natural selection occurs	Populations are geographically isolated	Different selection pressures
C	Geographic barrier	Different selection pressures	No geographic barrier
D	Populations are geographically isolated	Mutations occur in population	Gene flow occurs

Question 4

Order the following steps of allopatric speciation.

1 Individuals can no longer interbreed to produce viable and fertile offspring.

2 The gene pool of the new population is always significantly smaller than the original population.

3 Genetic changes accumulate over time until the morphology of the populations are significantly different.

4 A geographic barrier divides a population.

5 Different selection pressures act upon the different populations.

A 4, 5, 3, 2, 1
B 4, 5, 3, 1
C 4, 3, 2, 1
D 4, 5, 3, 2

Question 5

Categorise whether the following statements apply to allopatric and/or sympatric speciation.

1 Different selection pressures act upon the population(s).

2 Natural selection is embedded within the process.

3 Populations are physically isolated.

4 A geographic barrier splits a population.

5 Gene flow is still possible between the divided populations.

6 The formed species cannot interbreed and produce viable and fertile offspring.

	Allopatric speciation	Sympatric speciation
A	1,3,4,6	1,2,3,5,6
B	1,2,5,6	1,2,3,4,6
C	1,2,3,4,5,6	1,2,5,6
D	1,2,3,4,6	1,2,5,6

Exam-style questions

Within lesson

Question 6 (1 MARK)

Through the formation of the Grand Canyon, a natural barrier was created that divided a squirrel population. As time moved on, the two separated populations were exposed to different selection pressures and evolved accordingly. This is an example of

A natural selection.
B bottleneck effect.
C allopatric speciation.
D sympatric speciation.

Question 7 (1 MARK)

Scientists bred a horse and a donkey to determine whether they were the same species. The offspring produced were viable and healthy. Kael concluded that the horse and the donkey are the same species. Taylen disagrees and argues that there is insufficient data to draw a conclusion.

It is reasonable to conclude that

A Taylen is correct as the offspring may die young.
B Taylen is correct as the fertility of the offspring has not been determined.
C neither are correct as the information proves that the horse and donkey are different species.
D Kael is correct as a species is determined by whether two individuals would be able to breed with each other and produce a viable offspring.

Question 8 (5 MARKS)

Over the past million years, Australia's climate has become much drier, leading to reduced areas of forest. Different cockroach species from various forests share a recent common ancestor dating back to just before the climate began to become drier.

a Some scientists believe the different species are likely to have evolved through allopatric speciation.
  i Name a feature that scientists would look for in the forest environment to support the occurrence of allopatric speciation. (1 MARK)
  ii Explain how the feature named in part **ai** could contribute to allopatric speciation. (2 MARKS)
b If the different cockroach species could interbreed and produce viable and fertile offspring, would this disprove the scientists' hypothesis? Justify your response. (2 MARK)

Adapted from VCAA 2017 Sample Section A Q25

Question 9 (5 MARKS)

Galápagos tortoises (*Chelonoidis spp.*) can be found on many of the islands that make up the Galápagos Islands. Originally, 14 different species were identified based on the islands on which they lived and on their morphology. Santa Cruz, the second largest of the Galápagos Islands, has two isolated tortoise populations. Population A contains more than 2000 individuals covering an area of 156 square kilometres. Population B is a small population of 250 individuals covering an area of 40 square kilometres. The position of the two populations on the island of Santa Cruz is shown. The two populations are separated by a distance of 20 kilometres.

Source: Poulakakis et al. (2015), as adapted by VCAA 2016 Section B Q9

In 2015, scientists investigated whether the individuals of the two populations belong to the same species or whether they are two different species. They concluded that the two populations were different species and most likely diverged through allopatric speciation.

a Describe the process of allopatric speciation for the Galápagos tortoises populations on Santa Cruz island. (3 MARKS)

b Explain how scientists could conclude that the populations were different species. (2 MARK)

Adapted from VCAA 2016 Section B Q9a

Multiple lessons

Question 10 (1 MARK)

Northern elephant seals, *Mirounga angustirostris,* were nearly hunted to extinction in the 1890s, with only about 20 individuals left at the end of the century. The population has now grown to more than 120 000. In the 1890s, southern elephant seals, *Mirounga leonina,* were not as severely hunted and currently there are estimated to be 600 000 southern elephant seals.

Based on this information, it is true to say that

A southern elephant seals have evolved as a result of the bottleneck effect.

B northern elephant seals would show more genetic variation than southern elephant seals as they evolved through natural selection.

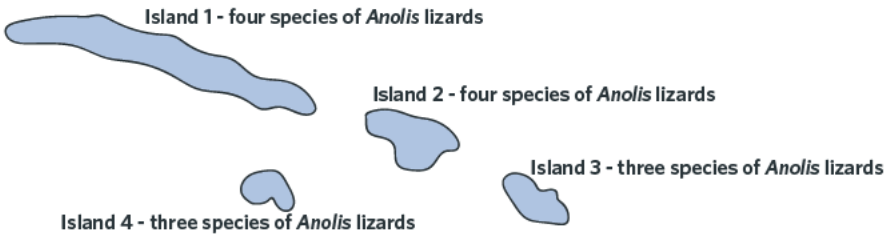
C southern elephant seals and northern elephant seals may have diverged through allopatric speciation.

D northern elephant seals and southern elephant seals could interbreed to increase genetic variation.

Adapted from VCAA 2015 Section A Q40

Question 11 (6 MARKS)

Scientists studied 15 species of lizards of the genus *Anolis* on four islands in the Caribbean Sea. On each island, there were up to four different species of these lizards. It is believed that these islands initially made up one larger island with a singular *Anolis* lizard species. Over time, the islands drifted apart and different species evolved.



a Would the evolution of the *Anolis* genus be an example of allopatric speciation? Justify your response. (2 MARKS)

b Outline the importance of genetic variation in the formation of *Anolis* species. (2 MARKS)

c Identify two natural methods that cause variation in a population. (2 MARKS)

Key science skills

Question 12 (6 MARKS)

The cattle tick *Rhipicephalus (Boophilus) microplus* is located in tropical and subtropical regions of the world. A study was conducted by a group of scientists to investigate whether *R. microplus* populations in different parts of the world were different species. To do this, they sourced a population from Africa, America, and Australia.

The African population is from Mozambique (MOZ), the American population is from Argentina (ARG) and the Australian population is from Australia (AUS).

By breeding specific individuals from different populations together, they can gather evidence on the viability and fertility of the offspring. The table shows the results.

Offspring Cross	**Viability?**	**Fertility?**
MOZ x MOZ	Yes	Yes
ARG x ARG	Yes	Yes
AUS x AUS	Yes	Yes
MOZ x ARG	Yes	Yes
MOZ x AUS	No	No
ARG x AUS	No	No

Source: Labruna et al. (2009)

a With reference to the data collected, justify whether the Australian and Argentinian populations are the same species. (2 MARKS)

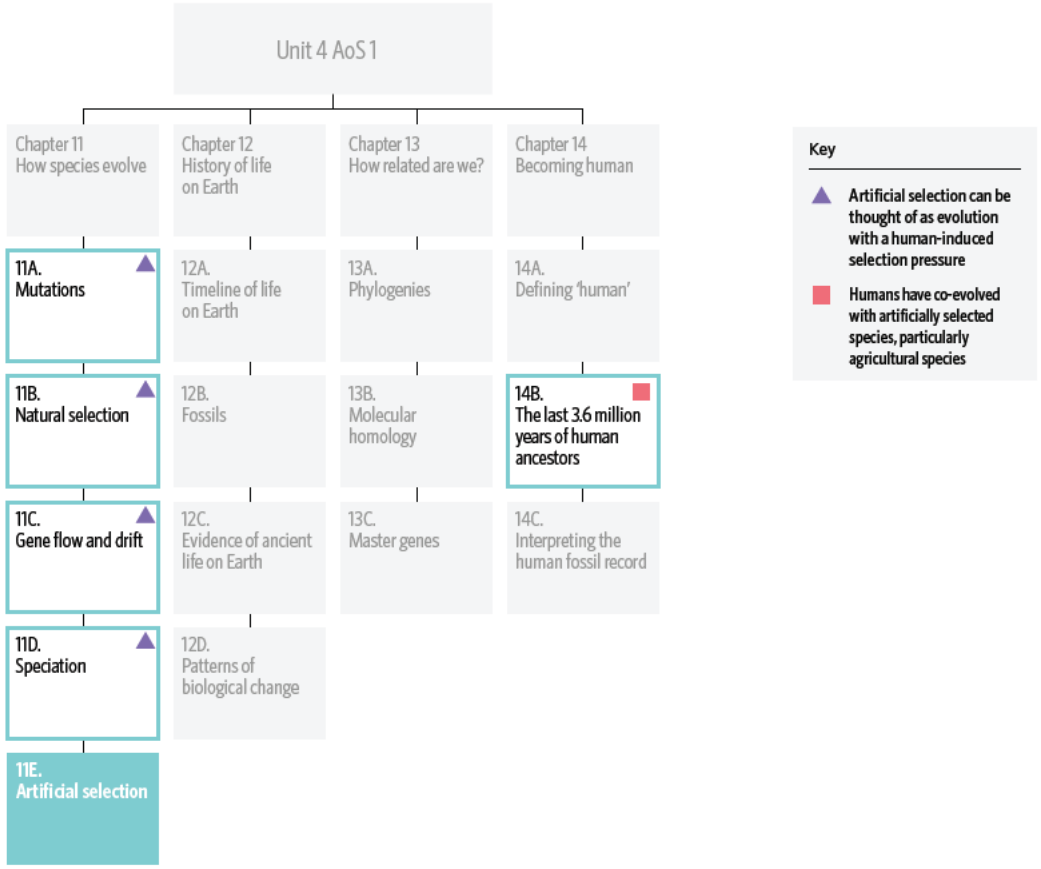
b Outline the process of allopatric speciation in the divergence of the Australian population from the Mozambican population. (3 MARKS)

c Scientists conclude that the Mozambican and Argentinian populations are the same species.

Suggest one reason why allopatric speciation may not have affected these populations. (1 MARK)

11E ARTIFICIAL SELECTION

Apart from a near inability to breathe, what do English bulldogs and corn have in common?



In this lesson you will learn that by selecting for particular traits in plants and animals, humans change which phenotypes are most common in the population.

Study design dot point

- the manipulation of gene pools through selective breeding programs

Key knowledge units

Artificial selection	4.1.3.1
The effect of artificial selection on allele frequencies	4.1.3.2

Artificial selection 4.1.3.1

OVERVIEW

Humans can select for traits such as high wool density in sheep or larger grain size in crops by altering the breeding population.

THEORY DETAILS

How do artificial and natural selection differ?

- **Artificial selection** – the selection pressure is human–induced, and there is a **desired trait** that humans are selecting for or removing from the population.
- **Natural selection** – the selection pressure is naturally occurring.

Much like natural selection, the process of artificial selection requires both variation in traits and heritability of those traits. However, the selection pressures in the process of artificial selection are influenced by direct human intervention. For instance, humans may allow only the fastest horses to mate. Alternatively, humans may remove all deer with large antlers from a population by over–hunting.

artificial selection the alteration of a population's gene pool due to direct human action, usually selecting for a desired trait. Also known as **selective breeding**

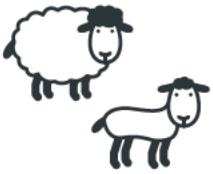
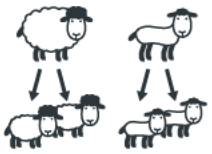
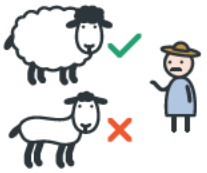
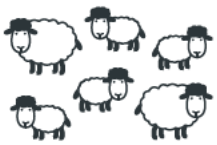
desired trait a heritable phenotype that humans select for during selective breeding

natural selection organisms that are better adapted to their local environmental selection pressures are more likely to survive and pass on their genes

The final stage is breeding, whereby the individuals with the artificially selected trait reproduce and pass the trait onto offspring. Consequently, using the previous examples, fast horses and deer with small antlers would become more common within a population. This is continued over many generations.

The process of artificial selection is summarised in the table.

Table 1 Process of artificial selection

Requirement for artificial selection	What this means	Example – Image	Example – Explanation
1 Variation	Individuals in a population vary genetically. This leads to phenotypic differences.		A sheep population has phenotypic variation, from high to low wool density.
2 Heritability	These traits – whether advantageous for survival or reproduction – can be passed on from parents to offspring.		Wool density is a heritable trait. Therefore, parents of high wool density are more likely to have offspring with high wool density.
3 Intervention	Selection is determined by humans who alter the breeding population.		As high wool density is favourable to humans, this trait is selected. A breeding population of sheep with high wool density is established, while individuals with low wool density are not permitted to breed.
4 Breeding	After selection, the breeding population reproduces, either by natural forces or human-induced breeding. This continues over many generations.		Subsequent generations show increased wool density compared to the initial population. Repeated selection reinforces high wool density expression.

While artificial selection may seem a simple concept, there are actually three methods of artificial selection:

1 Selecting for the trait you want

2 Selecting against the trait you want

3 Selecting against the trait you don't want

1. Selecting for the trait you want

Maize has been a staple crop in agriculture for thousands of years. Nonetheless, the origin of maize puzzled biologists around the world. Relatively recently, it was discovered that maize is the descendant of the wild grass teosinte. Teosinte is generally a poor crop species, but human selection for suitable farming characteristics (soft, large, many kernels, kernel permanence, etc.) over millennia has produced modern maize crops.

2. Selecting against the trait you want

By hunting animals with particular features, like large body size or horns, humans select against these traits. For example, in Australia, we have a 'legal limit' law, where only fish above a minimum size can be taken by fishermen. This means that small fish are returned to the water, and nets are designed so that small fish can escape but larger fish cannot. Consequently, the average fish body size is decreasing because humans accidentally allow small fish to survive and pass on their genes.

A huge problem can arise if the minimum legal size for a fish species is smaller than the size at which fish reach sexual maturity. In this case, the entire fish species can be at risk of being wiped out as all the breeders are removed from the population.

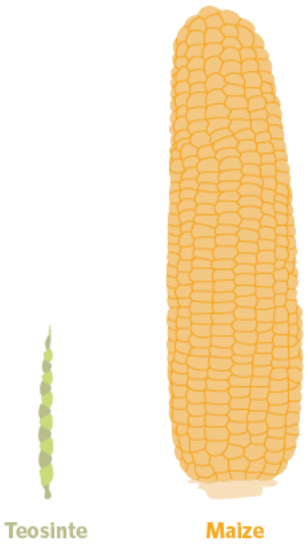


Figure 1 Maize (right) was derived from the ancient teosinte (left) through the process of artificial selection.

Tip All three methods of artificial selection will be covered in this lesson, however, VCAA generally only assesses type 1. Common question types for this lesson involve case studies where humans intervene in a breeding population, and you have to identify if natural or artificial selection has occurred.

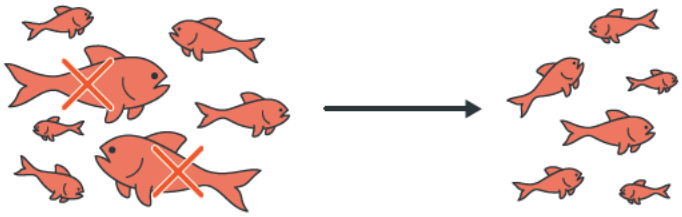


Figure 2 By removing large bodied fish from wild populations, we are effectively selecting for reduced body size.

3. Selecting against the trait you don't want

Today we select dogs with exceptional abilities or looks and intentionally breed them. However, early in the process of dog domestication, intentional breeding by humans was unlikely to have occurred. Instead, dogs with undesirable characteristics – like aggression – would have been killed. As dead dogs cannot reproduce, their genes are removed from the gene pool. Consequently, the alleles for low aggression become more common over time.

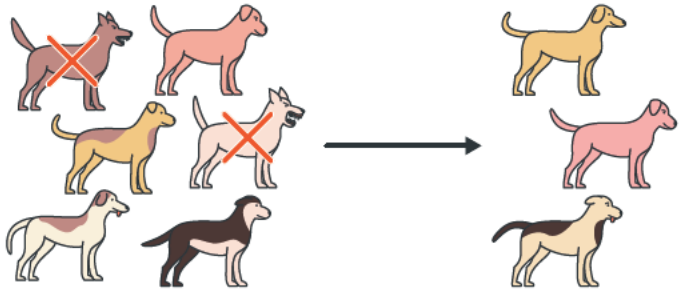


Figure 3 Removal of aggressive dog genes early in the dog domestication process

The effect of artificial selection on allele frequencies 4.1.3.2

OVERVIEW

Smaller gene pools and overexpression of deleterious alleles can reduce adaptability and fitness within an artificially selected population.

THEORY DETAILS

Figure 4 A diagram showing the effect of artificial selection on the gene pool. The dark colour trait is selected for by humans and the antennae size represents a trait that is not being directly selected for or against.

If poor breeding practices are implemented, artificial selection causes a human–induced genetic bottleneck. This is because in a large population, only a small percentage of individuals express traits desired by humans. Restricting breeding to these individuals reduces genetic variation. Reduced genetic variation has two major impacts on the population:

1. Increased **inbreeding** – this increases the amount of **homozygous** alleles in offspring. While high homozygosity is not always damaging, it can lead to expression of **deleterious recessive alleles**.
2. Lower adaptive potential – this means that the population is less likely to have alleles that will help individuals survive under new selection pressures.

lesson link Remember from ***11C*** that genetic drift (bottleneck and founder effects) and emigration also reduce genetic variation in the population. Reduced genetic variation always increases the risk of inbreeding and lowers adaptive potential in populations.

inbreeding sexual reproduction between two related individuals

homozygous identical alleles at the same location on homologous chromosomes

deleterious alleles that have an overall negative effect on individual fitness when expressed

recessive allele a trait that can be masked by a dominant allele on the homologous chromosome

Theory summary

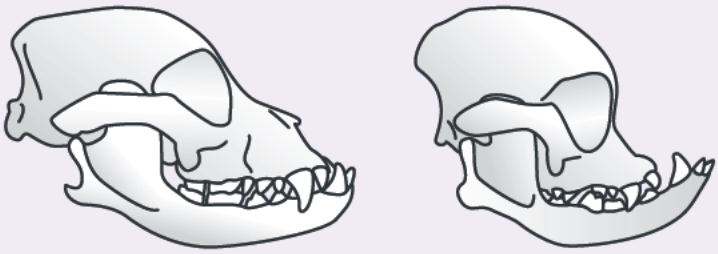
Historically, humanity has altered the genomes of species to express traits that we find desirable. Due to the effects of inbreeding and heavy selection pressures, this has resulted in large reductions in overall species fitness and overexpression of previously repressed alleles.

Case study

Deleterious recessive alleles

If a dominant allele is deleterious, natural selection will act against this allele and remove it from the population over generations. A recessive allele can be beneficial, deleterious, or neutral but by its nature is not always expressed. Consequently, a deleterious recessive allele can remain hidden within a population without being selected against. That is, until inbreeding leads to high homozygosity and expression of these deleterious traits.

It is important to note that the negative effects of inbreeding rarely stem from the expression of one massively deleterious allele, but hundreds of slightly deleterious ones.



Bulldog skull from 1908 Bulldog skull from 2008

Figure 5 In 100 years, selective breeding has dramatically changed the English bulldog skull shape. Inbreeding has led to the accumulation of recessive deleterious alleles, which means that most English bulldogs have respiratory and cardiovascular issues, poor immune systems, and are prone to arthritis.

Case study

Russian foxes

Modern dogs are descendants of wild wolves. However, the evolutionary processes that enabled this transformation have historically been theorised, and rarely demonstrated. The Russian 'domesticated red fox' experiment, ongoing since the 1960s, goes a long way to developing a deeper understanding of this process.

Since diverging from wolves thousands of years ago, the evolutionary changes of dogs can be characterised in two ways: physical and behavioural changes. While many scientists believed that early artificial selection acted primarily on these physical characteristics, Russian zoologist Dmitry Belyaev argued that behaviour, or tamability, was also selected for.

To demonstrate this, Belyaev began with a population of wild silver foxes in which he ranked individuals based on traits commonly associated with tameness (e.g. low aggression, affection towards people, etc.). The tamest individuals were bred together, and this was repeated over many generations.

After ten generations of this selection, almost 20% of bred foxes could be categorized as 'domesticated elite', displaying behaviour akin to that of modern dogs. Interestingly, characteristics not selected for were altered in the selection process. Changes in coat colour, developmental patterns, tail shape, floppy ears, and jaw structure could be seen within some of the population. These phenotypes mirrored some of the traits that distinguish modern dogs from wolves. The exact mechanisms of these shifts have been theorised but not confirmed. It should be noted that effort was taken to ensure inbreeding did not occur.

11E QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ heritable phenotype that is selected for via human intervention

b _____ the process whereby humans systematically breed individuals of similar desired phenotypes

c _____ when closely related individuals reproduce

d _____ a trait that is not expressed unless both alleles in the genotype are identical

Question 2

What is **not** an effect of inbreeding?

A Expression of deleterious alleles, previously 'hidden' within the genome.

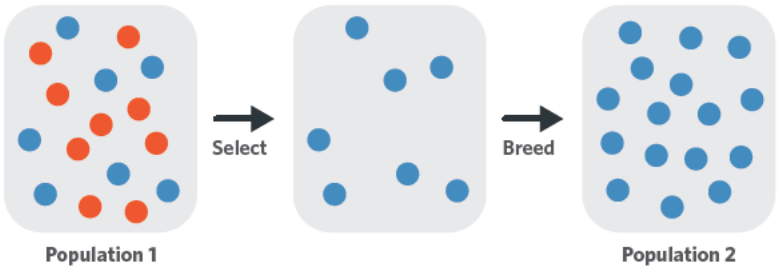
B High prevalence of identical alleles on homologous chromosomes.

C High heterozygosity within the population.

D Lowered ability to adapt to changes in the environment.

Question 3

The following diagram is a large, randomly reproducing population of wild coloured spheres (Population 1). Humans have isolated a small percentage of the blue spheres and allowed them to reproduce (Population 2).



Which of the following is likely true?

A Population 2 has a higher resistance to environmental change than Population 1.

B Population 1 has greater allelic diversity than Population 2.

C Natural selection acted strongly on Population 2.

D Significant inbreeding has affected the gene pool in Population 1.

Question 4

Scenarios I – VI are all examples of evolutionary changes over time.

I In an experiment, scientists accidentally allowed highly related *Callimico* monkeys to breed with each other. As a direct result of inbreeding depression, offspring suffered poor genetic fitness and a high infant mortality rate.

II Over generations, humans have bred together long-haired sheep.

III Humans killing aggressive dogs.

IV Due to minimum weight limits within the fishing industry, average individual fish weight is steadily declining.

V Due to black smog coating surfaces, white peppered moths experienced higher predation rates.

VI Mussels with thicker shells experience lower rates of predation than thinner-shelled mussels after invasion of human-introduced sea stars. The average shell thickness of the mussel is steadily increasing.

Select the correct classification from the list:

	Natural processes	Artificial selection
A	II, V, VI	I, III, IV
B	I, V, VI	II, III, IV
C	I, V, IV	II, III, VI
D	I, III, VI	II, IV, V

Question 5

Scientists are trying to replicate the evolution of ancient teosinte to modern corn. Teosinte used to have few, hard kernels. Starting with a population with large genetic diversity, the scientists would not have

A analysed the genomes of each teosinte plant, and bred together individuals with alleles associated with the expression of soft kernels.

B repeated the selection process over many generations.

C randomly bred individuals with each other over many generations.

D observed seemingly random changes for which they had not selected.

Exam-style questions

Within lesson

Question 6 (1 MARK)

Northern elephant seals, *Mirounga angustirostris*, were nearly hunted to extinction in the 1890s, with only about 20 individuals left at the end of the century. These seals show high aversion to humans, which is a genetically linked trait. The population has now grown to more than 120 000. In the 1890s, southern elephant seals, *Mirounga leonina*, were not as severely hunted and currently there are estimated to be 60 000 southern elephant seals.

Based on this information, it is reasonable to say that

A northern elephant seals have evolved as a result of the founder effect.

B humans have effectively selected for 'aversion to humans' in the northern elephant seal population.

C southern elephant seals would have experienced greater genetic drift than northern elephant seals.

D the mutation rate in northern elephant seals would have been greater than in southern elephant seals.

Adapted from VCAA 2015 Section A Q40

Question 7 (1 MARK)

Humans selectively bred ancient maize to produce modern corn.

Which of the following would not be a desired trait?

A High number of kernels per cob

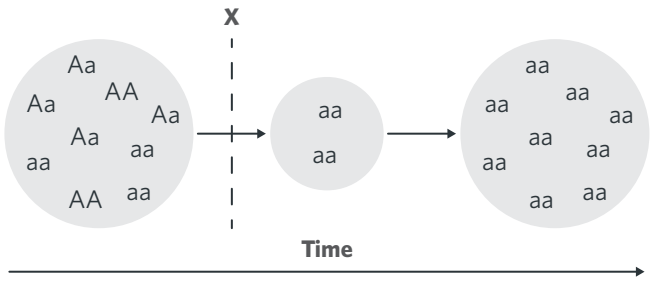
B Soft kernel covering

C Pest resistance

D Low resistance to environmental change

Question 8 (1 MARK)

Consider the diagram that models changes in allele frequencies for one trait in a population over two generations. In the diagram, the original population is shown on the left.



If the diagram models selective breeding, then X is

A a mass extinction.

B genetic drift.

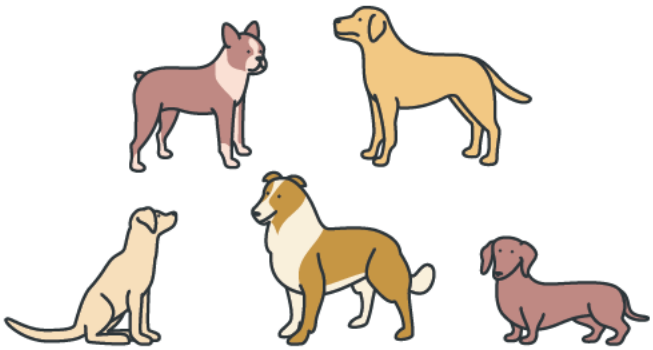
C selection for a desired trait.

D migration.

Adapted from VCAA 2014 Section A Q33

Question 9 (1 MARK)

The diagram shows five different breeds of dog that now exist within the *Canis lupus familiaris* species.



The development of variant breeds within *Canis lupus familiaris* is an example of

A selection acting on desired traits.

B genetic drift within isolated *Canis lupus familiaris* populations.

C natural selection on different populations.

D increase in the mutation rate due to environmental change.

Adapted from VCAA 2014 Section A Q38

Multiple lessons

Question 10 (1 MARK)

Native to South America, wild yams are thought to be the ancestor to modern potatoes. The Great Famine (sometimes known as the Irish potato famine) is notorious for demonstrating the potential effect of a single pathogen on crop species.

Since then, biologists have suggested the most likely reason the pathogen had such a large impact is that

A cultivated potatoes have a high susceptibility due to low genetic variation.

B the high pathogen mutation rate facilitated rapid evolution.

C a mutation in the potato genome disrupted B cell production.

D a volcanic eruption reduced sunlight availability for an extended period of time, stopping photosynthesis.

Question 11 (1 MARK)

Health professionals are concerned about the overprescription of antibiotics. Many antibiotics have become ineffective against certain bacterial strains.

The rise in the resistance of bacteria to antibiotics in human populations is due to

A underprescription of antibiotics to sick patients.

B antibiotic-resistant bacteria surviving.

C increasing doses of antibiotics causing mutations in bacteria.

D antibiotic-resistant phenotypes being favoured through artificial selection.

Adapted from VCAA 2013 Section A Q39

Question 12 (5 MARKS)

All modern dogs are descendants of ancient wolves.

Ancient wild wolf populations were large and genetically diverse. Some of the wolves displayed lowered levels of aggression and greater ability to become domesticated. Through selective breeding, a domesticated dog population was formed.

a Outline the process by which selective breeding has been used to derive modern dogs from this domesticated dog population. (2 MARKS)

b What is the major difference between artificial and natural selection? (1 MARK)

c Explain two potential unintended consequences of artificial selection. (2 MARKS)

Question 13 (6 MARKS)

Two species of *Cryptasterina* sea stars are found in coastal Queensland. *Cryptasterina pentagona* is found in warmer water further north, while *Cryptasterina hystera* is found further south in cooler water.

Researchers have concluded that these two species arose from a recent common ancestor. They believe that, due to human-induced climate change, the boundary between warm and cold water (the dotted line) is moving south. They have found that water temperature and predation of sea star larvae by warm-water predators are altering the population genomes.

a Consider the process of natural and artificial selection.

i Is this an example of natural or artificial selection? (1 MARK)

ii Justify your answer. (2 MARKS)

b Explain what would happen to a population of *Cryptasterina hystera* if it were introduced north of the dotted line. (3 MARKS)

Adapted from VCAA 2016 Section B Q8

Key science skills

Question 14 (6 MARKS)

Jean-Baptiste Lamarck proposed that offspring inherit the acquired characteristics of their parents. August Weismann, a prominent 19th-century evolutionary biologist, disagreed with Lamarck and performed an experiment to test Lamarck's theory.

In the experiment, Weismann cut the tails off 68 mice and allowed them to breed. He then cut the tails off all their offspring and bred these mice with each other. After 5 generations Weismann observed no change in tail size or shape in any of the mice.

a What conclusion can be drawn from the results of Weismann's experiment? (2 MARKS)

b A group of scientists have designed an experiment to generate a population of mice with stunted or missing tails. They use selective breeding to generate this mouse population.

i State the hypothesis of their experiment. (1 MARK)

ii This second experiment didn't feature a control group. What would have been the experimental conditions of the mice in a control group? (1 MARK)

c What is an ethical issue present in Weismann's experiment and how could it have been avoided? (2 MARKS)

ACTIVITY

Natural selection in centipedes

Introduction

You have a population of 30 centipedes (*Scolopendra cingulata*). They live in a sandy habitat. Each year the centipedes mate once at random and each pair produces one offspring. After each mating season, predatory birds called Rollers (*Coracias garrulus*) eat one half of the population (15 centipedes). This means that at the end of each year there is still a population of 30 centipedes. There are two forms of *Scolopendra cingulata*. The dark form (B) is dominant to the pale form (b). The dark centipedes are more conspicuous than pale centipedes against the yellow sand. Therefore, the dark centipedes are more easily seen by the Rollers.

Purpose

To simulate natural selection and observe some of its consequences.

Requirements

- Six-sided die
- Set of 30 centipede cards with 10 BB (dark), 10 Bb (dark), and 10 bb (pale)
- 20 extra centipede cards (a mixture of genotypes to be used as offspring).

Procedure A

1 Write a hypothesis to predict how the frequency of each allele (B and b) will change after five years.

2 Shuffle the 30 centipede cards to simulate random mating and deal the cards into 15 pairs, placing one on top of another (don't worry about the sex of the centipedes).

3 Determine the offspring, using the six-sided die when required as follows:

- BB × BB = BB
- bb x bb = bb
- BB x bb = Bb
- BB x Bb = roll the die. Even number is BB; odd number is Bb
- Bb x Bb = roll the die. One is BB; two or three is Bb; four is bb; five or six roll again
- Bb x bb = roll the die. Even number is Bb; odd number is bb.

4 Once you have finished mating the centipedes as described above, roll the die 15 times.

Each time, when you roll the die:

- remove a dark centipede if a one, two, three, four, or five is rolled
- remove a pale centipede if a six is rolled.

5 Repeat the above procedure five times to simulate five years. Draw out the table below and record your results.

Genotype	Number of centipedes					
	Starting population	Year 1	Year 2	Year 3	Year 4	Year 5
BB (dark)	10					
Bb (dark)	10					
bb (pale)	10					
Total	**30**	**30**	**30**	**30**	**30**	**30**

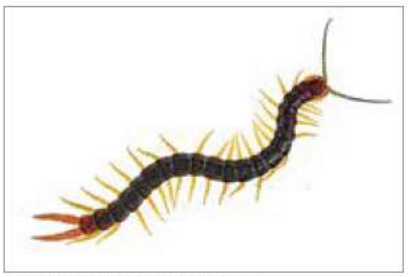


Image: Sytilin Pavel/Shutterstock.com

Figure 1 *Scolopendra cingulata* dark form

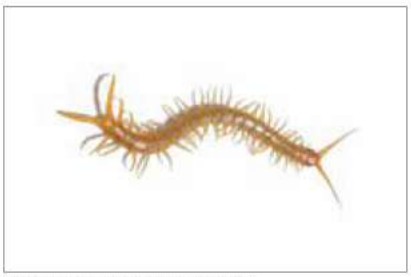


Image: Yashkin Ilya/Shutterstock.com

Figure 2 *Scolopendra cingulata* light form

Figure 3 *Coracias garrulus* eating *Scolopendra cingulata* dark form

Procedure B

Nearby, in another location, a separate population occupies an area of land covered by soil rather than sand. The soil is brown. In this region, the pale centipedes are more easily seen by the Rollers.

Starting with a new population (10 BB, 10 Bb, and 10 bb), repeat steps one to five of procedure A. This time when you roll the dice:

- remove a dark centipede if a one is rolled.
- remove a pale centipede if a two, three, four, five, or six is rolled.

6 Write a hypothesis to predict what will happen to the frequencies of alleles in the population over the five years.

7 Copy out the table below. Complete Procedure B, and record your data in the table.

Genotype	Number of centipedes					
	Starting population	Year 1	Year 2	Year 3	Year 4	Year 5
BB (dark)	10					
Bb (dark)	10					
bb (pale)	10					
Total	**30**	**30**	**30**	**30**	**30**	**30**

Questions

Procedure A

1 Which centipedes were selected against?

2 Was it the phenotype or the genotype that was selected against? Why do you think so?

3 The allele frequency is the proportion of certain alleles in a gene pool. For example, take the gene pool; AA, AA, Aa, and Aa. There are eight alleles in total, of which 6/8 are A and 2/8 are a. So, the allele frequencies are A = 0.75 and a = 0.25.

Work out the frequency of each allele (B and b) in the starting population and at the end of the fifth year.

4 How did the frequency of each allele (B and b) change over this period?

5 Did this support your hypothesis? Explain your answer.

Procedure B

1 Which centipedes were selected against?

2 What was the frequency of the B allele at the end of the fifth year?

3 What proportion of the centipedes were dark at the end of the fifth year?

4 Did this support your hypothesis? Explain your answer.

General questions

1 What is the name of the process that caused the change in the proportion of dark and pale centipedes? Explain this process.

2 When members of a breeding pair were both heterozygous, the die was needed to determine the offspring. When both parents were homozygous, the offspring could be decided without rolling the mating die. Explain why.

3 What is the selecting agent in this simulation?

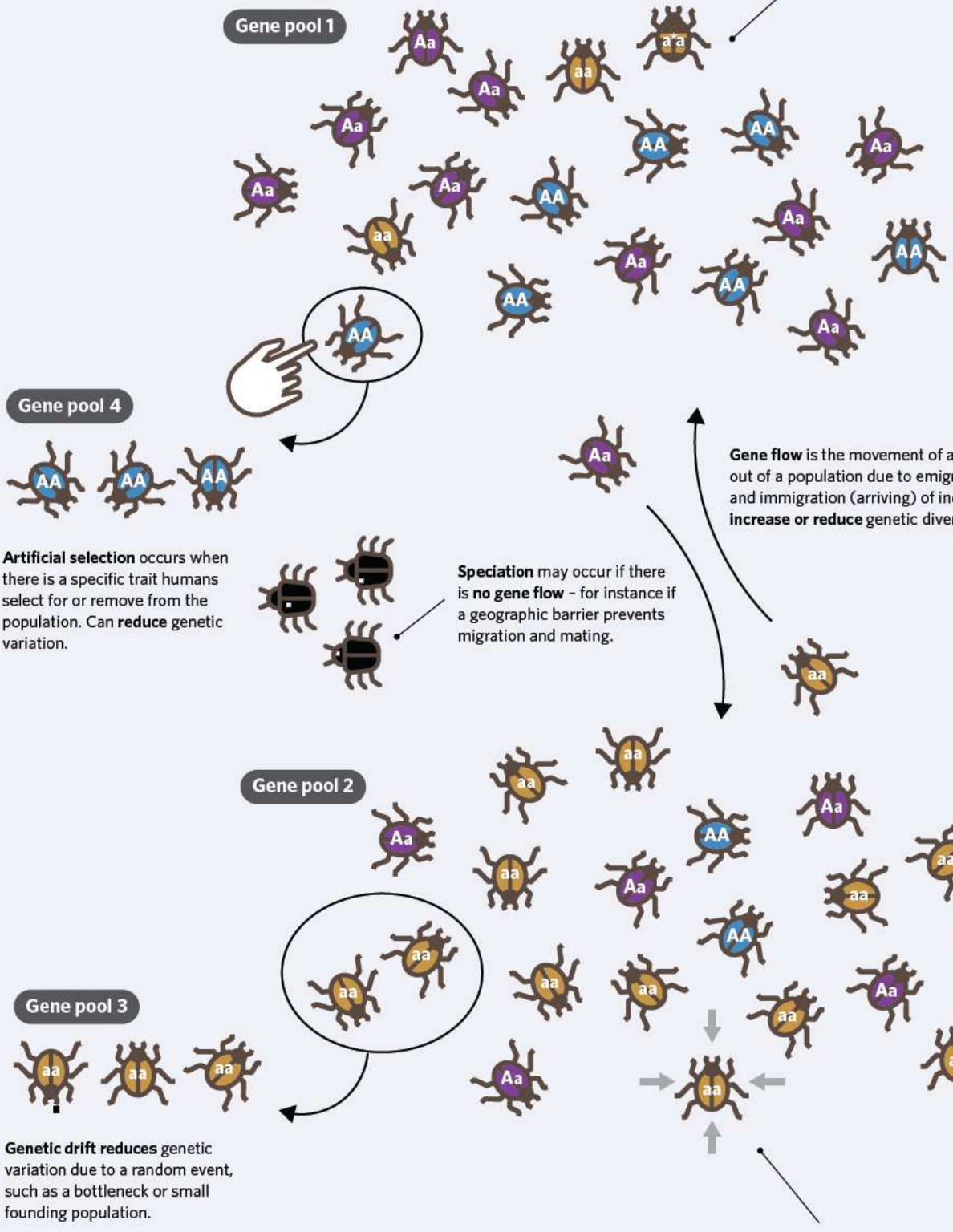
4 Using the results of the simulation as an example, explain why selection pressures acting on a population are more likely to cause the allele for a dominant trait to be eliminated than the allele for a recessive trait.

CHAPTER SUMMARY

Factors that affect allele frequencies

Remember that high genetic diversity means populations have a high **adaptive potential** and a low risk of **inbreeding**.

Mutations increase genetic diversity by introducing new alleles spontaneously or through the effect of mutagens. Types of mutations include: point, frameshift, block, and chromosomal abnormalities.



Gene flow is the movement of alleles in and out of a population due to emigration (leaving) and immigration (arriving) of individuals. Can **increase or reduce** genetic diversity.

Artificial selection occurs when there is a specific trait humans select for or remove from the population. Can **reduce** genetic variation.

Speciation may occur if there is **no gene flow** – for instance if a geographic barrier prevents migration and mating.

Genetic drift reduces genetic variation due to a random event, such as a bottleneck or small founding population.

Natural selection is the process by which individuals best adapted to selection pressures survive and reproduce more than less fit individuals. In gene pool 2, a selection pressure makes the yellow phenotype advantageous.

CHAPTER REVIEW QUESTIONS

SECTION A (12 MARKS)

Question 1 (1 MARK)

New alleles can be introduced into a population by

A natural selection.
B genetic drift.
C mutations.
D artificial selection.

Question 2

Which of the following statements is true about genetic variation?

A Variation increases a species' chances of survival when affected by a selection pressure.
B Variation increases a species' chances of survival when affected by a random pressure.
C Variation decreases a species' chances of survival when affected by a selection pressure.
D Variation decreases a species' chances of survival when affected by a random pressure.

Adapted from VCAA 2014 Section B Q6c

Question 3 (1 MARK)

Sickle-cell disease (SCD) is a group of blood disorders. People with SCD may have just a single nucleotide change in the HBB gene – the segment of DNA that codes for the beta-globin of the haemoglobin. This results in an altered haemoglobin molecule.

What type of mutation causes sickle-cell diseases?

A point mutation
B frameshift mutation
C block mutation
D chromosomal abnormality

Adapted from VCAA 2017 Northern Hemisphere Section B Q1b

Use the following information to answer Questions 4 and 5.

In 2015, scientists investigated whether the individuals of the two populations of Galápagos tortoises belong to the same species or whether they are two different species. The position of the two populations on the island of Santa Cruz is shown. The two populations are separated by a distance of 20 kilometres.

Average measurements of skull size were calculated for tortoises belonging to both populations A and B.

The skulls were measured in six different places. The results are shown in the table.

Measurement position	Average skull measurement (mm)	
	Population B	Population A
1	118	98
2	40	37
3	21	18
4	26	23
5	10	9
6	19	17

Source: Poulakakis et al. (2015), as adapted by VCAA 2016 Section B Q9a

Question 4 (1 MARK)

Scientists proposed the hypothesis that individuals in Population A belong to a different species from individuals in Population B. Which of the following supports this hypothesis?

A The skull measurements at position one have a difference of 20 mm.

B The island is small and remote.

C Each species is separated by 20km.

D Population A is much greater than Population B.

Question 5 (1 MARK)

A small group of individuals from Population A split off and formed a new population, called Population C. This would be an example of

A gene flow.

B natural selection.

C founder effect.

D bottleneck effect.

Question 6 (1 MARK)

In the 18th century, Robert Bakewell separated small-bodied, coarse-woollen sheep from the herd, and did not allow them to breed. This is an example of

A genetic fitness.

B natural selection.

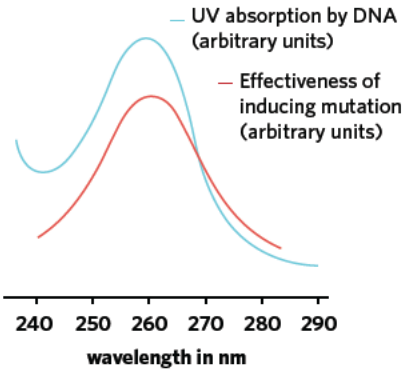
C allopatric speciation.

D selective breeding.

Adapted from VCAA 2017 Section A Q30

Question 7 (1 MARK)

An investigation was carried out to determine the mutation rate in DNA exposed to different wavelengths of UV light. The results are presented graphically in the diagram.



At what wavelength does DNA absorb the least amount of UV between 240 nm–290 nm?

A 240 nm

B 260 nm

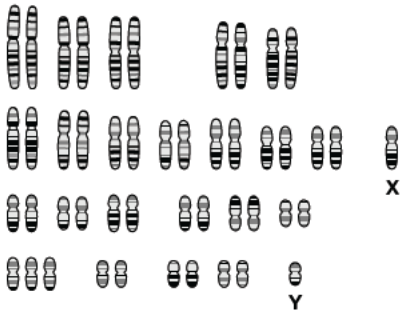
C 270 nm

D 290 nm

Adapted from VCAA 2005 Exam 2 Section A Q17

Question 8 (1 MARK)

The following karyotype of a 12 week old foetus has been prepared.



Examination of the karyotype reveals that the baby

A is female.

B has an extra X chromosome.

C is aneuploid.

D is polyploid.

Adapted from VCAA 2008 Exam 2 Section A Q2

Question 9 (1 MARK)

The following diagram shows an individual with the phenotype 'piebald spotting', a rare autosomal genetic condition. This condition is passed down genetically on an autosomal chromosome.

Identify where this mutation must have occurred to be inherited.

A Skin Cells
B Somatic Cells
C Neurons
D Germline Cells

Adapted from VCAA 2013 Section B Q7a

Question 10 (1 MARK)

Since the introduction of the poisonous cane toad to Australia in 1935, there has been an increase in the ratio of body length to head size in two species of snakes, the Red-bellied Black Snake and the Green Tree Snake. A smaller-headed snake cannot consume a large prey item, and also cannot swallow a large cane toad that has sufficient toxin to kill the snake.

Which of the following statements is false in regards to these two snakes?

A Before cane toads were introduced, there was genetic variation in head size in the populations of the two snake species.
B Even small cane toads contain enough toxin to kill large snakes.
C Larger headed snakes are better at catching and eating cane toads.
D Cane toad toxin acted as a selection pressure on the snake populations.

Question 11 (1 MARK)

Russian scientists have been running a long-term experiment since the 1950s to simulate the domestication of dogs by ancient humans. The scientists started with a group of wild silver foxes and, over time, bred foxes with traits typical of domesticated dogs. During the experiment, the scientists would have

A bred aggressive and loud foxes.
B noticed a change in the appearance of the experimental foxes compared to the wild population.
C observed no change in allelic diversity between selectively bred and wild foxes.
D kept the foxes isolated from humans.

Adapted from VCAA 2018 Section A Q22

Question 12 (1 MARK)

The myxoma virus was introduced to Australia in 1950 to control pest rabbits. The disease is spread by direct contact with infected animals, or by a flea or mosquito vector. In the first two years after release, it reduced the rabbit population from 600 million to 100 million. Now, the virus is less effective, killing only about 50% of infected rabbits.

The cause of increased resistance to the virus is most likely due to

A pest controllers successively reducing the levels of virus released into pest rabbit populations.
B the virus producing a change in a gene which enhanced the survival of the rabbit.
C a chance mutation in a rabbit gene conferring a survival advantage to some individuals.
D the virus producing a change in phenotype which enhanced reproduction of the rabbit.

SECTION B (28 MARKS)

Question 13 (4 MARKS)

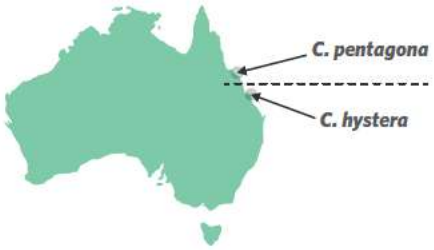
The Kākāpō (*Strigops habroptilus*) is a species of large, nocturnal, flightless, and ground-dwelling parrots native to New Zealand. The total size of the known adult population is only 148 individuals, mostly located on two predator-free islands.

a With reference to selection pressures, suggest why populations of Kākāpō are only found on predator-free islands. (1 MARK)

b Referring to the theory of natural selection, explain why the Kākāpō is at risk of extinction. (3 MARKS)

Question 14 (4 MARKS)

Two species of *Cryptasterina* sea stars are found in coastal Queensland. *Cryptasterina pentagona* is found in warmer water further north, while *Cryptasterina hystera* is found further south in cooler water.



Researchers have concluded that these two species arose from a recent common ancestor via natural selection.

a Identify a possible selection pressure that may have driven natural selection for these two sea star species. (1 MARK)

b Explain how this selection pressure could have led to speciation in *Cryptasterina* sea stars. (3 MARKS)

Question 15 (4 MARKS)

Over the past million years, Australia's climate has become much drier, leading to reduced areas of woodlands.

This reduction of woodlands has resulted in fragmented patches of habitat, creating a geographical barrier between spider populations.

Studies of different spider species from various woodlands show they share a recent common ancestor dating back to just before the climate began to become drier.

a Which process of evolution has likely affected the spider species? Justify your response. (2 MARKS)

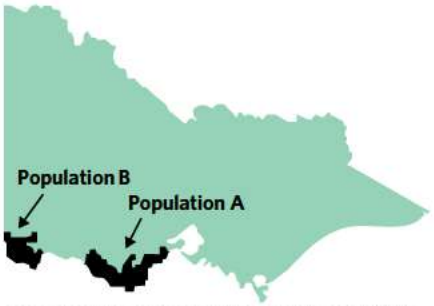
b If two spiders from different species successfully produced a fertile offspring, would this suggest the spiders are actually the same species? Explain why. (2 MARKS)

Question 16 (5 MARKS)

The rufous bristlebird (*Dasyornis broadbenti)* is a ground-dwelling songbird. The rufous bristlebird is found in gardens near thick, natural vegetation, and builds nests in shrubs close to the ground.

The rufous bristlebird feeds on ground-dwelling invertebrates. It is a weak flyer and is unlikely to repopulate areas where it has become locally extinct. Two distinct populations of rufous bristlebird exist in Victoria.

The distribution of each population is shown on the map of Victoria. The distance between Population A and Population B is over 200 km.



Source: Department of Sustainability and Environment (2003), as adapted by VCAA 2017 Section B Q5

a Population B has a smaller population size and a lower genetic diversity than Population A.

i Describe the 'founder effect'. (2 MARKS)

ii Explain whether genetic drift likely occurred in the bristlebird populations. (1 MARK)

b Identify whether gene flow would affect the rufous bristlebird populations. Justify your response. (2 MARKS)

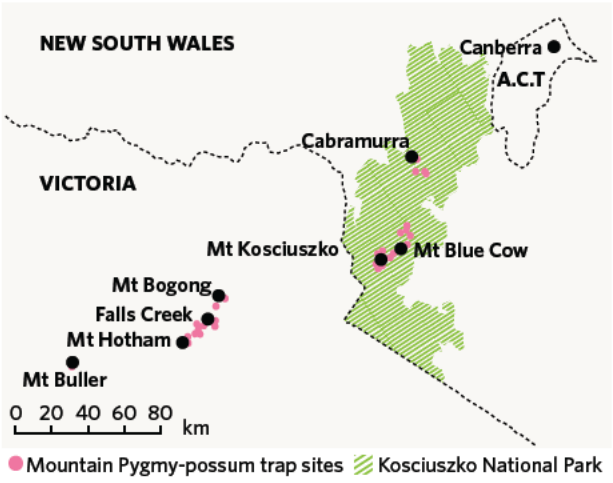
Adapted from VCAA 2017 Section B Q5a

Question 17 (11 MARKS)

The mountain pygmy-possum (*Burramys parvus)* is a highly specialised marsupial with a small total population restricted to fragmented subpopulations in the alpine and sub-alpine regions of Victoria and New South Wales shown in the map. They were thought extinct but were rediscovered in 1966.

Since then, many of the known populations have declined. For instance, on Mt Buller the population declined from around 350 adults in 1996 to a low of around 40 adults in 2008. Due to ongoing threats, the mountain pygmy-possum was declared 'Critically Endangered' by the International Union for Conservation of Nature (IUCN).

Over the past decades scientists have surveyed the populations, monitored population size and the number of heterozygous individuals, and established partnerships with nearby ski-resort managers to help raise the profile of the species.

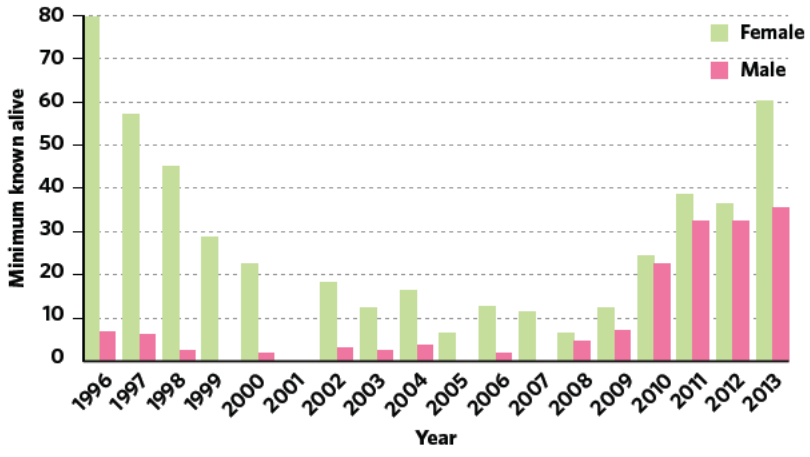


Source: adapted from Garnett, Woinarski, Lindenmayer, & Peter (2018)

a Explain why scientists tested the proportion of heterozygous individuals and population size in the populations of mountain pygmy-possum. (3 MARKS)

b Suggest how scientists could tell if gene flow was occurring between the Mt Buller and Mt Hotham populations of mountain pygmy-possum. (2 MARKS)

c The figure shows the data that scientists collected from the Mt Buller pygmy-possum population. The figure includes any individuals that were translocated to Mt Buller.



Source: adapted from Garnett, Woinarski, Lindenmayer, & Peter (2018)

i Describe the trend in male and female pygmy-possum abundance from 1996–2013. Include data in your answer. (3 MARKS)

ii Over two consecutive years, scientists translocated 12 male pygmy-possums from the Mt Hotham to the Mt Buller population. Identify which years these may have been. (1 MARK)

iii Name the evolutionary process that is being imitated artificially by humans. (1 MARK)

iv Suggest a benefit of the translocation of male individuals. (1 MARK)

UNIT 4 AOS 1, CHAPTER 12

History of life on Earth

12

12A Timeline of life on Earth

12B Fossils

12C Evidence of ancient life on Earth

12D Patterns of biological change

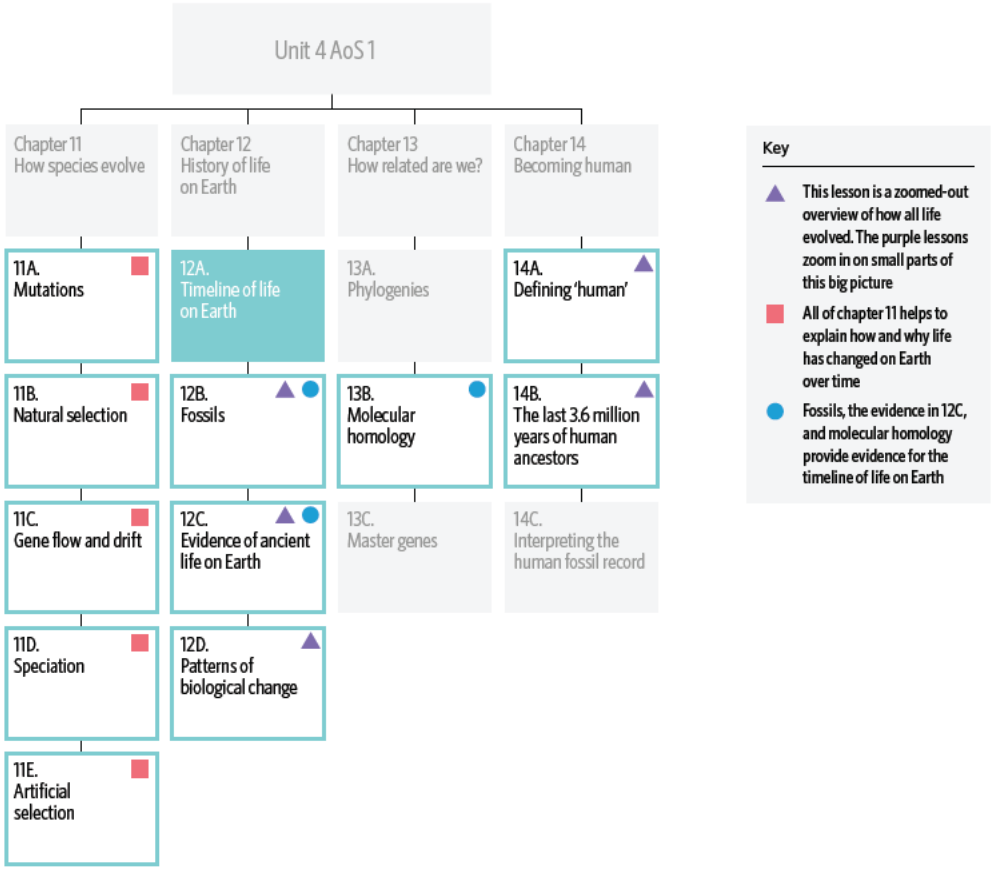
Key knowledge

- significant changes in life forms in Earth's geological history including the rise of multicellular organisms, animals on land, the first flowering plants, and mammals
- evidence of biological change over time including from palaeontology (the fossil record, the relative and absolute dating of fossils, types of fossils and the steps in fossilisation), biogeography, developmental biology and structural morphology
- patterns of biological change over geological time including divergent evolution, convergent evolution, and mass extinctions

Image: Abrilla/Shutterstock.com

12A TIMELINE OF LIFE ON EARTH

Scientists don't know how life started on Earth. What scientists do know is that there is no evidence of living things on Earth over four billion years ago, but simple bacterial cells existed on Earth 3.5 – 3.8 billion years ago. All the living things we see around us today are descendants of these ancient bacterial cells.



In this lesson you will learn about the major events in biology over the past four billion years.

Study design dot point

- significant changes in life forms in Earth's geological history including the rise of multicellular organisms, animals on land, the first flowering plants, and mammals

Key knowledge unit

From prokaryote to mammal	4.1.4.1

From prokaryote to mammal 4.1.4.1

OVERVIEW

The significant moments in Earth's biological history are: the emergence of prokaryotes (3.5 **bya**), widespread photosynthesis (2.4 bya), the first eukaryotes (2 bya), the first multicellular organisms (900 **mya**), the Cambrian explosion (535 mya), animals on land (400-530 mya), mammals (220 mya), and flowering plants (160 mya).

bya short for 'billion years ago'. Also written as **Ba** and **Ga**

mya short for 'million years ago'. Also written as **Ma**

THEORY DETAILS

Fossil and molecular evidence leave clues for scientists to trace back in time where and when certain living things evolved. You should know this is really hard to do, and scientists argue about their findings a lot. For instance, the origin of life on Earth is unknown. Some scientists theorise that the first single-celled organism arrived on a meteor from outer space.

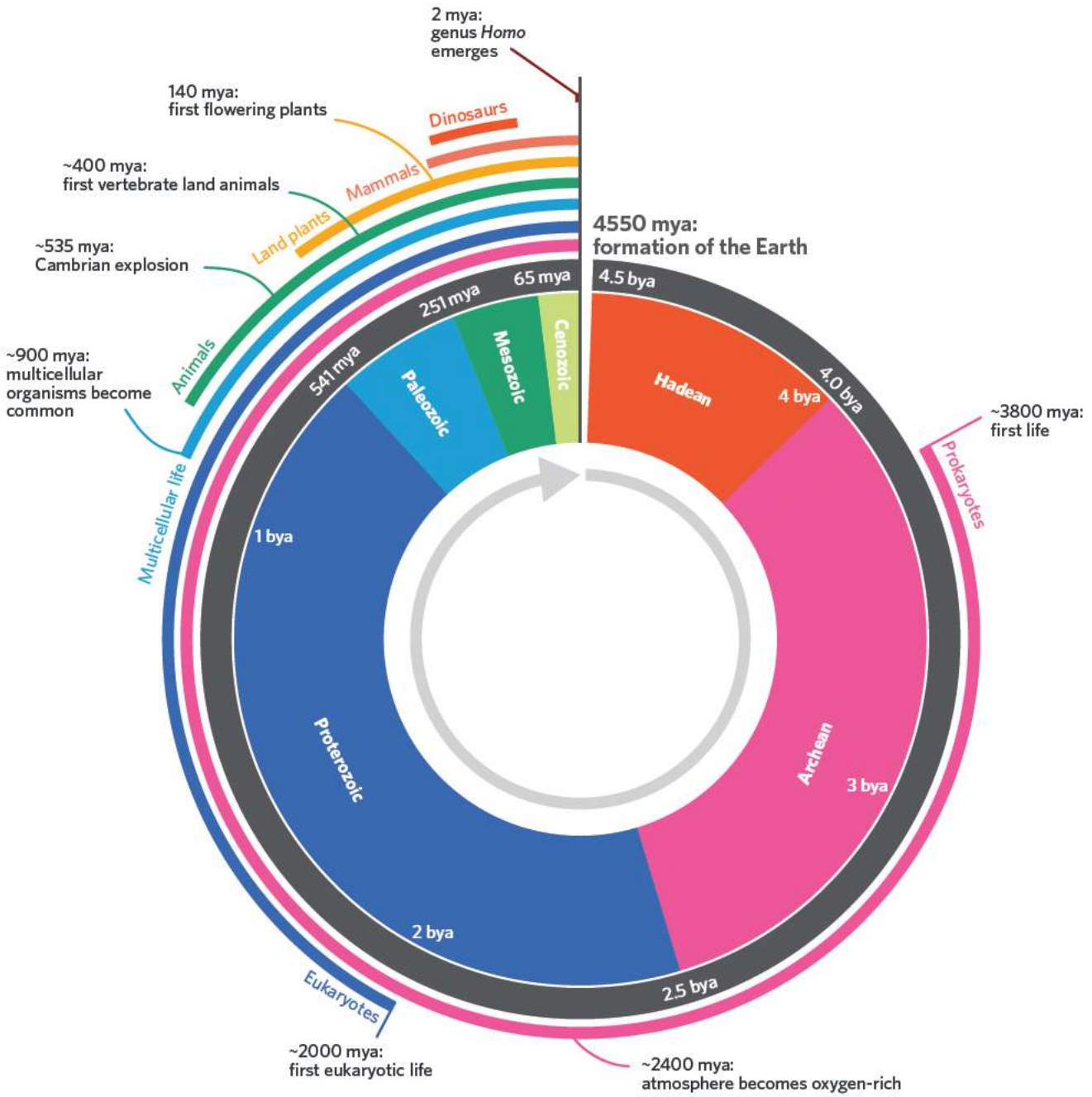


Figure 1 A timeline of the key biological events on Earth from 4.5 bya, including the rise of multicellular organisms, animals on land, the first flowering plants, and mammals.

Others suggest that, in the highly reactive environment of early Earth, organic molecules mutated to become self-replicating polymers that eventually were encased in a lipid bubble, and this 'protocell' evolved into more complex cells. In turn, protocells evolved to become all the diverse life forms you see around today – from your desk buddy, to the tomato in your sandwich, from the bacteria in your guts that aid digestion, to the mould growing on the old yoghurt in your fridge at home.

In this lesson, you will focus on the key events in biological history that are mostly undisputed by specialists.

3.5 billion years ago: prokaryotes

Scientists' best guess is that life evolved on Earth 3.8 bya near hydrothermal ocean vents, about 700 million years after the formation of the planet. The first solid piece of fossil evidence of life dates back to ~3.5 bya, in the form of **stromatolites**. There are a few key things you should remember about stromatolites:

- They are made by photosynthesising **prokaryotes** - like cyanobacteria.
- Stromatolites form layered rocks made of carbonate or silicate.
- Although most stromatolites are artifacts from the past, there are places on Earth where stromatolites are still forming.

geological time scale a system of chronological dating described in eras, eons, periods, epochs, and ages

stromatolite a rock structure formed when minerals (e.g. limestone) are trapped by prokaryotes

prokaryote a group of single-celled organisms with no nucleus and a circular loop of DNA. Bacteria and archaea are both prokaryotic

2.4 billion years ago: oxygenated atmosphere

It is likely that other bacteria and **archaea** existed at this time. However, during the first two billion years of Earth's existence the atmosphere had very little oxygen. Only **autotrophs** that could grow without oxygen were able to survive. But, by ~2.4 bya, the **phototrophs** had evolved and made the Earth's atmosphere oxygen-rich. Higher oxygen levels led to:

- Establishment of a thick ozone layer in the atmosphere. The ozone layer protects organisms from UV radiation.
- Development of the aerobic cellular respiration metabolic pathway. This meant organisms could produce more ATP, be larger, and have higher-energy lifestyles.

2 billion years ago: eukaryotes

You should remember from Unit 3 that mitochondria and chloroplasts have bacterial origins. Scientists believe that, around two billion years ago, the free-living prokaryotic ancestor of mitochondria was engulfed by a larger prokaryote but not destroyed. The larger prokaryote provided protection for the smaller prokaryote, and the smaller prokaryote supplied its host with ATP. These **endosymbiotic** cells were the first **eukaryotes** and may have looked a bit like a modern-day **protist**. Later, some of the eukaryotes ingested phototrophic bacteria and formed a second endosymbiotic relationship. Through many millions of years of evolution, these ingested bacteria became more specialised in their functions until the aerobic bacteria evolved into mitochondria and the phototrophic bacteria became chloroplasts.

900 million years ago: multicellularity

Multicellularity evolved ~900 mya as colonies of cells became dependent on living together. Certain cells in the colony developed more specialised functions and became tissues, which eventually combined to form organs. We don't know a lot about what the first multicellular animals looked like, as there is very little fossil evidence. They probably had soft, jelly-like bodies, similar to sponges or jellyfish.

535 million years ago: the Cambrian explosion

The **Cambrian** explosion (~535 mya) marked a drastic increase in the number of fossils in the fossil record. Fossils show that life forms rapidly evolved and diversified, resulting in animals and plants with very strange body plans, like those in Figures 3, 4, and 5. For the first time, animals with hard body parts (e.g. molluscs, echinoderms, and arthropods) and bilateral symmetry (e.g. trilobites and fish) appeared. This includes the first vertebrates, which evolved from jawless fishes and likely resembled lamprey or hagfish.

The very first fossil footprints on land were made around 500 mya by a lobster-sized centipede that ventured ashore occasionally. In contrast, evidence suggests that plants and vertebrates did not leave the ocean until around 465 and 400 mya respectively.

Image: totajila/Shutterstock.com

Figure 2 Stromatolites in Shark Bay, Western Australia

archaea a domain of prokaryotic cell that is similar in size and structure to bacteria, but are different genetically and usually live in extreme environments

autotroph an organism that makes its own food from inorganic substances. Phototrophs and chemotrophs are examples of autotrophs

phototroph an organism that uses light energy to make organic compounds for nutrition

endosymbiosis when one organism lives inside another in a mutually beneficial relationship

eukaryote a group of single and multi-celled organisms with a nucleus and linear strands of DNA. Animals, plants, fungi, and protists are eukaryotic

protist a single-celled eukaryote from the kingdom Protista. Examples include amoeba and algae

multicellular an organism that consists of more than one cell. Most multicellular organisms have different cells (or groups of cells) specialised for different functions

Cambrian a geological time period ~535 mya during which many new groups of living things evolved, including major phyla that still exist today

Image: Merlin74/Shutterstock.com

Figure 3 Trilobite fossils

Image: Catmando/Shutterstock.com

Figure 4 Artist's rendition of *Anomalocaris*, which were over one metre long and evolved during the Cambrian explosion

Image: Dotted Yeti/Shutterstock.com

Figure 5 Artist's rendition of *Hallucigenia* which evolved during the Cambrian explosion

Tip VCAA commonly test the order in which particular life forms evolve (rather than specific dates). You should be able to explain how life has evolved from very small and simple cells into larger, more specialised, and complex organisms.

230 million years ago to present: dinosaurs, mammals, and flowering plants

Once basic cell structure and successful body plans had been tried and tested, the evolution of the major phyla continued. The final quarter of a billion years of life on Earth were marked by some key events:

- 230 mya: the first dinosaurs diverge from archosaur ancestors
- 220 mya: mammals evolve from the reptile-like cynodonts
- 150 mya: the first bird, *Archaeopteryx*, lives in Europe
- 140 mya: the first **flowering plants** emerge; before now, only plants that reproduce with spores and cones would have existed
- 100 mya: the peak of the age of the dinosaurs
- 70 mya: grasses evolve
- 65 mya: the Cretaceous-Paleogene extinction wipes out the dinosaurs and clears the way for mammal adaptive radiation
- 63 mya: primates split into two groups: the haplorhines (which will evolve into apes and humans) and the strepsirrhines (which become lemurs and aye-ayes)
- 6 mya: the last common ancestor of humans, chimpanzees, and bonobos
- 400 000 – 200 000 years ago: *Homo sapiens* evolve.

flowering plants a group of plants that reproduce using flowers, fruit, and seeds (as opposed to plants like moss, ferns, and conifers, which reproduce with spores or cones). Also known as **angiosperms**

Theory summary

All living things on Earth evolved from single-celled prokaryotes that existed 3.5 bya. Photosynthesis was developed, then endosymbiosis led to the rise of eukaryotes. From here, multicellularity arose and the Cambrian explosion 530 mya marked a massive rise in diversity of living things. Eventually, animals and plants conquered land and, once the dinosaurs went extinct, mammals became widespread.

Tip Many people make the mistake of thinking that fungi are plants, but this is actually incorrect! Evidence suggests that fungi are more closely related to animals than they are to plants.

12A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the key geological time period where life rapidly diversified and trilobites first emerged

b _____ the earliest evidence of living things on Earth

c _____ cells with a circular loop of DNA and no membrane-bound organelles

d _____ the type of plant that emerged after plants that could reproduce with spores and cones

e _____ single-celled eukaryotes belonging to the phylum Protista

Question 2

Which of the following shows the correct order of events in biological history, from most ancient to most recent?

A	Multicellular life evolves	Eukaryotes evolve	Chordates evolve	*Homo sapiens* evolve
B	Eukaryotes evolve	Prokaryotes evolve	Multicellular life evolves	The Cambrian explosion occurs
C	Prokaryotes evolve	Eukaryotes evolve	The Cambrian explosion occurs	Simple, soft-bodied animals evolve
D	Eukaryotes evolve	Multicellularity evolves	Mammals evolve	Flowering plants evolve

Question 3

Identify the following organisms as prokaryotic or eukaryotic.

I Archaea

II Trilobites

III Cyanobacteria

IV Protists

V Flowering Plants

VI Bacteria

VII Fungi

	Prokaryotic	Eukaryotic
A	I, III, IV, VI, VII	II, V
B	I, III, VI	II, IV, V, VII
C	I, III, IV, VI	II, V, VII
D	II, III, VI	I, II, IV, V, VII

Question 4

Which timeline correctly shows when key life forms evolved on Earth?

A

B

C

D

Question 5

Fill in the blanks in the following sentence.

_____**I**_____ emerged after _____**II**_____ via the process of endosymbiosis, whereby first _____**III**_____ bacteria and then _____**IV**_____ bacteria were engulfed but not destroyed by a host cell.

	I	II	III	IV
A	Eukaryotes	prokaryotes	photosynthesising	respiring
B	Prokaryotes	eukaryotes	respiring	photosynthesising
C	Eukaryotes	prokaryotes	respiring	photosynthesising
D	Prokaryotes	eukaryotes	photosynthesising	respiring

Exam-style questions

Within lesson

Question 6 (1 MARK)

Different groups of living things emerged at different times in Earth's history. Which of the following shows the correct placement of the organisms, in order from most recent to most ancient?

A multicellular organisms - unicellular organisms - photosynthetic organisms - eukaryotes

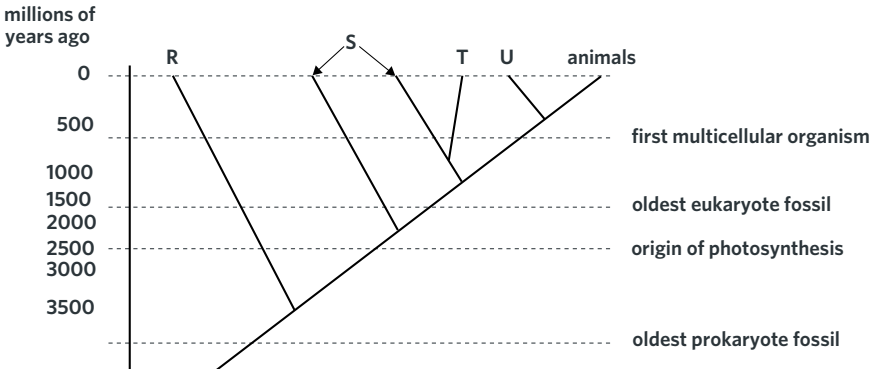
B photosynthetic organisms - multicellular organisms - eukaryotes - prokaryotes

C multicellular plants - eukaryotes - photosynthetic organisms - prokaryotes

D mammals - dinosaurs - birds - fish

Question 7 (1 MARK)

The phylogenetic tree shown represents one model of the order and approximate time of appearance of the major groups of living organisms and includes four groups represented by the letters R, S, T, and U.



Which of the following shows the correct placement of the organisms on the phylogenetic tree?

A R - prokaryotes, S - plants, T - protists, U - fungi

B R - archaea, S - fungi, T - protists, U - plants

C R - prokaryotes, S - protists, T - plants, U - fungi

D R - prokaryotes, S - protists, T - fungi, U - plants

Adapted from VCAA 2017 Section A Q32

Use the following information to answer questions 8 and 9.

The fossils pictured were found in the Burgess shale in Canada. They date back to the Cambrian explosion (510 – 570 mya).

Image: Merlin74/Shutterstock.com

Question 8 (1 MARK)

Using your understanding of Earth's geological history, these fossils would likely be an early example of

A flowering plants.

B multicellular organisms.

C arthropods.

D prokaryotes.

Question 9 (1 MARK)

The Cambrian explosion was an important period in Earth's history. It is marked by

A large amounts of volcanic activity around Indonesia.

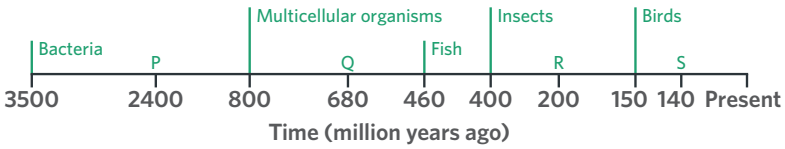
B a massive diversification in animal phyla.

C the emergence of dinosaurs.

D the first land plants and animals.

Question 10 (1 MARK)

The timeline pictured summarises the first appearance of some major groups of organisms in the evolution of life on Earth, as indicated by the fossil record. Four major groups are missing from the timeline and are represented by the letters P, Q, R, and S.



What are the correct groups of organisms labelled P, Q, R, and S?

	P	Q	R	S
A	Cyanobacteria	Flowering plants	Reptiles	Mammals
B	Cyanobacteria	Protists	Mammals	Flowering plants
C	Eukaryotes	Soft-bodied vertebrates	Flowering plants	Primates
D	Photosynthetic bacteria	Corals	Mammals	Flowering plants

Adapted from VCAA 2018 Section A Q27

Question 11 (4 MARKS)

Fossils found in Australia include representatives from across the ages of life on Earth. The table shows some of the groups of fossils found in Australia and their ages.

Type of fossil	Location	Geological time	Age
Stromatolites	Arkaroola, South Australia	Precambrian era	770 mya
Jellyfish	Flinders Ranges, South Australia	Ediacaran period	645-542 mya
Dinosaurs	many places, including Queensland and Victoria	Jurassic and Cretaceous periods	200-65 mya
Megafauna (large marsupials and flightless birds)	Naracoorte, South Australia	Cainozoic era	65-7000 ya

a The Cambrian period was after the Precambrian era and the Ediacaran period. Describe an organism that evolved on Earth during the Cambrian period. (2 MARKS)

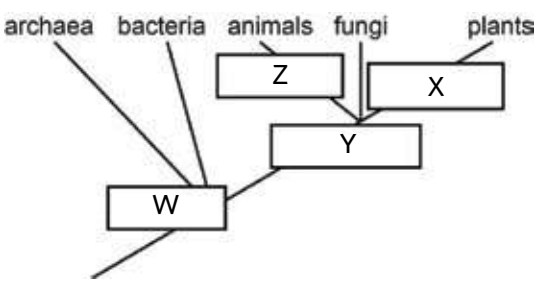
b Some stromatolites have been dated to 3500 mya. Would these stromatolites have been formed by prokaryotic or eukaryotic organisms? Justify your response. (2 MARKS)

Adapted from VCAA 2017 Sample Exam Section B Q7a

Multiple lessons

Question 12 (1 MARK)

Consider the evolution of mitochondria and chloroplasts. The diagram represents one model of the order of appearance of these organelles into groups of living things.



Which of the following shows the correct placement of the organelles on the model?

A W - chloroplasts, Y - mitochondria

B X - chloroplasts, Z - mitochondria

C Y - mitochondria, X - chloroplasts

D W - mitochondria, Y - chloroplasts

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q23

Question 13 (6 MARKS)

The early development of an oxygen-containing atmosphere approximately 2.45 – 2.22 billion years ago is attributed to the photosynthetic activity of ancient cyanobacteria.

a Explain why developing an oxygen-rich atmosphere was important to the development of life on Earth. (2 MARKS)

b Cyanobacteria are photosynthetic prokaryotes. Mountain ash, *Eucalyptus regnans*, are the tallest flowering plants on Earth.

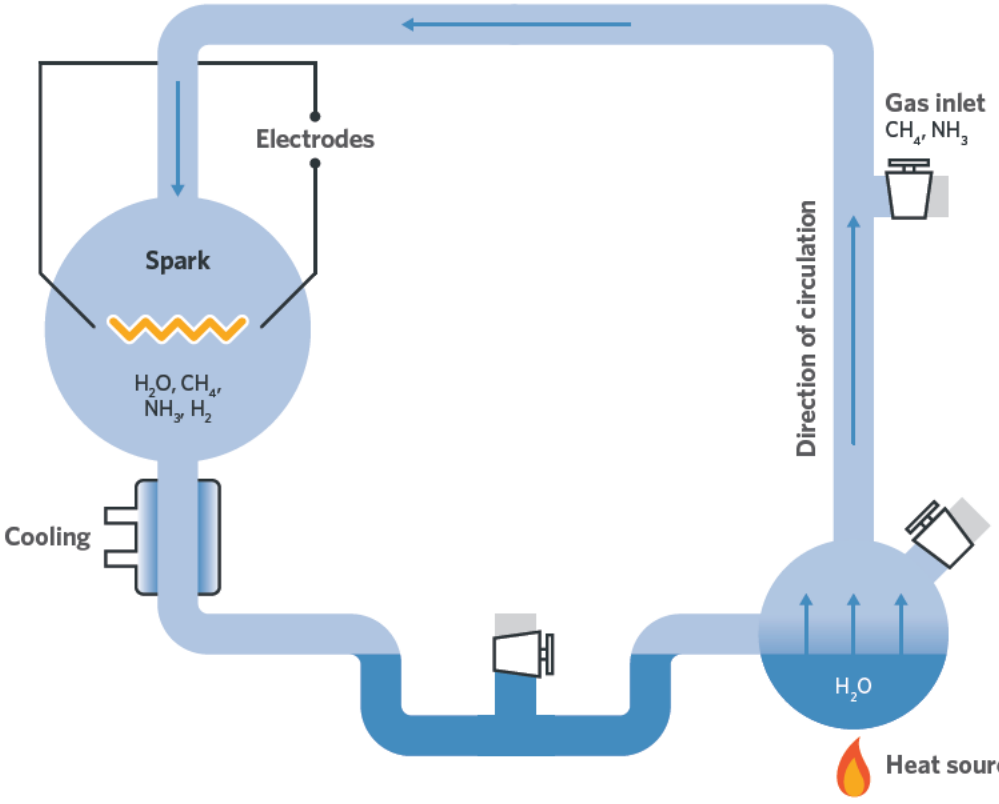
i Using your understanding of endosymbiosis, explain how cyanobacteria were crucial for the evolution of multicellular land plants like the mountain ash. (2 MARKS)

ii Identify one similarity and one difference between the cells of cyanobacteria and mountain ash. (2 MARKS)

Key science skills

Question 14 (7 MARKS)

In 1952, the scientists Stanley Miller and Harold Urey attempted to simulate the conditions of the four billion-year-old Earth in an experiment. They sealed water, methane, ammonia, and hydrogen inside a 5 L sterile flask connected to a 500 mL flask of water. The water in the 500 mL flask was heated for evaporation, and continuous electrical sparks were fired to imitate lightning. After a time, the simulated atmosphere was cooled again so that the water condensed.



After one day, the solution had turned pink. The experiment was finished after one week, and the scientists tested the solution for organic compounds. They found five amino acids. The experiment was the first to prove that organic compounds could be synthesized from inorganic compounds in an early Earth-like simulation.

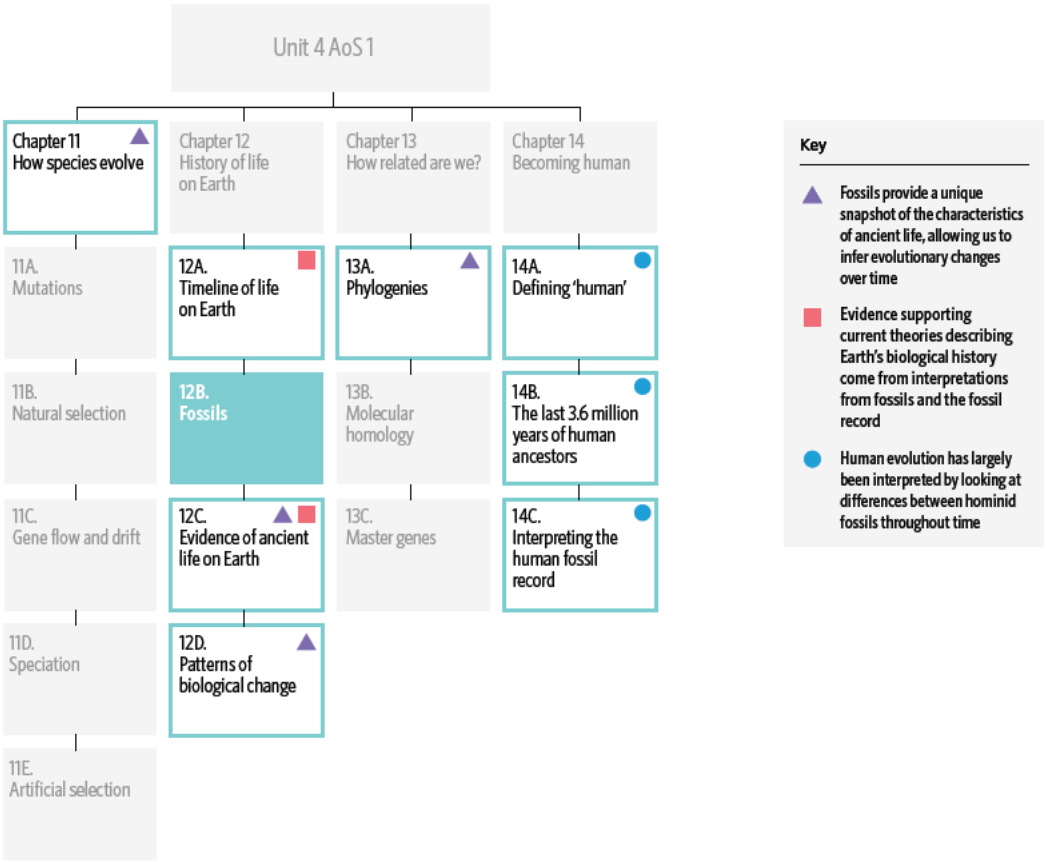
a Identify two ways in which the scientists attempted to simulate conditions of early Earth. (2 MARKS)

b Miller and Urey did not replicate this experiment. Explain the consequences of poor replicability. (2 MARKS)

c If someone were to attempt to replicate this experiment, identify three factors that should remain constant across each replicate. (3 MARKS)

12B FOSSILS

Teeth, skeletons, footprints, and more shells than anyone can realistically care about. Fossils can tell us so much about Earth's history, but first, we have to be able to interpret them.



Much of our current knowledge concerning the biological history of Earth and the effects of evolution was built upon observations of fossils. **In this lesson** you will learn how fossils are formed, and the techniques we can use to determine their age.

Study design dot point

- evidence of biological change over time including from palaeontology (the fossil record, the relative and absolute dating of fossils, types of fossils and the steps in fossilisation), biogeography, developmental biology and structural morphology

Key knowledge units

How to make a fossil	4.1.5.1
Types of fossils	4.1.5.2
Fossil dating	4.1.5.3

How to make a fossil 4.1.5.1

OVERVIEW

Usually when an animal dies, its body decomposes or is consumed. But sometimes, given the right set of conditions, this body can be preserved through one of the many processes of fossilisation.

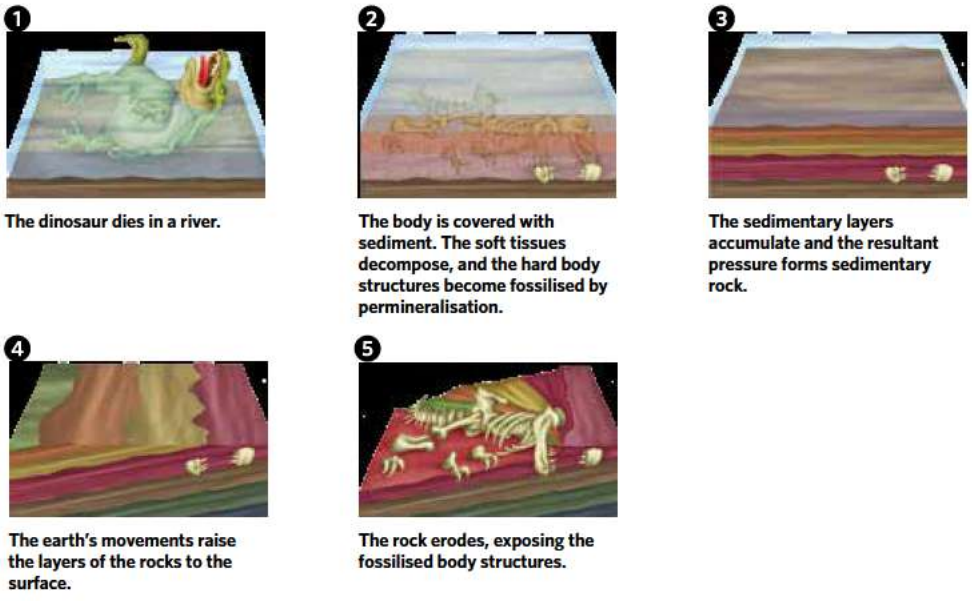


Image: stihii/Shutterstock.com

Figure 1 The process of a dinosaur becoming a fossil by permineralisation after being buried within sedimentary rock

THEORY DETAILS

Fossils are the preserved remains of long-dead organisms that have somehow escaped the ever-pressing onslaught of time and decay, and provide a snapshot into the biological history of the Earth. The process of **fossilisation** usually begins when remnants of an organism are rapidly covered by sediment. Over time, these layers of sediment build up upon each other and pressure pushes these layers together forming **sedimentary rock**. When devoid of oxygen, microorganisms, and other disturbances the remains are preserved until they can be classified into one of the four main types of fossils (discussed below in 'Types of fossils').

fossil the preserved body, impressions, or traces of an ancient organism

fossilisation the process by which an organism becomes a fossil

sedimentary rock rock that has formed through the accumulation of sediment and hardening under pressure

Conditions that reduce the rate of decomposition typically increase an organism's chance of becoming fossilised. These conditions include:

- areas of rapid sediment accumulation
- constant cool temperatures
- low light availability
- physical protection from scavengers and decomposers (e.g. fungi, bacteria).

For example, as aquatic systems regularly deposit large amounts of sediment, many aquatic animals and plants are preserved.

Types of fossils 4.1.5.2

OVERVIEW

Fossils can be categorised into four main types: permineralised, impression, trace, and mummified fossils.

THEORY DETAILS

Permineralised fossils

Groundwater contains many different minerals such as silica, sulphur, and carbonates. When organic material is trapped within sedimentary rock below the groundwater line, the groundwater slowly seeps through pores in the organic material, depositing hard minerals in the process. Over time, all organic material is eventually replaced by these hard minerals but the shape of the organic material stays the same. Soft organic tissues are not usually preserved as these decompose quickly whereas the hardest parts of the body (such as the skeleton) typically undergo the process of permineralisation. **Permineralised fossils** represent the fossils that most people tend to think of.

permineralised fossil a fossil formed when organic matter is gradually replaced by hard minerals. Also known as a **mineralised fossil**

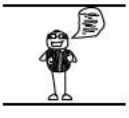



Image: marco3t/Shutterstock.com


Image: PRILL/Shutterstock.com

Figure 2 The remains of an *Ammonite* (left), an ancient and widespread form of marine life, and a reptile-like tetrapod *Seymouria* (right), formed by permineralisation. The *Ammonite* and *Seymouria* fossils are not actually made of shell and bone, but of minerals that have hardened into rocks in the shape of shell and bone.

impression fossil a fossil formed when an organism is encased in material but decomposes or is removed and the gap is filled with another substance. Also known as **cast** and **mould fossils**

trace fossil fossils of objects or structures indicating the presence of organisms, rather than the organisms themselves (e.g. nests, footprints, and burrows)

mummified fossil a fossil formed when the body is under conditions that slow down or stop the decaying process

Impression fossils

Impression fossils include cast and mould fossils, although these two fossils are slightly different. Fossils within this category show the shape of an ancient organism, but no organic material is preserved. When the body of a plant or animal leaves an impression in soft sediment but either decomposes or is removed, this creates a mould**.** The resultant impression can then be filled with other materials and covered by sedimentary layers, creating a cast. Over time, this is fossilised within sedimentary rock.


Image: Lillian+Tveit/Shutterstock.com


Image: tazabreu/Shutterstock.com

Figure 3 Fossilised impressions from leaves (left) and shells (right) in sedimentary rock are examples of impression fossils.

Trace fossils

Trace fossils are more difficult to define. Rather than the actual body being fossilised, records of an organism's biological activity are fossilised. Trace fossils can be created in a number of ways depending on the nature of the fossil. For instance, faeces can become permineralised and footprints can become moulds. Other trace fossils include burrows, bird nests, and stromatolites.


Image: marco3t/Shutterstock.com

Figure 4 This fossilised tridactyl dinosaur footprint (top) and stromatolites (bottom) are examples of trace fossils.

> ***Tip*** VCAA particularly likes to assess the formation of stromatolites. They are formed when sediment gets trapped within algal mats of cyanobacteria that grow in successive layers. While this formation process is reminiscent of permineralised fossils, as the cyanobacteria are not preserved, stromatolites are considered a trace fossil.

Mummified fossils

Mummified fossils are not typically found in sedimentary rock. They can be found anywhere with the conditions necessary to slow down or stop the decaying process. Constant humidity, cool temperatures, lack of decomposers or scavengers, low winds, and darkness are all factors that can reduce the rate of decay. Mummified organisms have been found trapped in tree sap, frozen in ice, and in dry caves.

Figure 5 The mummified remains of a baby woolly mammoth, frozen in ice for 37 000 years

Fossil dating 4.1.5.3

OVERVIEW

Now that we have dug up all these fossils, we should probably figure out their age. This can be determined by analysing the atomic structure of fossils or by inferring their age relative to other fossils.

THEORY DETAILS

Absolute dating

Absolute dating techniques can be used to calculate the **absolute** age of a fossil. While there are many absolute dating techniques, such as luminescence and electron spin resonance, VCAA generally only assess **radiometric dating** methods, and only these will be discussed here.

absolute age provides an estimate of the age (in years) of a fossil or rock

radiometric dating a dating technique used to determine the absolute age of a fossil by measuring the relative amounts of radioisotopes to their products

> ***Tip*** VCAA has never tested if students know the procedures of luminescence or electron spin resonance, but they do expect you to know of their existence.

A **radioisotope** (or radioactive isotope) is an unstable form of the element it is named after. Due to its instability, the radioisotope can spontaneously break down into a more stable product. For instance, carbon-14 breaks down into nitrogen-14.

radioisotope a radioactive atom of a specific element. This atom breaks down into a more predictable and stable product

While these radioisotopes can break down at any point, on average the rate of breakdown is constant and can be modelled. The **half-life** characterises this breakdown, describing the amount of time before half the mass of a radioisotope is broken down into predictable and stable products. You can see in Table 1 that the half-life of carbon-14 is 5 730 years. This means that if an organism had 100 atoms of carbon-14 in it, and a scientist found a mummy of that individual 5 730 years after it died, there would only be 50 atoms of carbon-14 left, along with 50 atoms of nitrogen-14. The half-life varies between radioisotopes, as shown in Table 1.

half-life the time taken for half the mass of a radioisotope to break down into its products

Table 1 Summary of radiometric dating pathways commonly assessed by VCAA

Radioisotope series	Half-life	Dating period	Dating of
Carbon-14 – nitrogen-14	5 730 years	1 000–50 000 years	Organic materials
Uranium-235 – lead-207	700 million years	1 million–4.5 billion years (used together with U-238 – Pb-206 dating)	Uranium-containing materials (shells, corals)
Uranium-238 – lead-206	4.5 billion years	1 million–4.5 billion years (used together with U-235 – Pb-207 dating)	Uranium-containing materials (shells, corals)
Potassium-40 – argon-40	1.3 billion years	100 000+ years	Igneous (volcanic) rocks

This gradual decay of radioisotopes is integral to the accurate dating of fossils and rocks. By comparing the ratio of a radioisotope to its broken-down product, we can calculate how much of this radioisotope has decayed.

Then, using the half-life, we can calculate the absolute age of the sample. However, absolute dating can be unreliable if there are very low levels of radioisotope, or if a fossil is too old or young for the radioisotopes present in the sample.

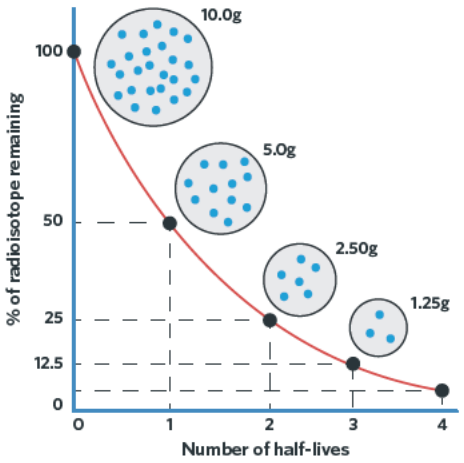


Figure 6 Graph showing the rate of decay of a radioisotope over multiple half-lives

Tip Because carbon-14 decays over time but carbon-12 is relatively stable, scientists can also measure the ratio of carbon-14 to carbon-12 to determine the absolute age of organic material. However, VCAA tends to test the carbon-nitrogen decay pathway more often.

Relative dating

It can be difficult to calculate the absolute age of fossils due to reduced availability of suitable radioisotopes. In these cases, the **relative age** of a fossil can be obtained. This estimates a fossil's age compared to the known absolute ages of fossils or volcanic rocks in other **strata** in sedimentary rock. Calculating the absolute age of sedimentary rock should be avoided, as the sediment layers may be comprised of rocks much older than the sedimentary rock itself.

The principle of **fossil succession** shows how the age of fossils in the sedimentary rock can be understood relative to other fossils. As sedimentary rock is formed by the accumulation of sedimentary layers on top of each other, fossils closest to the surface will always be the youngest, and the further down you find a fossil, the older this fossil will be.

An **index fossil** can be used to quickly and easily define the relative age of a target fossil. For the best index fossils, the species must be physically distinctive, have had a large population, have existed in many geographical areas, and only lived within a known short period. Trilobites are excellent index fossils as each species tended to exist over a large range and distinct time period. Fossils that do not meet these criteria can be used, but the conclusions will be less accurate. If your target fossil is found in the same sedimentary layer as this index fossil, then the age of the two fossils are approximately the same. If your fossil is found in a higher or lower stratum, then the age can be defined using the principle of fossil succession.

relative age the age of a fossil as determined by relative dating techniques. Describes the age of a fossil compared to other fossils, instead of a fossil's age in years

strata separate layers within sedimentary rock

fossil succession the principle that fossils of the same age will be in the same layer of sedimentary rock, and fossils found in a higher or lower sedimentary layer will be younger or older respectively. Also known as the **law of superposition**

index fossil a group of widespread fossils which existed for a short period and have a known age. Can be used as a reference to easily determine the age of unknown fossils

Theory summary

Fossils are the preserved remains of ancient life. There are four main types of fossils: permineralised, impression, trace, and mummified. Scientists estimate when fossils were formed using absolute or relative dating techniques. Absolute dating techniques reveal the age of a fossil in years by analysing the breakdown of radioisotopes. Relative dating techniques indicate a fossil's age by analysing its position in sedimentary rock compared to other fossils.

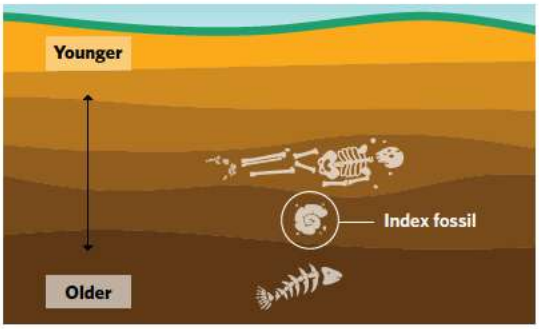


Figure 7 Relative dating to determine the approximate ages of fossils trapped within different sedimentary strata

12B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ layers of matter settle down on each other, creating pressure that eventually forms this rock
b _____ an unstable atom that may radioactively decompose into a more stable element
c _____ a fossil that shows the external, two-dimensional shape of an ancient organism
d _____ preserved remains or indications of an ancient organism
e _____ a fossil showing indirect evidence of ancient animal behaviours or body structure
f _____ a type of fossil where the entire body is preserved with minimal decomposition
g _____ this value is determined through absolute dating techniques
h _____ after one of these, half of a radioisotope's atoms in the material will have undergone decomposition
i _____ fossils of organisms which existed within a short, known geological time period
j _____ a technique used to calculate the age of a sample by measuring quantities of specific atoms called isotopes
k _____ this is formed when the body of an organism gets replaced over time with inorganic minerals
l _____ this value does not describe the age of a sample but tells you its age compared to other samples
m _____ the principle describing why fossils of different ages are found at different depth

Question 2

Classify each of the following descriptions as either permineralised, impression, trace, or mummified fossils.

I Cycads (a type of plant) are commonly found as fossils in sedimentary rock. During the fossilisation process, the leaves decay completely, but a two-dimensional trace of the leaves remain.

II Scientists have found fossil evidence of ancient rabbit scratchings and droppings.

III Well-preserved bodies of the ancient woolly mammoth have been found trapped within the ice in Siberia.

IV 300 million years ago, an organism died and was covered by sedimentary layers. The body completely decomposed, leaving an empty cavity which was filled with other materials.

V 'Sue', the most complete fossilised skeleton of the *Tyrannosaurus rex*, had the organic material in the skeleton replaced with hard minerals.

VI Fossilised impressions of dinosaur footprints have been found, which scientists can use to calculate weight, stride length, and walking speed.

VII Extremely detailed fossils showing only the skeletal structure of the 'stickleback' fish have been found.

VIII Small animals can become trapped in tree resin which hardens to become amber. With no access to microbial life, the trapped animal does not decompose and is almost perfectly preserved.

	Permineralised	Impression	Trace	Mummified
A	V, VIII	I, VI	II, IV	III, VII
B	V, VII	I, IV	II, VI	III, VIII
C	IV, V	I, VII	II, VI	III, VIII
D	I, V	II, VIII	IV, VI	III, VII

Question 3

Which of the following statements regarding fossil dating is false?

A Ideally, an index fossil should represent a species that existed for a short period of time.

B Carbon-14 is commonly used when calculating the absolute age of recent fossils.

C If the remains of an animal are found within the same sedimentary layer as an index fossil, then the animal's relative age is similar to the absolute age of the index fossil.

D Scientists can calculate the absolute age by only measuring the total mass of an isotope within the fossil.

Exam-style questions

Within lesson

Question 4 (1 MARK)

Radio-isotopic dating (radiometric dating) is used to determine the age of fossils and their surrounding rocks. Which statement about radio-isotopic dating is true?

A Radio-isotopic dating techniques are only reliable when dating fossils that were formed less than 50 thousand years ago.

B Potassium is the best element to provide useful radio-isotopic evidence for calculating the age of all fossils due to its large half-life.

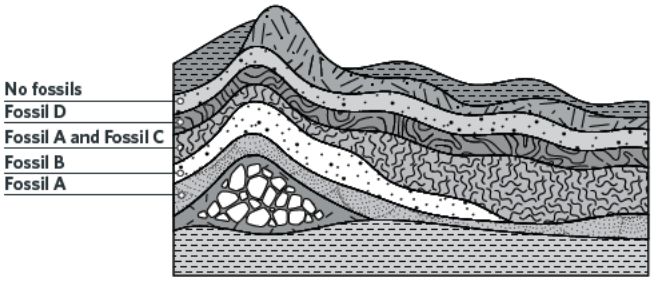
C Radio-isotope dating calculations assume that breakdown of a radioactive isotope decreases with age.

D Radio-isotopic dating techniques can be used to compare if one fossil is older than another, by providing an estimate of how many years ago each fossil was formed.

Adapted from VCAA 2017 Northern Hemisphere Section A Q34

Use the following information to answer questions 5 and 6.

The fossils present in different rock strata in a particular location are shown in the diagram.



Question 5 (1 MARK)

From the diagram above, it can be concluded that

A Fossil A is the oldest fossil present.

B Fossil A and Fossil C belong to the same species.

C Fossil A followed migratory patterns.

D all these species are extinct.

Adapted from VCAA 2017 Sample Section A Q31

Question 6 (1 MARK)

Using radiometric dating techniques, the age of Fossil C was calculated to be 60 million years old. This suggests that

A Fossil B is an ancestor of Fossil C.

B Fossil B is less than 60 million years old.

C very little carbon-14 could be found in Fossil A.

D Fossil D is an example of a mineralised fossil.

Adapted from VCAA 2017 Sample Section A Q31

Use the following information to answer questions 7 and 8.

The diagram is a reconstruction of a fossil of the ornithopod dinosaur *Diluvicursor pickeringi* found in a 113-million-year-old rock in western Victoria. The fossil consisted of a tail, a partial hind limb and some vertebrae. *D. pickeringi* grew to 2.3 m long. Evidence suggests that the dinosaur was fossilised in a log-filled hollow at the bottom of an ancient riverbed, where all the organic material in the bones of *D. pickeringi* has been replaced with inorganic material. Two stratigraphically younger fossils that had been found previously at a nearby site are closely related to *D. pickeringi*.

Question 7 (1 MARK)

It is most probable that the two stratigraphically younger fossils would have been found in a layer of rock that

A contained a smaller quantity of potassium-40 than the rock surrounding the *D. pickeringi* fossil.

B was located at a depth less than 2.3 m below the ancient riverbed.

C was formed from hot, ash sediment.

D was closer to the the present-day ground surface than the rock surrounding the *D. pickeringi* fossil.

Adapted from VCAA 2018 Section A Q25

Question 8 (1 MARK)

From the information given, what can be said about the *D. pickeringi* fossil?

A Only the tail, partial hind limb, and vertebrae were covered in sedimentary layers.

B *D. pickeringi* is an example of a mineralised fossil.

C *D. pickeringi* is an ancestor to the two stratigraphically younger fossils found at the nearby site.

D *D. pickeringi* is an example of an impression fossil.

Adapted from VCAA 2018 Section A Q25

Question 9 (1 MARK)

Which one of the following statements correctly explains why 50 000 years is the limit of the radiocarbon dating method for determining the age of fossils?

A Carbon-14 is produced when high energy light penetrates the ozone layer. As the ozone layer was too thick over 50 000 years ago to let this high energy light though, carbon-14 was rare.

B Fossils older than 50 000 years have accumulated too much carbon contamination from the surrounding rock and minerals for accurate measurements.

C After 50 000 years, almost all carbon-14 has radioactively decayed into its breakdown products, and accurate age estimations cannot be made.

D The half-life of carbon-12 is short and so, by 50 000 years, there is too little carbon-12 left to measure.

Adapted from VCAA 2017 Sample Section A Q29

Use the following information to answer Questions 10 and 11.

The image shows two thylacines (*Thylacinus cynocephalus*, also called Tasmanian tigers) at Hobart zoo in the early 1900s. Declared extinct in 1986, thylacines were large, dog-like marsupials.

A fossilised carcass of a thylacine was found in a cave on the Nullarbor Plain. The carcass was dated to about 5 000 years old.

Question 10 (1 MARK)

The most likely method used to date the thylacine carcass would involve

A concluding that the age of the thylacine was similar to the age of other fossils found within the cave.

B using radiometric techniques to date the age of rocks within the cave.

C analysing how decayed the body is and comparing to known rates of decay in similar marsupials.

D calculating the proportion of carbon-14 atoms to the products of the carbon-14 decay pathway.

Adapted from VCAA 2013 Section A Q31

Question 11 (1 MARK)

The cave on the Nullarbor Plain hosted a stable, cool, and dry internal environment with very low levels of light. The thylacine carcass was found in the open, with little evidence of serious decomposition.

What type of fossil does the thylacine carcass represent?

A Impression fossil

B Mummified organism

C Trace fossil

D Mineralised fossil

Question 12 (1 MARK)

Potassium-40 has a half-life of 1.25 billion years. In a sedimentary layer comprised of igneous rocks, the ratio of potassium-40 to its radioactive breakdown product, argon-40, is approximately 1:3.

The age of the fossils in the sedimentary layer will be close to

A 2.5 billion years.

B 5 billion years.

C 1.25 million years.

D 300 million years.

Adapted from VCAA 2015 Section A Q35

Multiple lessons

Question 13 (1 MARK)

Stromatolites are mounds that can be found across the world. They are mostly produced by single-celled organisms called cyanobacteria, which obtain energy through photosynthesis but can be formed by other single-celled organisms.

Stromatolites are formed when sediment gets trapped in the algal mats of cyanobacteria. Fossilised cells of single-celled organisms are generally not found within these stromatolites.

Which of the following is true concerning stromatolites?

A Stromatolites are considered trace fossils, as the cell bodies are not preserved within them.

B Stromatolites cannot be considered fossils, as the cell bodies are not preserved within them.

C As cyanobacteria became extinct approximately 1 billion years ago, all stromatolites must be at least 1 billion years old.

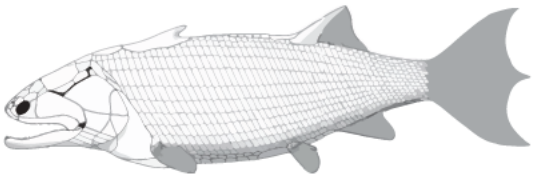
D Stromatolites cannot be found in sedimentary rock.

Adapted from VCAA 2017 Section A Q32

Question 14 (7 MARKS)

Osteichthyans are a group of fish with bony skeletons, rather than the cartilaginous skeletons found in earlier fish species.

The diagram shows the body structure of perhaps the oldest Osteichthyan to exist, where an almost complete fossil was found in China in 2009. The scientists calculated the relative age of the fossil by referring to fossils of several ancient molluscs (shellfish).



The molluscs were calculated to live 400 million years ago.

a Explain how scientists would have calculated the absolute age of the ancient mollusc fossils. (2 MARKS)

b How can the absolute age of the ancient mollusc fossils be used to estimate the age of the ancient Osteichthyan fossil? (2 MARKS)

c The Osteichthyan fossil was found in a sedimentary layer deeper than those of the ancient molluscs.
What is the relative age of the Osteichthyan fossil? (1 MARK)

d Should these ancient molluscs be used as an index fossil in the future? Explain. (1 MARK)

e Describe one important step in evolution from ancient unicellular eukaryotes to Osteichthyans. (1 MARK)

Adapted from VCAA 2018 Northern Hemisphere Section B Q7

Key science skills

Question 15 (1 MARK)

In India, a group of scientists were studying fossils from a coal deposit formed during the Permian period (245-290 million years ago). They found three fossil species from the same genus in different levels (strata) of the coal. When radiocarbon dating on these fossils was performed, it showed exactly the same levels of carbon-14 in all three fossil species. The data is summarised in the table.

Fossil species	***Gangamopteris major***	***Gangamopteris obliqua***	***Gangamopteris clarkeana***
Depth at which fossil was found in the coal deposit (m)	6.2	8.1	4.7
Proportion of carbon-14 (%)	0.0001	0.0001	0.0001

Which one of the following is the correct conclusion to draw from these findings?

A Carbon dating cannot be used in coal deposits due to high levels of carbon pollution.

B *G. obliqua* is the common evolutionary ancestor of *G. major* and *G. clarkeana*.

C There is no evolutionary relationship between these three fossil species.

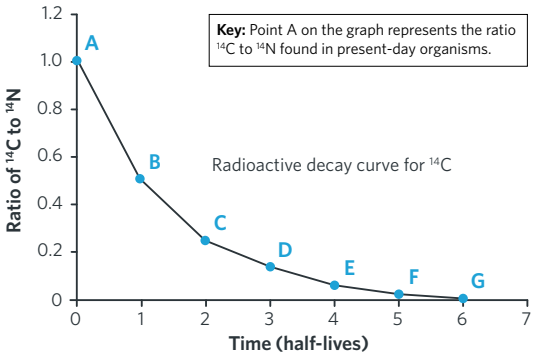
D *G. clarkeana* is the youngest fossil species present, as it is found closest to the surface.

Adapted from VCAA 2016 Section A Q38

Question 16 (2 MARKS)

One form of dating the age of a fossil is by radioactive carbon dating. The ratio of carbon-14 to nitrogen-14 (^{14}C: ^{14}N) in the fossil is analysed and compared with the ratio of these elements in an organism living today.

The graph shows the rate of decay for carbon-14.



A fossil kangaroo skull was found in a limestone cave. The skull's ^{14}C: ^{14}N ratio was analysed and found to contain one-half of the carbon-14 of a kangaroo that died in 2012.

a Which point (A-G) represents the fossil's ^{14}C:^{14}N ratio? (1 MARK)

b Given the half-life of carbon is approximately 5 730 years, what is the absolute age, in years, is the kangaroo skull? (1 MARK)

Adapted from VCAA 2012 Exam 2 Section B Q6a

Question 17 (6 MARKS)

Scientists studying the fossils in an ancient lake bed have an almost perfect fossil record ranging more than 25 000 years. In this fossil record, there are two forms of a fish called a 'stickleback'. One form of the fish has large spines on its back (dorsal spines) and large pelvic bones. The other form has smaller or no spines and smaller pelvic bones. Modern-day stickleback fish with large dorsal spines are common in the ocean, while stickleback fish with small spines are more common in freshwater.

The table contains a summary of some structural features of the fossils found in different sediment layers in the ancient lake bed. Scientists are trying to gain an understanding of the evolutionary pathway of the stickleback fish.

Sediment layer	Top	Middle	Lower
Proportion of carbon-14 relative to ancient surface levels (%)	50	25	6.25
Pelvis	small	large	small
Dorsal spines	small or absent	large	small or absent

a The scientists want to accurately describe key time periods in the stickleback evolution. Should the scientists calculate the relative or absolute ages for the stickleback fossils? (1 MARK)

b The half-life of carbon-14 is approximately 6 000 years. Calculate the absolute ages of stickleback fossils within the top, middle, and lower sedimentary layers. (2 MARKS)

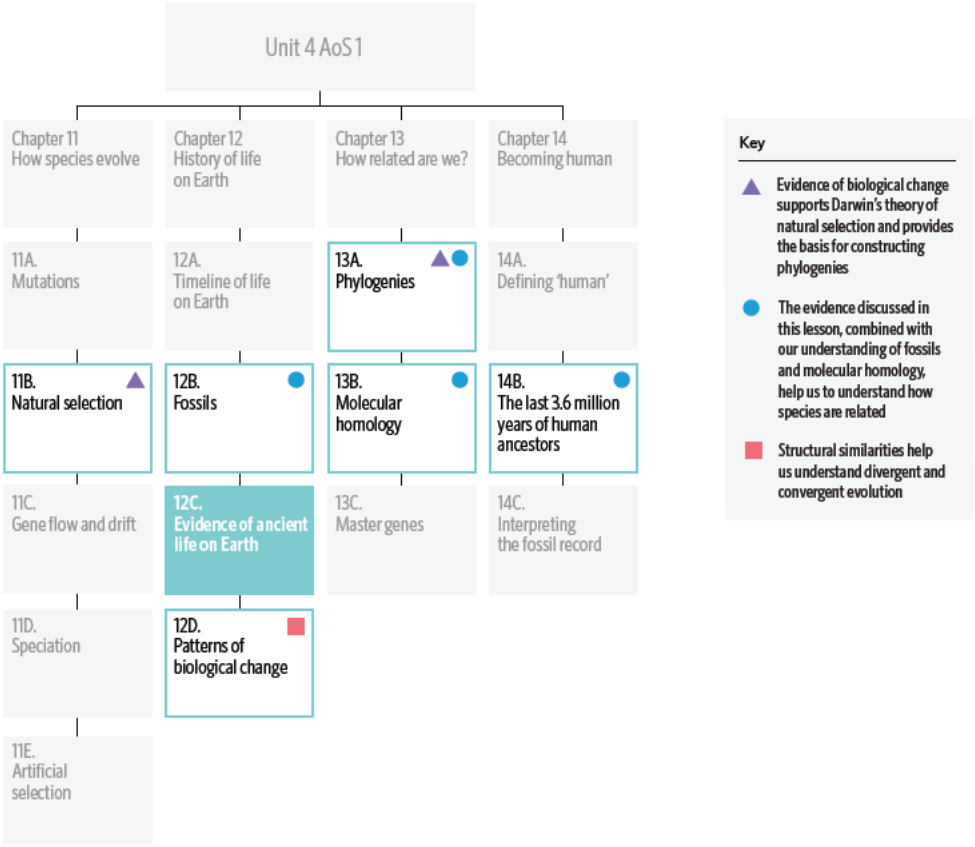
c Suggest a hypothesis that could explain the change in the structural features seen in the different sediment layers. (1 MARK)

d Using evidence from the scenario describe the changes in the lake environment over the past 25 000 years. (2 MARKS)

Adapted from VCAA 2015 Section B Q10

12C EVIDENCE OF ANCIENT LIFE ON EARTH

Darwin's theory of evolution was very controversial when it was first proposed, in part because it seemed ridiculous that organisms and species could change over time. But it's not ridiculous! There is extensive evidence that modern life is not what it used to be.



In this lesson you will investigate some of the evidence for biological change over time, otherwise known as evolution. This evidence indicates that:

1) all species have a common ancestor that existed billions of years ago and that

2) the descendants of this common ancestor have slowly evolved over time to create the many unique life forms that exist today.

Study design dot point

- evidence of biological change over time including from palaeontology (the fossil record, the relative and absolute dating of fossils, types of fossils and the steps in fossilisation), biogeography, developmental biology, and structural morphology

Key knowledge units

The fossil record	4.1.5.4
Biogeography	4.1.5.5
Developmental biology	4.1.5.6

lesson link In the next ***lesson 12D***, you will learn about one more piece of evidence for evolution: structural morphology.

The fossil record 4.1.5.4

OVERVIEW

The fossil record is evidence that life on Earth has changed over time.

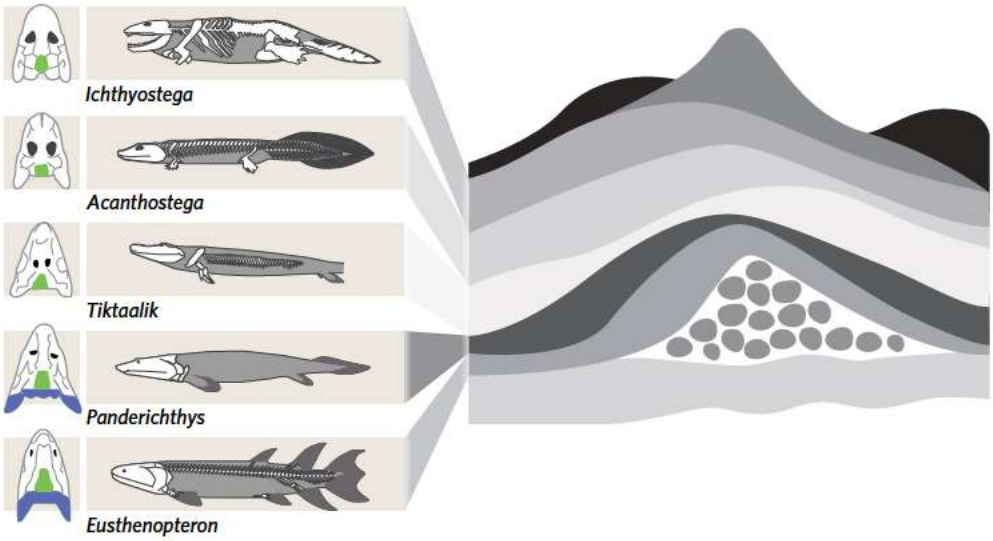


Figure 1 Evolutionary progression of fishes to tetrapods, where gradual shift in traits are seen in skull shapes, skeletal structure, and the reduction of gills (blue). Relative depth of fossils within sedimentary rock is shown on the right.

THEORY DETAILS

Until recent advances in molecular evidence (e.g. proteomics, genomics), **the fossil record** supported some of the most persuasive arguments for evolution. The fossil record is the collection of all fossils on Earth, which we can use to document patterns of evolution over geographical space and time, within and between species.

Structural similarities between fossils indicate relatedness, which can be used to conclude ancestral origins. If a fossil exhibits characteristics common to both an ancient ancestral group and a younger descendant group, it is called a **transitional fossil**. This organism is assumed to be an intermediate species in the evolutionary pathway of the lineage.

While the fossil record provides good evidence for changes over time, it is by no means infallible. Certain types of organisms tend to appear in the fossil record with high frequency, while others barely appear at all. This trend is referred to as a **fossilisation bias**. For instance, hard body parts such as bones, teeth, and exoskeletons are more likely to be preserved rather than soft parts such as organs, skin, and other soft tissues. Organisms that live in areas of high sediment accumulation are also much more likely to become fossilised and overrepresented in the fossil record.

the fossil record documentation of fossils across time and space

transitional fossil fossils that show an intermediate stage of evolution

fossilisation bias certain organisms are more likely to be fossilised, based on physical and behavioural characteristics

Case study

'Tiktaalik'

Evolutionary progression can be difficult to infer from the fossil record alone, as sometimes scientists cannot find all members of an evolutionary pathway. These missing fossils are commonly known as a 'gap' or 'missing link' in the fossil record.

'*Tiktaalik*', first discovered in 2006, is thought to bridge the evolutionary gap between ancestral fish and land-based tetrapods (Fig. 1). *Tiktaalik* seems better adapted to walking on land when compared to *Eusthenopteron* and *Panderichthys*, as evidenced by *Tiktaalik's* pronounced forelimbs, heavyset skeletal structure, and lack of gills. In contrast, these adaptations to terrestrial life are even more apparent in *Acanthostega* and *Ichthyostega*. As *Tiktaalik* shows features similar to both land and water-based species, *Tiktaalik* is a transitional fossil connecting the evolutionary progression from fish to tetrapods.

Biogeography 4.1.5.5

OVERVIEW

The geographic distribution of organisms and fossils on the planet can be best explained by considering both evolution and the movement of landmasses over geological time.

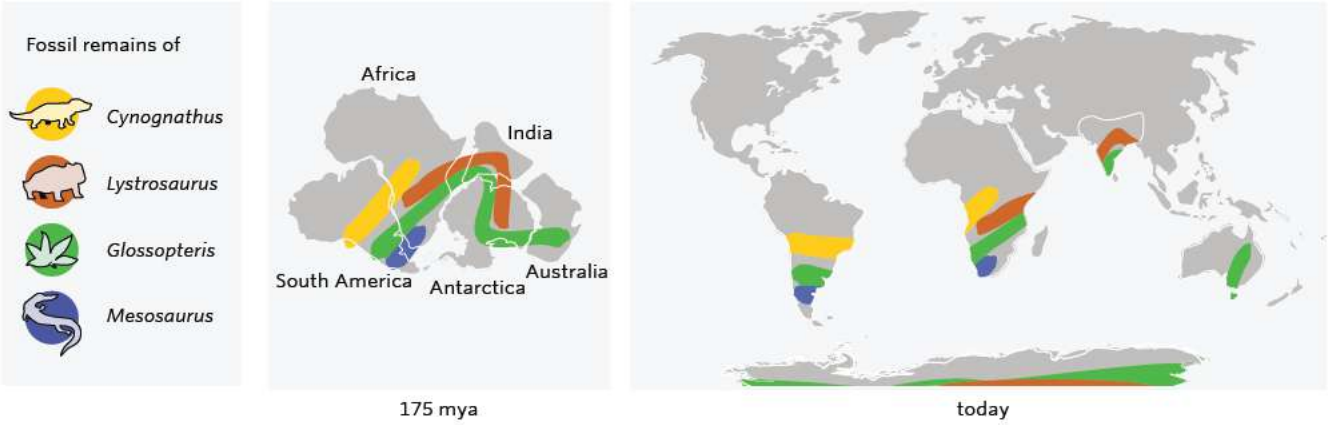


Figure 2 Species distributions 175 million years ago (left) and current fossil distributions (right) as the continents have drifted apart

THEORY DETAILS

Earth is split up into seven major landmasses called continents. Despite this, many of the species across the continents share traits, indicating similar evolutionary pathways. **Biogeography** seeks to understand the distribution of species on Earth using the theories of plate tectonics and evolution.

250 million years ago, all of the Earth's continents were conjoined into one **supercontinent** called Pangaea. This landmass allowed widespread migration of terrestrial animals. However, the supercontinent was situated across **tectonic plates.** Approximately 200 million years ago, the plates began to split apart through **continental drift** eventually forming the modern continents.

As the supercontinent fragmented, oceans formed barriers between the landmasses and species split into isolated populations. Over millions of years, these populations speciated to form the range of species we have today. We know this because ancestor species range across Pangaea and their evolutionary pathways can be seen within the fossil record.

Ultimately, continental drift can help explain why fossils of the same species are found on entirely separate continents when no obvious migration patterns exist.

biogeography the study of the geographic distribution of species over geological time

supercontinent a massive historical landmass (e.g. Pangaea, Gondwana, Laurasia) that broke apart to form the modern continents

tectonic plates Earth's outer crust is divided into tectonic plates that float on the magma below. These movements explain several natural phenomena, including earthquakes and mountain range formation

continental drift the movement of tectonic plates around Earth over millions of years

Case study

Glossopteris

Fossils of the genus *Glossopteris* have puzzled biologists since their discovery in the 1820s. They couldn't understand how their fossil distribution could span the unconnected landmasses of South America, South Africa, India, Antarctica, and Australia (Figure 3). How was it that this immobile fern with no apparent adaptations to ocean dispersal became so widespread?

It wasn't until continental drift theory was initially suggested by Alfred Wegener in 1912 that the reason for their distribution become clear. Wegener's theory proposed that all of the continents used to belong to a large supercontinent known as Pangaea, and that members of the genus *Glossopteris* occupied an extensive range over this landmass, corresponding to multiple modern continents. Despite their complete extinction during the *end-Permian* mass extinction ~251 million years ago, their fossils are still being found today.

Figure 3 Fossilised leaves from a plant of the *Glossopteris* genus

Developmental biology 4.1.5.6

OVERVIEW

Similarities can be seen when comparing early embryonic development between members of the phylum Chordata, indicating evolution from a common ancestor.

THEORY DETAILS

All sexually reproducing organisms originate from a single cell called a **zygote**. This zygote replicates and differentiates to form different tissues, eventually becoming a fully functioning animal. The first of several stages in the developmental process is known as the *embryonic stage*.

Comparative embryology is the comparison of developing **embryos** across species, generally focusing on structures and developmental timing. Within the early development of **chordates**, many similarities can be drawn between species. When similarities are found, we can conclude that these species have evolved from a common ancestor. Given that all members of the phylum Chordata share the four key structures outlined in Table 1, we can conclude that every member of phylum Chordata has evolved from a common ancestor.

Similar comparisons can be made within other evolutionary groups and phyla, however, the study of comparative embryology in VCE Biology is generally limited to chordates.

developmental biology the study of the processes through which organisms grow and develop

zygote the cell formed by the combination of two gamete cells

comparative embryology the comparison of embryo development and structures across species

embryo a stage of offspring development, not unique to chordates

Chordata a group of animals including fish, amphibians, birds, reptiles, and mammals. Also known as **chordates**

Table 1 Key structural features within the early development of chordates

Structure Name	Appearance & location	Function
Pharyngeal arches **(1)**	a series of arch-shaped bands of tissue that form near the early brain of developing embryos	develops into a range of structures, from gills in aquatic chordates to bones of the inner ear in terrestrial chordates
Dorsal nerve cord **(2)**	a hollow cord made of nerve tissue that runs down the back of the embryo	a precursor to the spinal cord and brainstem
Notochord **(3)**	a cartilaginous rod found in the embryos of chordates	a precursor to the vertebral column in vertebrates
Post-anal tail **(4)**	a muscular tail seen in early chordate development	provides means of movement early in the evolution of aquatic chordates, but has since been reduced in humans

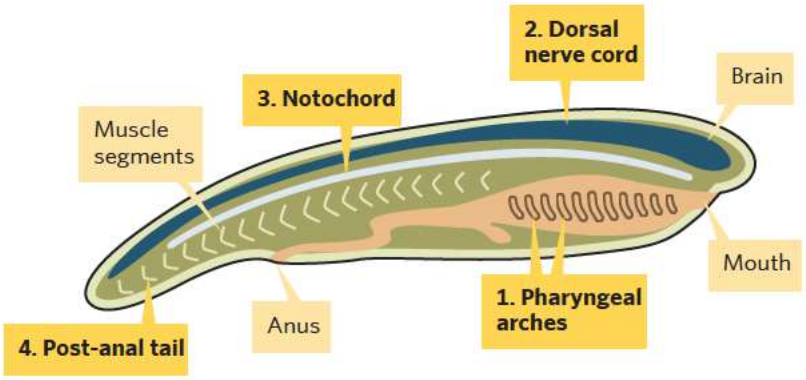


Figure 4 Key structural features within the early development of chordates

Theory summary

Here, you have examined three pieces of evidence for biological change over time. Together, they help prove the theory of evolution by showing that all modern organisms have evolved from common ancestors.

12C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a key stage in the growth of complex life which is studied in the field of developmental biology

b _____ a fossil that shows characteristics of both recent and ancient groups of life

c _____ the general term for large landmasses such as Pangaea and Gondwana

d _____ the movement of landmasses over millions of years

e _____ the study of where organisms live through time and space

f _____ the tendency of certain organisms to be overrepresented within the known fossil record

g _____ a piece of evidence for biological change that shows that 1) historic species looked very different to current species and 2) current species evolved from ancient species, with transitional stages in between

h _____ a piece of evidence for biological change that reveals that chordates develop in a very similar manner because they share a common ancestor

Question 2

Three main pieces of evidence for evolution have been discussed in this lesson. They are: biogeography, the fossil record, and developmental biology. Match each of the statements below with the piece of evidence to which it relates.

I There are *Glossopteris* fossils in Antarctica, Australia, New Zealand, Papua New Guinea, and South America.

II Plate tectonics help explain how continental plate movement affects geography.

III Broad groups of living things that evolved before the breakup of the supercontinent Pangaea (about 200 million years ago) are distributed worldwide.

IV The ancestors of the modern day horses had toes instead of hooves.

V All chordates have a notochord, tails, and pharyngeal arches during embryonic development.

VI Transitional fossils show the stages of evolution from an ancient ancestor to the extant descendants.

VII Evolutionary ancestry can be theorised by comparing structural changes in the fossil record with fossil locations across continents.

	Biogeography	The fossil record	Developmental biology
A	II, III, VII	I, III, VI	V
B	I, II, III, VII	I, IV, VI, VII	V
C	I, II, III	I, III, VI	IV, V
D	II, III	I, IV, VI, VII	V

Question 3

Which of the following is not evidence for evolution?

A The gradual movement of tectonic plates over the Earth's mantle.

B The presence of gill slits and pharyngeal arches in all embryonic chordates.

C Fossils of *Tiktaalik* that show the progression of living things from water-based habitats to land-based habitats.

D Finding the fossilised remains of a common ancestor on two isolated continents such as Australia and South America.

Question 4

Which of the following does not align with ideas encompassed by fossils and the fossil record?

A The depth of a fossil can indicate its age.

B Marine mammals are more common in the fossil record than jellyfish, despite jellyfish being more abundant.

C Fossils of different ages can be found in the same sedimentary layer.

D The presence of a dorsal nerve cord in a fossil indicates the organism was a chordate.

Exam-style questions

Within lesson

Question 5 (1 MARK)

Biogeography is the study of

A geographic structures and their effect on biodiversity.
B the distribution of plants and animals in particular areas.
C evolutionary links between fossils and living organisms.
D ecological relationships between plants and animals.

Adapted from VCAA 2013 Section A Q32

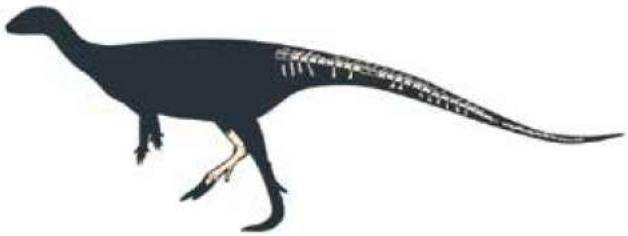
Question 6 (1 MARK)

Developmental biology is the study of

A the development of individual ecosystem structures.
B the distribution of organisms across geological space.
C the processes determining the development of fossils in the fossil record.
D the processes of growth of individual organisms.

Question 7 (1 MARK)

A fossil of the ornithopod dinosaur *Diluvicursor pickeringi* was found in a 113-million-year-old rock in western Victoria. The fossil consists of a tail, a partial hind limb, and some vertebrae. *D. pickeringi* grew to 2.3 m long. Palaeontologists believe that the Victorian ornithopods share a recent common ancestor with several ornithopod fossils found in Antarctica, South America, and Africa.



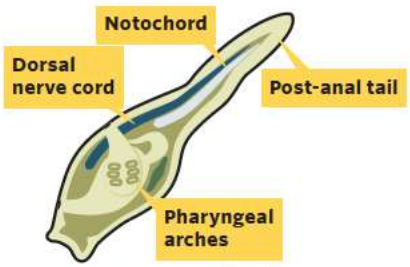
Which is the most likely explanation for the distribution of ornithopod fossils?

A Ocean currents carried ornithopod carcasses between continents.
B The small forelimbs of the ornithopods suggest they recently evolved flightlessness.
C Ornithopods migrated between the continents when Antarctica, South America, and Africa were joined to Australia in the distant past.
D Seagoing scavenger birds carried the bones of the ornithopods to other continents.

Adapted from VCAA 2018 Section A Q26

Question 8 (1 MARK)

Members of the class Ascidiacea are considered to be members of the phylum Chordata based on structural observations in early development.



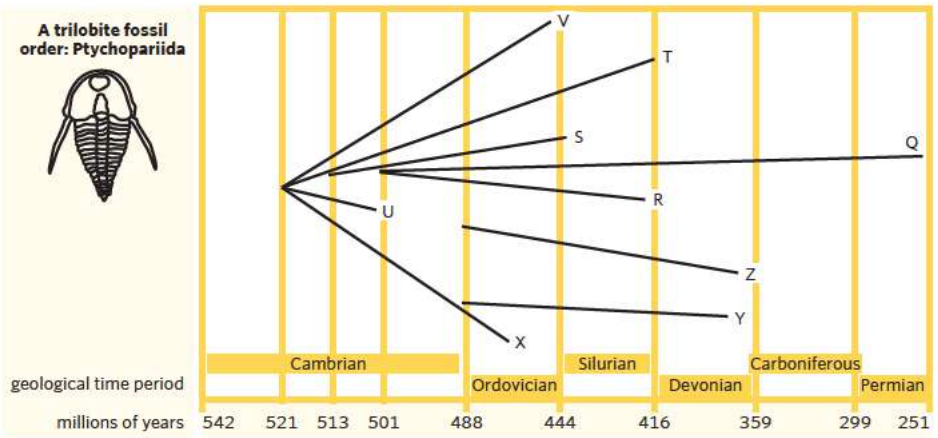
Free-swimming larva

The presence of which structure/s provides the strongest evidence for this claim?

A pharyngeal arches
B notochord & dorsal nerve cord
C a post-anal tail
D all of the above

Use the following information to answer Questions 9 and 10.

Trilobites existed from the Early Cambrian period (521 million years ago) until the end of the Permian period (250 million years ago). The chart based on fossil evidence, shows the phylogeny of some trilobite orders present in the Earth's oceans over this time.



Question 9 (1 MARK)

Trilobite fossils of the orders S, Q, and R share many common ancestors.

Their most recent common ancestor lived approximately

A 444 million years ago.
B 521 million years ago.
C 251 million years ago.
D 501 million years ago.

Adapted from VCAA 2014 Section A Q34

Question 10 (1 MARK)

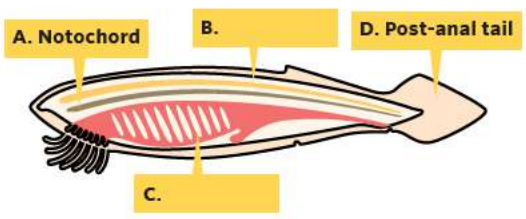
Trilobites are much more common in the fossil record than equally abundant organisms living in the same areas within the same periods.

Which one of the following is the most likely explanation for this trend?

A Trilobites have a hard exoskeleton, increasing the chance that they will become fossilised.
B Trilobites had no natural predators and therefore were not eaten before becoming fossilised.
C Large limb-like appendages suggest trilobites were strong swimmers.
D Trilobites tended to live in highly volcanic areas, which quickly accumulated sedimentary layers.

Question 11 (4 MARKS)

Pictured is a diagram of a chordate during early embryonic development.



a Identify structures B and C in the diagram. (2 MARKS)

b Explain how the presence of these features during the early development of chordates supports the theory of evolution. (2 MARKS)

Multiple lessons

Question 12 (4 MARKS)

The fossil *Archaeopteryx* has features resembling both ancient dinosaurs and modern birds.

a What type of fossil does *Archaeopteryx* represent, and what does this suggest about the evolutionary origins of modern birds? (2 MARKS)

b Scientists used radiometric dating to calculate the *Archaeopteryx* fossil above to be approximately 150 million years old. Explain how these dating techniques allow scientists to establish the age of fossils. (2 MARKS)

Key science skills

Question 13 (1 MARK)

Some scientists argue that Australian marsupials are the descendants of marsupials that first evolved in what is now South America. These early marsupials moved to what became modern-day Australia. Other scientists argue that marsupials originated in Australia, with some of the early marsupials moving to South America. What evidence would support the view that marsupials originated in Australia rather than South America?

A The existence of very old placental mammal fossils in Australia.

B Finding, in Australia, a fossil of a marsupial that is older than any other known marsupial fossil.

C Finding many more marsupial fossils in South America than Australia.

D Finding, in South America, a fossil of a marsupial that is older than any other known marsupial fossil.

Adapted from VCAA 2017 Sample Exam Section A Q30

Question 14 (5 MARKS)

The diagram shows the separation of continents in the past 250 million years.

Image: VectorMine/Shutterstock.com

a What is the name given to the study of the geographic distribution of plants and animals? (1 MARK)

b Scientists are trying to discover the origins of the therapsids, an ancient order of organisms thought to be the ancestors of all mammals. They have found two fossils of the same therapsid species within the fossil record, as summarised in the table.

Key feature within stratum	Depth (m)
Therapsid species	4.9
Igneous ash	5.1
Glossopteris	5.1
Therapsid species	5.3

i What absolute dating pathway would have been used to determine the age of the igneous ash? (1 MARK)

ii How can the age of the igneous ash be used to estimate the age of the *Glossopteris* fossil? (1 MARK)

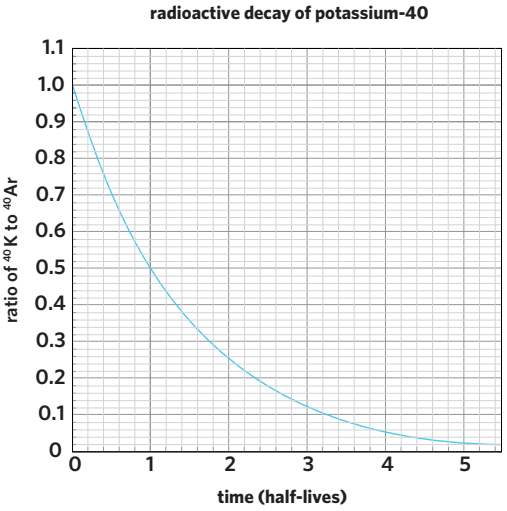
c The absolute age of the igneous layer was dated to 251 million years old.

Does this support the idea that the therapsid species originated less than 251 million years ago? Explain. (2 MARKS)

Question 15 (6 MARKS)

The *Lystrosaurus* is an extinct genus of heavyset terrestrial organisms whose fossils can be found in sedimentary rock across Antarctica, India, and South Africa. A group of scientists are trying to determine the age of a *Lystrosaurus* fossil using K-Ar radiometric dating, which has a half-life of 1.3 billion years. The *Lystrosaurus* fossil was found in a sedimentary layer formed from igneous ash. The ratio of potassium-40 to argon-40 (^{40}K:^{40}Ar) in the strata is analysed and compared with the ratio of these elements in recently formed igneous rock. The ^{40}K:^{40}Ar ratio has been calculated at 0.87.

The graph shows the radioactive decay of potassium-40.



a What is the absolute age of the igneous rock? (2 MARKS)

b What is the approximate age of the *Lystrosaurus* fossil? (1 MARK)

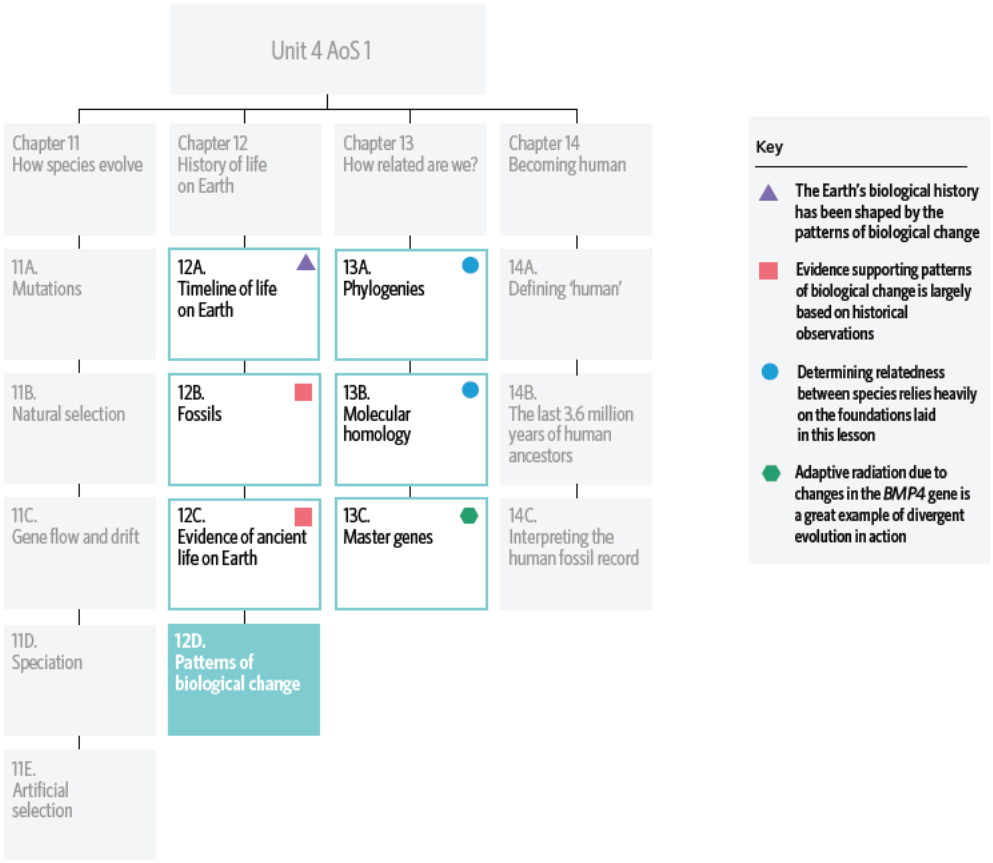
c An unknown bivalve fossil was found in a sedimentary layer below that of the *Lystrosaurus* fossil. What is the age of the bivalve? Justify your answer. (1 MARK)

d It is unlikely that *Lystrosaurus* was able to swim long distances.

Given the age of the fossil, explain how *Lystrosaurus* fossils can be found on the Antarctic, Indian, and South African landmasses. (2 MARKS)

12D PATTERNS OF BIOLOGICAL CHANGE

Scientists have noticed patterns in species diversity and abundance on Earth over the ages. Three of these patterns are divergent evolution, convergent evolution, and mass extinctions.



In this lesson you will learn about different patterns of evolution that we can see in the fossil record and their influences on biodiversity.

Study design dot points

- evidence of biological change over time including from palaeontology (the fossil record, the relative and absolute dating of fossils, types of fossils and the steps in fossilisation), biogeography, developmental biology and structural morphology
- patterns of biological change over geological time including divergent evolution, convergent evolution, and mass extinctions

Key knowledge units

Divergent evolution	4.1.6.1
Convergent evolution	4.1.6.2
Mass extinctions	4.1.6.3

Divergent evolution 4.1.6.1

OVERVIEW

Two populations of the same species, but exposed to different selection pressures, can accumulate differences. This process is known as divergent evolution.

THEORY DETAILS

Divergent evolution describes the evolutionary process where two or more populations of a single species accumulate enough genetic differences to be classified as different species.

divergent evolution when a common ancestor speciates into two or more descendant species

This speciation can occur in a number of ways, although mostly from individual populations adapting to different selection pressures (see lesson 11B) or genetic drift shifting the population genomes over extended periods of time (see lesson 11C). The process of allopatric speciation (lesson 11D) is a classic example of divergent evolution. **Adaptive radiation** is a form of divergent evolution where a single species rapidly diversifies into multiple species. Adaptive radiation can cause massive increases in biodiversity and usually occurs in ecosystems with lots of unfilled niches.

adaptive radiation rapid divergent evolution, producing a wide array of species/forms

Even if the new species look very different from each other, divergent evolution can be recognised by comparing body parts, or structural morphology. This study is called **comparative anatomy**, and it examines the similarities and differences between groups by finding **homologous**, **vestigial**, and **analogous** structures. Skeletal structures are similar across related groups and are easily fossilised compared to other body parts. Consequently, comparative anatomy tends to focus on similarities and differences between skeletons.

comparative anatomy the study of the similarities and differences in structure between animals, including fossils of extinct species. Also known as **structural morphology**

homologous structure a structure present in two or more species that may look and function very differently in each species, but is derived from a common ancestor

vestigial structure a part of an organism that has lost all or most of its usefulness as a result of evolution by natural selection

analogous structure a structure present in two or more species that fulfils the same function but does not originate from a common ancestor

If divergent evolution has occurred, then there should be evidence that the two species share homologous or vestigial structures (*not* analogous). Homologous structures have the same fundamental structure or parts, but different biological functions. For example, humans, bats, and dolphins have similar arm bone structures; they share a humerus, radius, ulna, carpals, metacarpals, and phalanges. But humans mostly use arms for grasping, while bats and dolphins respectively use them for flying and swimming. It is unlikely that these separate lineages would have independently evolved such similar structures, therefore these groups must share a common ancestor. You can see in Figure 1 that dolphins inherited these arm bones from a land-dwelling tetrapod ancestor (*Pakicetus*), who also has this homologous structure.

A **vestigial structure** has lost its original function in an organism, but once did serve a purpose for its ancestors. For example, the vestigial pelvis in dolphins serves little to no purpose, but supported hindlimbs in *Pakicetus* (Figure 1).

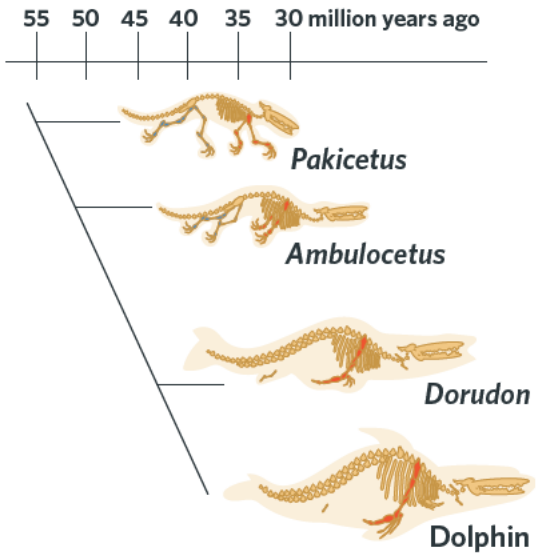


Figure 1 The evolution of dolphins from an ancestral land mammal. The hindlimbs have become less pronounced in each timestep, eventually becoming vestigial in dolphins. The forelimbs have evolved into flippers.

lesson link Divergent and convergent evolution are visually represented in this lesson using simplified phylogenetic trees. If you are having difficulties, refer to lesson ***13A: Phylogenies*** for more information on how to interpret phylogenetic trees

lesson link Sometimes evolutionary patterns can be difficult to resolve through comparative anatomy alone. In these cases, protein or DNA sequences can be compared to more accurately determine the relatedness between species. Refer to ***13B: Molecular homology*** for more information.

Convergent evolution 4.1.6.2

OVERVIEW

Two unrelated species can evolve structures with similar functions when exposed to similar selection pressures. This process is known as convergent evolution.

THEORY DETAILS

Convergent evolution occurs when two or more species independently evolve similar traits as they adapt to similar selection pressures or niches. If the most recent common ancestor between two species did not have that similar trait, then the two lineages must have evolved this trait independently. These traits are known as analogous structures.

convergent evolution evolution of analogous traits due to similar selective pressures

Analogous structures are the opposite of homologous structures. They are structures that serve similar biological functions but are not derived from a common ancestor.

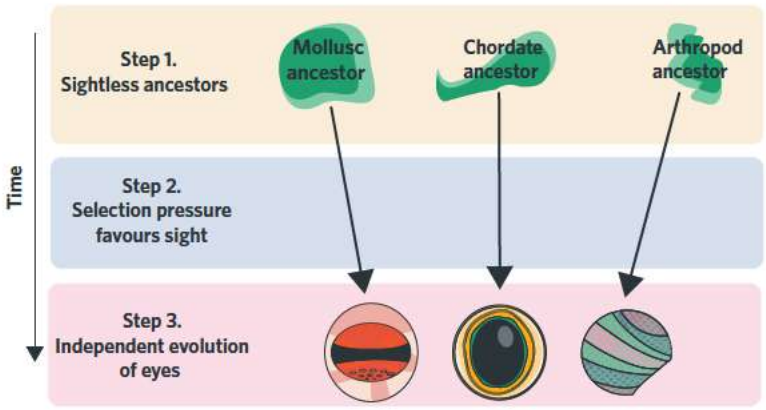


Figure 2 Convergent evolution of eyes (analogous structures) across phyla. Eyes of the horsefly (Arthropoda) (right), common cuttlefish (Mollusca) (left), and cat (Chordata) (middle) are structurally very different, but all fulfil the function of light reception.

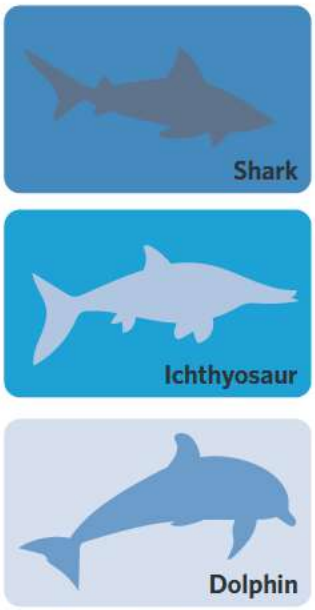


Figure 3 Convergent evolution of body shape and fins (analogous structures) for sharks (fish), ichthyosaurs (reptiles), and dolphins (mammals) in response to living in near-identical niches (predatory aquatic environment)

For example, despite sharing no recent common ancestors, sharks, ichthyosaurs, and dolphins share streamlined body shapes and fins (Figure 3). Streamlined bodies with fins seems to be the most efficient phenotype for a top order marine predator, and each of these groups individually evolved these traits by the process of natural selection. Eyes (in insects, molluscs, and vertebrates, see Figure 2) and wings (insects, bats, birds) and are also examples of analogous structures as they evolved independently in different groups. Species can also independently evolve analogous behaviours, such as egg guarding or sleeping patterns.

Mass extinctions 4.1.6.3

OVERVIEW

A mass extinction event occurs when the global rate of extinction is much greater than the background extinction rate.

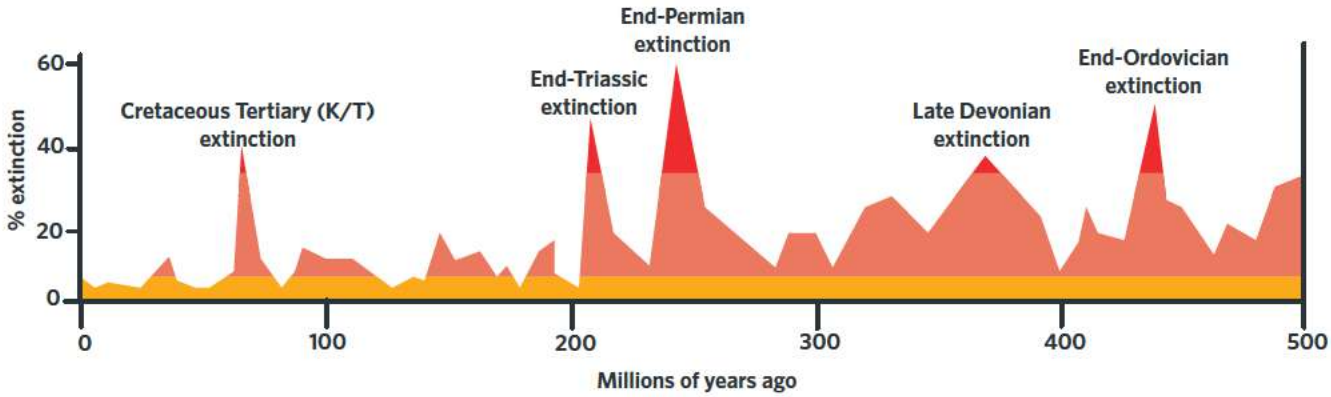


Figure 4 Periods of mass extinction throughout history

THEORY DETAILS

Speciation and extinction events are part of the natural progression of biodiversity on Earth. Despite this, for most of Earth's history, the normal rate of extinction (or **background extinction rate**) has remained relatively low.

A **mass extinction** can be identified by comparing the actual extinction rate with the expected background extinction rate. Mass extinctions are characterised by a drastic reduction in total biodiversity, leaving many previously filled niches empty. This may occur due to strong selective pressures, widespread environmental shift, or natural disaster. At least five mass extinction events have occurred in Earth's history (Figure 4, Table 1).

As a mass extinction leaves many previously filled niches empty, these events are usually followed by a period of rapid adaptive radiation. This is reflected in the fossil record, where increases in biodiversity and shifts in dominant life forms are commonly seen directly after a mass extinction event.

background extinction rate expected rate of extinctions within a geographic area

mass extinction period of rapid species extinction, reducing biodiversity. Evident when the extinction rate is much greater than the background extinction rate

Table 1 Mass extinction events throughout history.

Extinction event	Approximate time (million years ago)	Biodiversity loss	Duration of extinction event	Cause of mass extinction
The Ordovician event	~443	57% of genera + 86% of species	1.9 – 3.3 million years	Highly variable weather patterns
The Denovian event	~359	35% of genera + 96% of species	2 – 29 million years	Global cooling followed by global warming
The Permian event	~251	56% of genera + 96% of species	< 2.8 million years	High volcanic activity + global warming, rapidly changing ocean chemistry
The Triassic event	~200	47% of genera + 80% of species	0.6 – 8.3 million years	High atmospheric CO_2 causing global warming and shifting ocean chemistry
The Cretaceous event	~65	40% of genera + 76% of species	< 2.5 million years	Asteroid impact causing rapid global cooling

Adapted from Barnosky et al. (2011).

Scientists warn that Earth may have entered its sixth mass extinction event due to human-induced habitat loss, pollution, hunting, invasive species, and ecosystem change. The IUCN (International Union for the Conservation of Nature) keeps a global record of the number of threatened or endangered species worldwide. Current estimates suggest that over 27% of all known species are threatened with extinction, and this figure doesn't even take into account unidentified species or species that have recently become extinct. Australia has lost more mammals than any other country. Since European settlement ~200 years ago, >10% of all mammals have become extinct (Woinarski, Burbidge, & Harrison, 2015).

According to Barnosky et al. (2011), if current rates of extinction continue then 75% of species will be extinct in 540 years. Compared to previous mass extinction events, which took millions of years to lose so many species (see Table 1), this is a remarkably short amount of time. Humanity is on track to be the greatest ecological catastrophe in all of Earth's biological history.

Tip Table 1 provides context concerning mass extinctions throughout history. VCAA does not expect you to memorise these events.

Case study

Australian marsupials

The relatively recent Cretaceous-Paleogene (K-T) extinction event, approximately 65 million years ago, caused the extinction of the dinosaurs, leaving many niches unfilled. According to the fossil record mammalian life exploded shortly after this via adaptive radiation.

Research suggests marsupials originated in South America, and a single migration event introduced them to Australia before the South American-Antarctic-Australian land bridge split apart approximately 80 mya. While marsupials are non-existent on most continents, they dominate the Australian landscape thanks to our good friend adaptive radiation.

Australian environments range from tropical rainforest to harsh desert, each posing new selective pressures. Despite this, marsupials have adapted to fill almost every available niche, and have an equally wide range of physical and behavioural adaptations to suit.

Adaptive radiation of marsupials in Australia occurred after the extinction of the dinosaurs, suggesting that marsupial diversification may have been due to niche availability after the mass extinction. Unfortunately, substantial gaps in the fossil record and scientific literature have made it difficult to confirm this, but it remains a tempting hypothesis.

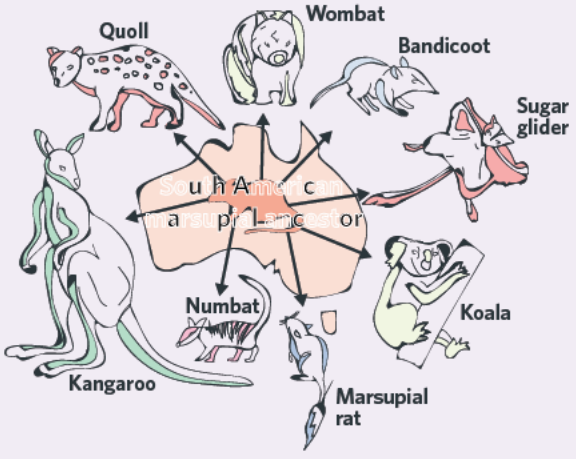


Figure 5 Adaptive radiation and diversification of marsupials in Australia due to adaptive radiation from a South American ancestor

Theory summary

Earth's biological history is incredibly complex. By mapping the patterns of divergent evolution, convergent evolution, and mass extinctions, we can better understand and protect Earth's biodiversity.

12D QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ type of divergent evolution where descendants rapidly diversify into many forms

b _____ describes how often extinctions usually occur within a region

c _____ a structure with a similar function in two organisms, but different evolutionary roots

d _____ evolution of similar characteristics due to similar environmental pressures

e _____ two or more species evolving from a single ancestor species

f _____ a part of an organism that is no longer used by members of this species e.g. wings of flightless birds

g _____ a shared structure in two organisms that is indicative of divergent evolution

h _____ when the extinction rate is significantly greater than the background extinction rate

Question 2

Which is not true of a mass extinction?

A Mass extinctions are commonly followed by a period of rapid divergent evolution.

B Widespread population extinction of a single species is an example of a mass extinction.

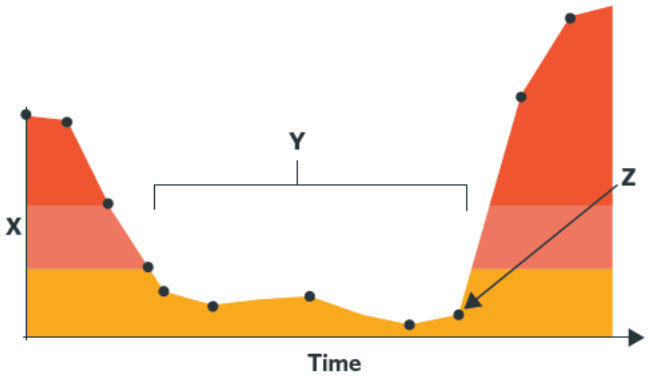
C Mass extinctions can be caused by natural disasters such as volcanic eruptions or asteroids.

D Mass extinctions are naturally part of Earth's biological progression.

Question 3

The following diagram shows two mass extinction events, indicated by two peaks. What belongs in the spaces X, Y, & Z in the diagram?

	X	Y	Z
A	Extinction rate	Background extinction rate	Environmental/ Global change
B	Background extinction rate	Extinction rate	Environmental/ Global change
C	Extinction rate	Extinction event	Environmental/ Global change
D	Extinction rate	Extinction event	Adaptive radiation



Question 4

Fill in the blanks in the following sentences.

Convergent evolution is a type of evolutionary pattern between two species that _____**I**_____ a common ancestor. Due to _____**II**_____ selective pressures, both species develop _____**III**_____ structures.

	I	II	III
A	share	different	vestigial
B	do not share	similar	analogous
C	do not share	different	analogous
D	share	similar	homologous

Question 5

Fill in the blanks in the following sentences.

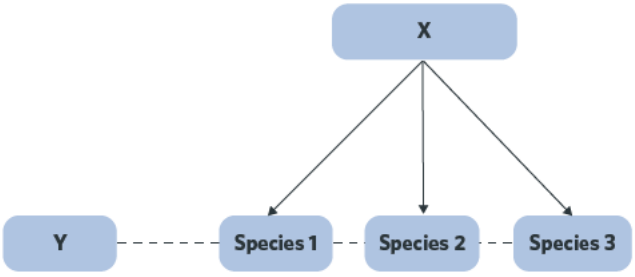
_____**I**_____ is typically followed by a period of widespread _____**II**_____. This evolutionary process is a form of _____**III**_____. Such a process can be identified by finding _____**IV**_____ between species with _____**V**_____.

	I	II	III	IV	V
A	A mass extinction	divergent evolution	adaptive radiation	homologous structures	separate lineages
B	Widespread extinction	diversification	speciation	analogous structures	similar lineages
C	Environmental change	extinctions	mass extinction	index fossils	separate lineages
D	A mass extinction	adaptive radiation	divergent evolution	homologous structures	similar lineages

Question 6

Which option correctly identifies species X, trait Y, and the pattern of evolution in the following diagram?

	X	Y	Pattern of Evolution
A	Common ancestor	Analogous trait	Convergent
B	Different ancestor	Homologous trait	Convergent
C	Common ancestor	Homologous trait	Divergent
D	Different ancestor	Analogous trait	Divergent



Exam-style questions

Within lesson

Question 7 (1 MARK)

Mass extinctions

A occur when the background extinction rate is greater than the extinction rate.

B have been caused by continental drift and earthquakes.

C are commonly followed by a period of rapid divergent evolution.

D have been caused by low mutation rates.

Adapted from VCAA 2017 Section A Q33

Question 8 (1 MARK)

Biologists have found evidence for mass extinction events in Earth's history at approximately 65 million years ago (mya) and at approximately 200 mya. The fossil record indicates a rapid increase in diversity of species after these mass extinction events.

This increased diversity of species can be explained by

A widespread species extinctions providing many unoccupied niches.

B rapid environmental change causing bottlenecks in isolated populations.

C increased mutation rates due to strong environmental pressures.

D increased numbers of fossils produced by the extinction event.

Adapted from VCAA 2015 Section A Q36

Question 9 (1 MARK)

The American *Trichocereus macrogonus* and the South African *Euphorbia pentagono* are unrelated plants belonging to different families. Both plants live in dry regions.

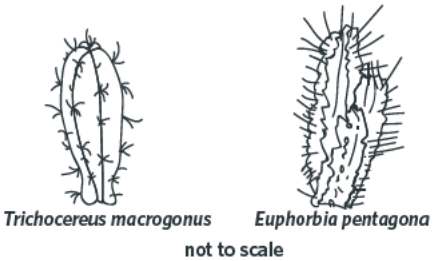
They both have thick, succulent stems to store water and spines for protection. These are examples of

A homologous structures.

B divergent evolution.

C random genetic drift.

D analogous structures.



Adapted from VCAA 2014 Section A Q27

Question 10 (1 MARK)

The Australian platypus (*O. anatinus*) and short-beaked echidna (*T. aculeatus*) are both members of the order *Monotremata*. They share a common ancestor and the platypus is endemic to Australia, but the short-beaked echidna is found in Australia and New Guinea. The echidna lives in a terrestrial environment, has spines and lays eggs. The platypus also lays eggs, but lives in an aquatic environment and does not have spines.

These differences in lifestyle and morphology are examples of

A adaptive radiation.

B adaptations to different selection pressures.

C analogous structures.

D vestigial structures not being selected against.

T. aculeatus ***O. anatitus***

Image: StockSmartStart/Shutterstock.com

Question 11 (1 MARK)

Functional eyes can be seen in many different phyla across the world, including molluscs, arthropods, and chordates.

All members of these three phyla share a distant common ancestor. However, studies suggest this ancestor did not possess a set of functional eyes.

This suggests that

A each of these lineages experienced very different environmental pressures.

B eyes evolved independently in each of the three lineages.

C the evolution of eyes can be explained by random genetic changes.

D given enough time, all lineages will evolve functional eyes.

Multiple lessons

Question 12 (1 MARK)

Over the past million years, Australia's climate has become much drier, leading to reduced areas of forest and woodland. Studies of different spider species from various woodlands show they share a recent common ancestor dating back to just before the climate began to become drier.

The different species are likely to have evolved through the process known as

A genetic drift.

B convergent evolution.

C artificial selection.

D divergent evolution.

Adapted from VCAA 2017 Sample Exam Section A Q25

Question 13 (1 MARK)

Which of the following is an example of a vestigial structure?

A Pharyngeal slits in terrestrial mammals and birds, which form the bones in the inner ear.

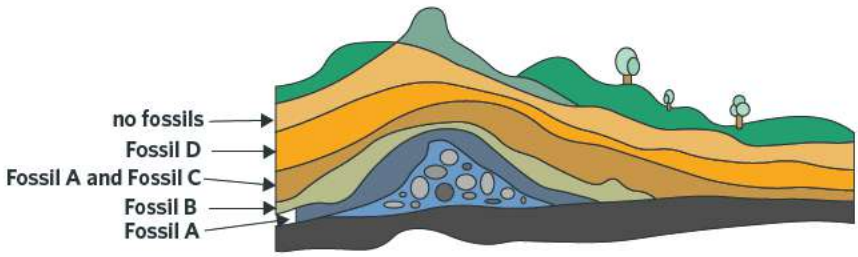
B The pelvic bones in modern-day whales and dolphins, which serve no observable purpose.

C Similar limb shapes in penguins and fish, which serve similar functions.

D Similar bone structures in the forelimbs of bats and humans.

Use the following information for Questions 14 and 15.

The fossils present in different rock strata in a particular location are shown in the diagram.



Question 14 (1 MARK)

From the information given, it can be concluded that

A Fossil D is extinct.

B Fossil A and Fossil C were alive at the same time.

C Fossil B is less than 5 million years old.

D Fossil A is the ancestor of Fossils B, C, and D.

Adapted from VCAA 2017 Sample Exam Section A Q31

Question 15 (1 MARK)

Scientists found that Fossil A and Fossil D have functionally different appendages with similar bone structures, and described these structures as homologous.

It is reasonable to conclude that

A Fossil A is an ancestor to Fossil D.

B they were subject to similar selection pressures.

C Fossil A is related to Fossil D.

D these structures evolved independently of each other.

Adapted from VCAA 2017 Sample Exam Section A Q32

Question 16 (9 MARKS)

Members of the suborder Serpentes (modern snakes) are limbless, carnivorous reptiles. Originally thought to be the precursor to modern lizards, the presence of vestigial limbs suggests this theory is incorrect. Rather, members of the suborder Serpentes are descendants of lizards.

a Explain what is meant by the term vestigial limbs. (1 MARK)

b How did natural selection produce vestigial limbs in modern snakes? (2 MARKS)

c Scientists recently found a fossil, *Tetrapodophis amplectus*, surrounded by ash within sedimentary rock. The fossil pictured possesses skeletal hindlimbs and is an intermediary species between ancient lizards and modern snakes.

Scientists have calculated the relative age of *Tetrapodophis amplectus* to be 100 million years old, using the absolute age of the igneous sedimentary layer.

i Explain how the scientists calculated the age of the igneous sedimentary rock. (2 MARKS)

ii Why didn't the scientists calculate the age of the rock using carbon-14? (1 MARK)

iii How can the scientists approximate the age of *Tetrapodophis amplectus* from the surrounding rock? (2 MARKS)

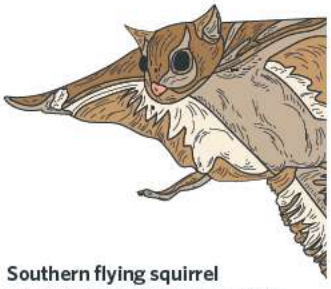
iv How can this be used to determine when modern snakes began to diverge from lizards? (1 MARK)

Question 17 (4 MARKS)

The Australian sugar glider and the North American flying squirrel both have skin extensions connecting their front and hind legs. These extensions allow the animals to glide over short distances between trees. However, these animals do not share any

recent common ancestors.

Short-headed glider, sugar glider, flying phalanger, flying possum (*Petaurus breviceps*)



Southern flying squirrel North American flying squirrel (*Glaucomys volans*)

a Name the type of evolution that describes the relationship between *Petaurus breviceps* and *Glaucomys volans*. (1 MARK)

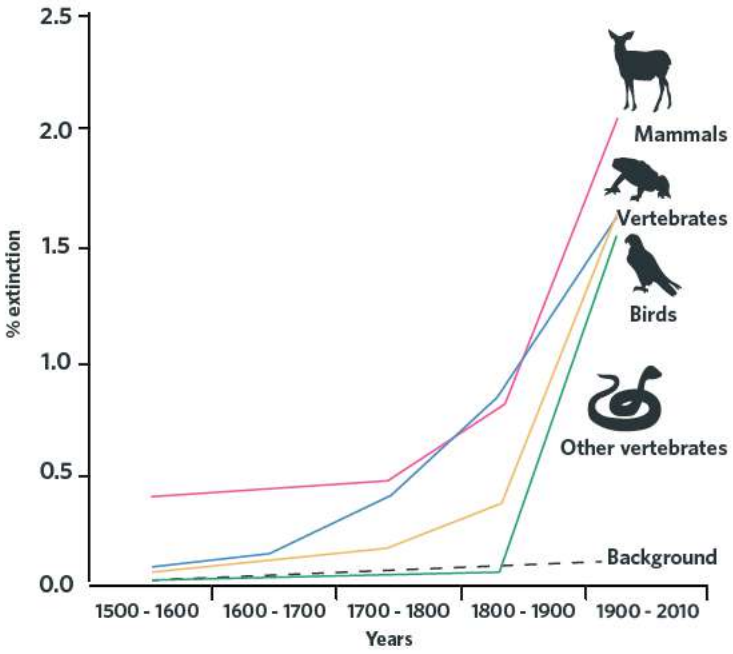
b Explain how these species independently evolved the ability to glide. (3 MARKS)

Key science skills

Question 18 (3 MARKS)

The IUCN (International Union for the Conservation of Nature) keeps a global record of the number of threatened or endangered species worldwide.

The graph shows a conservative estimate of the extinction rate of vertebrates within recent history.



Source: adapted from Ceballos et al. (2015)

a What does the line marked 'background' describe? (1 MARK)

b Does this graph support the idea that we are currently experiencing a mass extinction? Justify your response. (2 MARKS)

Question 19 (8 MARKS)

On the evolution of mammals

Most modern mammals exhibit sensory and behavioural adaptations to nocturnal activity indicating a strictly nocturnal period during early mammalian evolution. This is known as the 'nocturnal bottleneck' hypothesis.

Researchers analysed a mammalian behavioural dataset of 2 415 species from all orders to reconstruct ancestral activity patterns. They found that a higher proportion of mammals are nocturnal when compared to other classes of vertebrates (Maor, Dayan, Ferguson-Gow, & Jones, 2013).

Additionally, most mammalian species, including strictly diurnal ones, exhibit visual adaptations similar to those found in nocturnal birds and reptiles. Compared with most diurnal vertebrates, mammals exhibit a reduction in colour-sensing photoreceptors for use in bright environments (cones), and increased levels of low light-sensing photoreceptors (rods), a finding reflected in mammalian genetics (Gerkema, Davies, Foster, Menaker, & Hut, 2013). There is also evidence that enhanced olfactory sensitivity (smell), broader range of hearing, and sophisticated whisker-based perception may have evolved as substitutes for insufficient visual information (Maor et al., 2013).

While ancient mammalian life was likely preyed upon by dinosaurs, the effect was not large enough to significantly reduce the genetic variation of mammals. Scientists think that nocturnality may have allowed mammals to avoid adverse interactions with diurnal dinosaurs.

Shortly after the Cretaceous-Paleogene (K-Pg) mass extinction event 65 million years ago, which triggered the extinction of the dinosaurs, the fossil record indicates a rapid period of placental mammalian expansion. This is known as the 'explosive' model (O'Leary et al., 2013). More recent molecular analyses indicate this increase may have begun up to 20 million years before the K-Pg extinction event, known as the 'long-fuse' model (Foley, Springer, & Teeling, 2016).

a Name the pattern of evolution which is commonly thought to follow a mass extinction. (1 MARK)

b Explain why a mass extinction facilitates this pattern of evolution. (1 MARK)

c Identify behavioural and physical evidence from the text which indicate modern mammals evolved from a nocturnal bottleneck. (2 MARKS)

d Is the predation from diurnal predators likely to have caused a genetic bottleneck? Justify your response. (2 MARKS)

e Compare the explosive and long-fused models, and whether this supports the classical view of adaptive radiation. Give evidence from the text to support your answer. (2 MARKS)

ACTIVITY

The monotreme fossil record

In 2013, a group of Australian scientists discovered a fossilised tooth in Riversleigh, Queensland. This tooth once belonged to an extinct species of platypus called *Obdurodon tharalkooschild*. Unlike the modern platypus (*Ornithorhynchus anatinus*), this platypus had teeth, allowing it to eat larger prey. Based on the tooth size, *O. tharalkooschild* is likely to have been twice the size of the modern platypus. Radiometric dating of the deposit surrounding the fossil estimates its age to be between 5 and 15 million years old.

Figure 1 Fossilised skull of the now-extinct *Obdurodon dicksoni*, dated to between 15 and 19 million years old

O. tharalkooschild is likely to look similar to a slightly older species, *Obdurodon dicksoni,* where a complete fossilised skull was found in the same area in Riversleigh, Queensland (Figure 1). The skull is estimated to be between 15 and 19 million years old.

1 Explain the process by which the *Obdurodon dicksoni* specimen shown in Figure 1 may have become fossilised.

2 The *Obdurodon dicksoni* fossil in Figure 1 may represent an intermediate between the ancestor of all mammals and the modern platypus. If this were true, what type of fossil would the *Obdurodon dicksoni* skull be?

3 Name another type of fossil and suggest a possible specimen of this type that could provide evidence for the existence of *O. dicksoni*.

4 Modern platypuses and *O. tharalkooschild* share many similar features. Would these features have evolved through convergent or divergent evolution?

5 Are the following homologous or analogous structures/features?

- **a** The bill of *O. dicksoni* and mallard ducks.
- **b** The teeth of *O. tharalkooschild* and grey wolves.
- **c** The ability to swim in modern platypuses and otters.

Another platypus species, *Monotrematum sudamericanum*, was found in South America and was dated to around 61 million years old. Its teeth are around twice the size of teeth from *Obdurodon*.

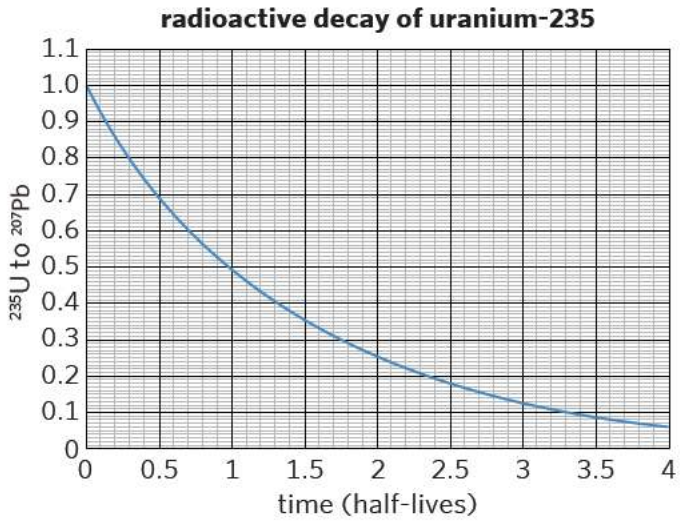
6 What are some key events in the timeline of Earth that occurred after the time *M. sudamericanum* was alive?

7 If *M. sudamericanum* were a transitional fossil between a common mammal ancestor and modern platypuses, what would this suggest about the timing and location of modern platypus divergence from other mammals?

8 By referring to plate tectonic theory, explain where and when the last common ancestor of modern platypuses and *M. sudamericanum* may have existed.

9 Scientists may have used uranium-235 to lead-207 dating to determine the age of *M. sudamericanum*. Since the half-life of uranium-235 is 700 million years, what must the proportion of uranium-235 to lead-207 be in the final sample, assuming the initial proportion was 1?

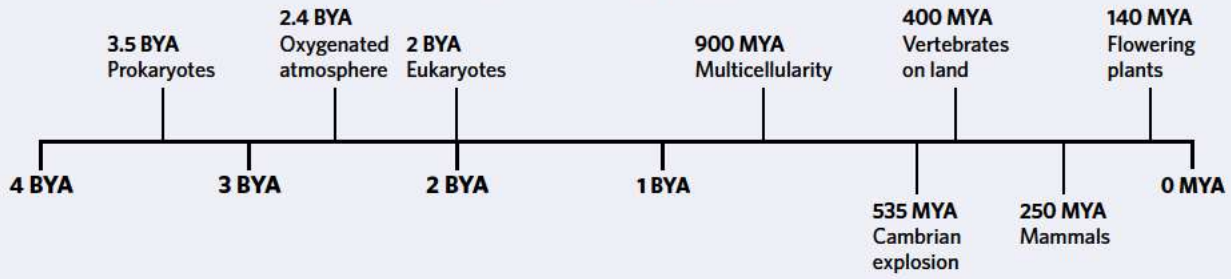
Use the graph to calculate your answer.



SUMMARY

12A

Timeline of life on Earth



12B & 12C

The fossil record

Fossils are preserved remains and traces of living things.

Conditions for fossilisation:

1. Rapid sediment accumulation
2. Constant cool temperature
3. Low light
4. Protection from scavengers/decomposers

Types of fossils:

1. Permineralised
2. Impression
3. Trace
4. Mummified

Dating methods:

1. **Absolute** dating - **radiometric dating** calculates age based on the decay rate of radioisotopes with a known half-life.
2. **Relative** dating - determines relative age based on which layer of sediment fossil lies in. **Index fossils** help determine the age of a layer.

Transitional fossils show the intermediate stages of evolution.

12C

Biogeography

Continental drift explains how and why organisims are distributed over the Earth (e.g. Australia and South America have similar species (marsupials) because they were once connected). **Pangaea** (left) began breaking up around 250 mya.

Developmental biology

Shows that chordates have a common ancestor because all chordates have:

1. Pharyngeal arches
2. Dorsal nerve cord
3. Notochord
4. Post-anal tail

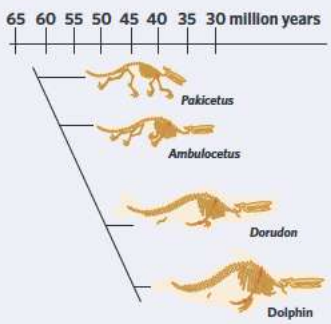
Comparative anatomy

Slight changes in the anatomy of different organisms including homologous, vestigial, and analogous structures are evidence of their evolutionary past.

12D

Convergent and divergent evolution

Divergent evolution - when two species have variation in a shared ancestral structure due to adaptation to different environments. Indicated by **homologous structures** and **vestigial structures.**



Convergent evolution - when distantly related species experience similar environmental pressures and adapt similar structures independently. Indicated by **analogous structures**.

Mass extinctions

Occurs when the **extinction rate** is above the **background extinction rate.** Has occurred at least five times in the Earth's history and results in massive loss of species. Loss of species opens up niches, allowing **adaptive radiation** to occur to fill these niches.

QUESTIONS

SECTION A (17 MARKS)

Question 1 (1 MARK)

Uranium-235 has a half-life of 700 million years. The ratio of current levels of uranium-235 to its stable isotope in a fossil sample is approximately 3:1. The age of the fossil will be close to

A 700 million years.
B 350 million years.
C 1.4 billion years.
D 2.1 billion years.

Adapted from VCAA 2015 Section A Q35

Question 2 (1 MARK)

Fossils found in Australia include representatives from across the ages of life on Earth. The table shows some of the groups of fossils found in Australia and their ages.

Type of fossil	Location	Geological time	Age
stromatolites	Arkaroola, South Australia	Precambrian era	770 mya
jellyfish	Flinders Ranges, South Australia	Ediacaran period	645–652 mya
dinosaurs	many places, including Queensland and Victoria	Jurassic and Cretaceous periods	200–65 mya
megafauna (large marsupials and flightless birds)	Naracoorte, South Australia	Cainozoic era	65–7000 ya

NOTE: mya – million years ago; ya – years ago

Which of the following statements is true?

A Stromatolites were likely dated using carbon-14 dating.
B Stromatolites are made by photosynthesizing prokaryotes.
C Stromatolite fossils are formed through permineralisation.
D Stromatolites are one of the earliest examples of multicellular eukaryotes.

Adapted from VCAA 2017 Sample Exam Section B Q7a

Question 3 (1 MARK)

Fossils of the same plant species have been found distributed across multiple continents including North America, Europe, and Asia. The plant species is assumed to have lived 300 million years ago, as indicated by radiometric dating techniques. Which of the following is the most likely explanation for the distribution of this plant species?

A Every continent used to be joined together in one large supercontinent.
B The fossil was dated by comparing the proportion of a radioisotope to its breakdown products within the fossil.
C The seeds of the plant were well adapted to oceanic dispersal.
D The fossils were carried by birds between continents.

Question 4 (1 MARK)

Mass extinctions

A are only ever caused by human influence.
B increase the rate of mutations in surviving populations.
C only kill off the most advanced forms of life.
D occur when the extinction rate is greater than the background extinction rate.

Adapted from VCAA 2017 Section A Q33

Question 5 (1 MARK)

The chances of an animal becoming fossilised are increased by

A direct exposure to sunlight.

B the presence of soft tissues.

C rapid burial within sedimentary layers.

D the death of the animal in a predator-rich environment.

Question 6 (1 MARK)

Radio-isotopic dating (radiometric dating) is used to determine the age of fossils and surrounding rocks.
Which statement about radio-isotopic dating is true?

A Radio-isotopic dating techniques can only indicate the order of fossil formation, not how many years ago the fossil was formed.

B Carbon is primarily used when calculating the age of igneous rocks.

C Radio-isotopic dating techniques can be used to accurately calculate the age of sedimentary rock.

D Radio-isotopic dating relies on the decomposition of unstable atoms to stable atoms.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q34

Question 7 (1 MARK)

The technique of carbon dating would be most suitable for dating organic remains that are aged

A 30 000 years.

B 300 000 years.

C 1 000 000 years.

D 1 000 000 000 years and beyond.

Adapted from VCAA 2011 Exam 1 Section A Q12

Question 8 (1 MARK)

Scientists concluded two modern animals shared a vestigial structure. How can the presence of vestigial structures provide evidence that these animals have a recent common ancestor?

A Despite these structures serving different functions, their skeletal structures are similar. Therefore, they must share a recent common ancestor.

B Through exposure to similar selection pressures the two animals evolved structures with similar functions. Therefore, they must share a recent common ancestor.

C Vestigial structures are the result of exposure to different selection pressures.

D It is unlikely that two animals would independently evolve the same vestigial structure. Therefore, they must share a recent common ancestor.

Question 9 (1 MARK)

The fossil record provides evidence for evolution by

A showing changes between fossils over time.

B explaining how fossils of the same species can be found across continents.

C allowing scientists to calculate the age of fossils with relative dating techniques.

D telling us which species hold the record for most fossils.

Question 10 (1 MARK)

Relative dating techniques are used to determine the age of fossils and the surrounding rocks. Which statement about relative dating techniques is true?

A Relative dating techniques require the presence of index fossils.

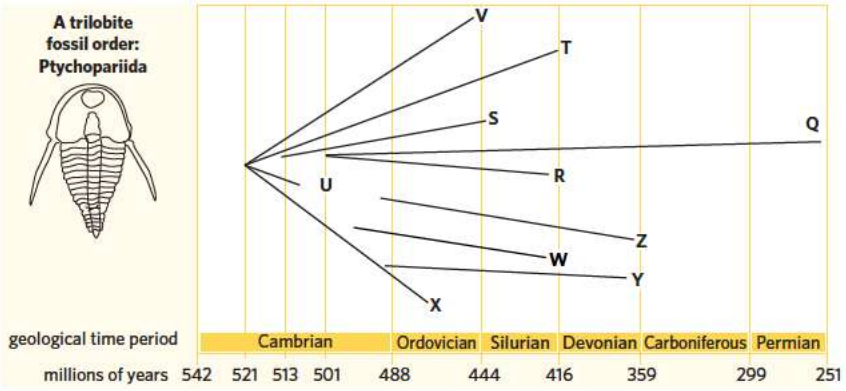
B Carbon is the best element to use when determining the age of all fossils.

C Relative dating techniques indicate a fossil's age by determining if one fossil is older than another.

D Relative dating techniques are only useful for fossils formed less than 100 million years ago.

Use the following information to answer Questions 11–14.

Trilobites existed from the early Cambrian period (521 million years ago) until the end of the Permian period (250 million years ago). The chart is based on fossil evidence and shows the phylogeny of some trilobite orders present in the Earth's oceans over time. Trilobite fossils in a particular layer of rock were used to date a fossilised shell in the same layer. A paleontologist dated the trilobite fossils to 382 million years old.



Question 11 (1 MARK)

The Trilobite fossils are most likely to belong to which of the following orders?

A U
B S
C R
D Z

Adapted from VCAA 2014 Section A Q34

Question 12 (1 MARK)

The age of the fossilised shell was most likely determined using

A the principle of fossil succession.
B potassium–argon dating.
C radiometric dating techniques.
D the absolute age of the fossilised shells.

Adapted from VCAA 2014 Section A Q35

Question 13 (1 MARK)

The geological time periods shown on the chart differ in duration because the time periods reflect

A changes in the rate of evolution.
B knowledge gaps in the fossil record.
C key periods of biological change in Earth's history.
D stochastic changes to the trilobite populations.

Adapted from VCAA 2014 Section A Q36

Question 14 (1 MARK)

Scientists have determined the relatedness of different orders of trilobites, based on their fossilised remains. Scientists would have determined their respective degrees of relatedness by concluding that

A fossils in the same sedimentary layers were closely related.
B fossils with homologous structures were closely related.
C fossils with analogous structures were closely related.
D fossils found in the same areas were closely related.

Question 15 (1 MARK)

Which of the following statements correctly explains why 100 000 years is the minimum limit of radiometric dating methods using the potassium–argon series?

A Before 100 000 years, potassium–40 does not decay at a constant rate.

B Before 100 000 years, not enough potassium–40 has decayed to accurately calculate the age of the rock.

C Not enough potassium–40 has leached into the fossil or rock within 100 000 years.

D The half-life of argon–40 is long, and therefore the mass would have barely suffered radioactive decay.

Question 16 (1 MARK)

Which of the following correctly describes the difference between prokaryotes and eukaryotes?

A All prokaryotes are unicellular and all eukaryotes are multicellular.

B Eukaryotes only evolved after the Cambrian explosion.

C Stromatolites cannot be made by eukaryotes.

D Eukaryotes have membrane-bound organelles, prokaryotes do not.

Question 17 (1 MARK)

A mummified carcass of an ancient wolf pup was found frozen in a cave in Canada's Yukon Territory.

The carcass was dated about 50 000 years old. The most likely method used to date the mummified carcass would involve

A determining the age of the ice using the carbon–nitrogen radiometric pathway.

B using radiometric dating to determine the age of the cave.

C comparing the structure of the carcass to the structure of other wolf pup fossils.

D calculating the absolute age with radiometric dating techniques.

Adapted from VCAA 2013 Section A Q31

SECTION B (29 MARKS)

Question 18 (9 MARKS)

Over the past 20 years, a number of new mammalian fossils have been discovered. A fossilised *D. optatum* skull was found near the south-eastern Australian coast and a mummified *P. cinereus* skull was found within a cave in central Australia.

A fossilised impression of *A. cignorum* was found in the same area as *D. optatum.*

a Consider the conditions that may have led to the fossilisation of members of these species. Identify one condition in the environment of each species that made fossilisation possible.

The same answer cannot be used for multiple species. (3 MARKS)

Species	Environment	Condition
D. optatum	Near the coast of south-eastern Australia	
P. cinereus	Cave in western Queensland	
A. cignorum	Near the coast of south-eastern Australia	

Adapted from VCAA 2016 Section B Q10a

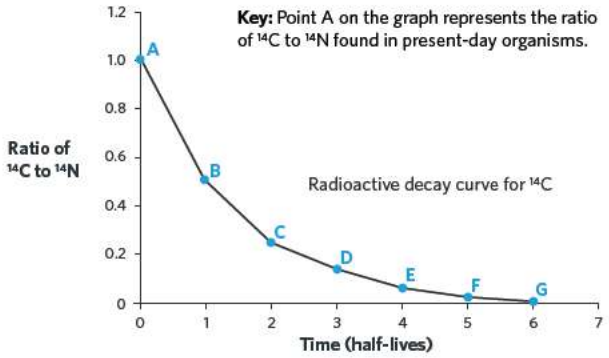
b What is the name given to the study of similar or different structures found between the bones and skeletal structures of animals, including fossilised remains? (1 MARK)

Adapted from VCAA 2015 Section B Q9b

c Pictured are the skulls of *D. optatum* (left), *P. cinereus* (right). After studying the skulls, scientists concluded that the two species were related.

Discuss the evidence the scientists would have used to support this conclusion. Use an example from the skulls in your response. (2 MARKS)

d One form of dating the age of a fossil is by radioactive carbon dating. The ratio of carbon-14 to nitrogen-14 (^{14}C:^{14}N) in the fossil is analysed and compared with the ratio of these elements in an organism living today. The graph shows the rate of decay for carbon-14. The *P. cinereus* skull ^{14}C:^{14}N ratio was analysed and found to contain three-quarters (¾) of the carbon-14 of a kangaroo that died in 2012.



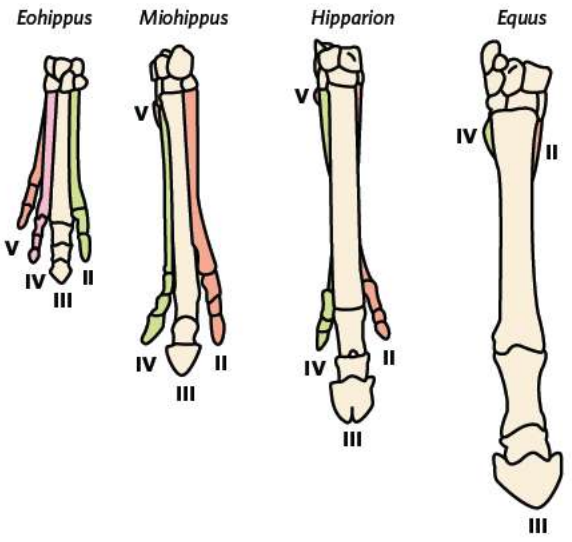
i Given the half-life of carbon-14 is approximately 5 730 years, what is the absolute age of the *P. cinereus* skull? (2 MARKS)

Adapted from VCAA 2012 Exam 1 Section B Q6a

ii While walking back to their car, a scientist dropped the *P. cinereus* skull in a freshly dead kangaroo corpse. What type of error is this? (1 MARK)

Question 19 (6 MARKS)

Modern horses (genus *Equus*) are thought to have originated in North America approximately five million years ago.



a By observing the leg structures in the fossil record, scientists have concluded that horses in the genus *Equus* are descendants of the genus *Eohippus*, which lived approximately 33.9 – 56 mya.

i Identify whether the shown foot structures are homologous or analogous. (1 MARK)

ii Identify whether this is an example of convergent or divergent evolution. (1 MARK)

b Given that North and South America only recently joined together (approximately 3 mya), what is the oldest fossil of genus *Equus* you would expect to find on the continent of South America? Why? (2 MARKS)

c Explain a difference between absolute and relative dating techniques. (2 MARKS)

Question 20 (7 MARKS)

Scientists conducted an experiment to test a hypothesis about the evolution of multicellular organisms. In the experiment, the scientists took a single-celled bacterial organism that also had an 'aggregated multicellular' form in which eight or more single cells were clumped together. The scientists mixed the single-celled form and the 'multicellular' form in a container with a predator. This bacterial organism did not possess membrane-bound organelles. They also mixed the single-celled form and the 'multicellular' form in a container without a predator.

They observed an increase in the number of 'multicellular' bacteria compared to single-celled bacteria after being exposed to a predator and noticed no change in the proportion of single-celled and 'multicellular' bacteria when not exposed to a predator.

a State the independent variable and the dependent variable in this experiment. (1 MARK)

b State the hypothesis being tested by the scientists in the experiment. (1 MARK)

c Controls are an important part of the experimental process.

i Did the scientists use a control in this experiment? Explain. (1 MARK)

ii How does this affect the scientists' interpretation of the results? (2 MARKS)

d According to current understandings, could a similar bacterial aggregate be an ancestor to all modern multicellular life? Explain. (2 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q19

Question 21 (7 MARKS)

Galápagos tortoises (*Chelonoidis* spp.) can be found on many of the islands that make up the Galápagos Islands. Originally, 14 different species were identified based on the islands on which they lived and on their morphology. Santa Cruz, the second largest of the Galápagos Islands, has two isolated tortoise populations. Population A contains more than 2000 individuals covering an area of 156 square kilometres. Population B is a small population of 250 individuals covering an area of 40 square kilometres.

The position of the two populations on the island of Santa Cruz is shown in the image. The two populations are separated by a distance of 20 kilometres.

In 2015, scientists investigated whether the individuals of the two populations belong to the same species or whether they are two different species.

Average measurements of skull size were calculated for tortoises belonging to both populations A and B. The skulls were measured in six different places. The six measurements were also compared to average measurements taken from skulls of other Galápagos tortoise species. The results are shown in the table. Comparisons have been made with three other Galápagos tortoise species.

Measurement position	Average skull measurement (mm)				
	Population B	Population A	*Chelonoidis vicina*	*Chelonoidis chathamensis*	*Chelonoidis ephippium*
1	118	98	86	80	74
2	40	37	28	27	25
3	21	18	16	14	12
4	26	23	21	18	17
5	10	9	8	7	6
6	19	17	16	14	13

Source (map and table): Poulakakis et al. (2015), adapted by VCAA 2016 Section B Q9

a Examine the data. Does the data support the hypothesis that individuals in population A and population B belong to the same species? Use evidence to support your answer. (2 MARKS)

b The Galápagos tortoise is incapable of swimming. After surveying the island, scientists found a large river separating the two populations.

i Name the type of speciation that has occurred. (1 MARK)

ii Explain how the river could contribute to this speciation event. (2 MARKS)

iii Name an evolutionary pattern that describes this process of speciation. (1 MARK)

iv Identify a piece of evidence that scientists could have found within the fossil record that would support this evolutionary pattern. (1 MARK)

Adapted from VCAA 2016 Section B Q9

UNIT 4 AOS 1, CHAPTER 13

How related are we?

13

13A Phylogenies

13B Molecular homology

13C Master genes

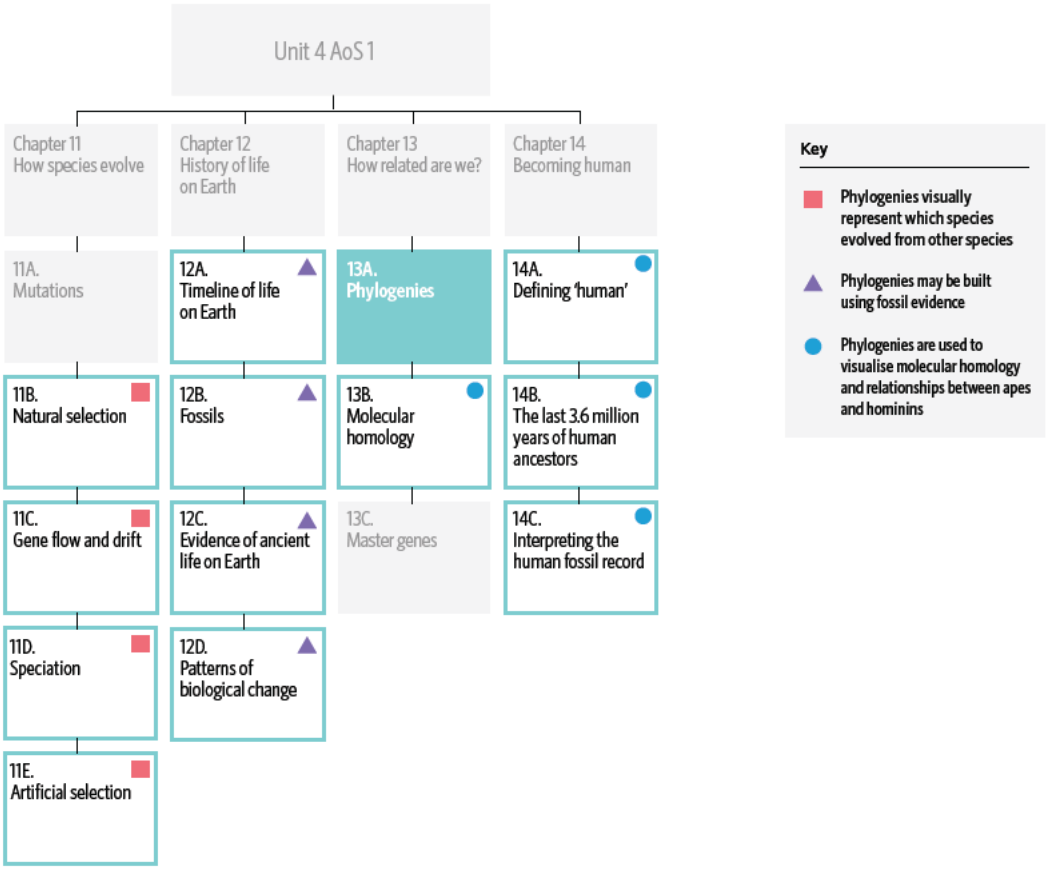
Key knowledge

- the use of phylogenetic trees to show relatedness between species
- molecular homology as evidence of relatedness between species including DNA and amino acid sequences, mtDNA (the molecular clock), and the DNA hybridisation technique
- the evolution of novel phenotypes arising from chance events within genomes, specifically sets of genes that regulate developmental processes and lead to changes in the expression of a few master genes found across the animal phyla, as demonstrated by the expression of gene *BMP4* in beak formation of the Galápagos finches and jaw formation of cichlid fish in Africa

Image: zilber42/Shutterstock.com

13A PHYLOGENIES

Do you remember designing family trees back in primary school? Well, phylogenies are family trees between different species.



In this lesson you will learn how to use phylogenetic trees to illustrate relationships between different groups of organisms.

Study design dot point

- the use of phylogenetic trees to show relatedness between species

Key knowledge unit

Interpreting phylogenetic trees	4.1.8.1

Interpreting phylogenetic trees 4.1.8.1

OVERVIEW

In this lesson, you will learn about the structure and uses of phylogenetic trees.

THEORY DETAILS

Phylogenetics is the study of the evolutionary history of an organism or group of organisms. The goal of phylogenetics is to describe an organism's relationships, such as from which organisms it may have evolved or to which species it is most closely related.

Phylogenetic trees are diagrams that are used to illustrate the **evolutionary relationships** among organisms. Phylogenetic trees are a hypothesis of the evolutionary past, since one cannot go back to confirm the proposed relationships. Trees are useful for displaying:

- relatedness between taxa
- the timeline of **lineages**
- shared characteristics of different taxa.

phylogenetics the study of the relatedness between organisms

phylogenetic tree a diagram used to show the relatedness between organisms

evolutionary relationship the relatedness of organisms based on shared ancestry

lineage a direct sequence of species that evolved from a common ancestor

Structure of a phylogenetic tree

Phylogenetic trees usually have a line at the base called the **root** representing the common ancestor. Each line on the tree is called a **branch**. These branches split away from each other at **nodes**, which represent a divergence between those two **taxa**. The end of a branch is called the **leaf**. This is where the present–day or extinct species are found, labelled with the species or taxa name (Figure 1).

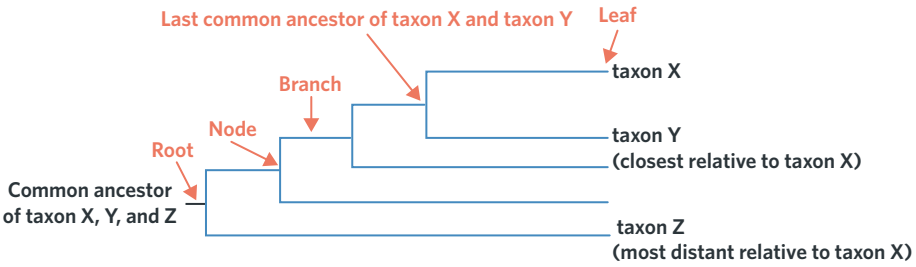


Figure 1 The basic structure of a phylogenetic tree with the names of each part labelled

Reading phylogenetic trees

Phylogenetic trees can be used to determine the most closely related species to a particular taxon. Using the tree below (Figure 2), you can trace back from the leaf for humans to reach the next node (node A) which splits humans from monkeys, showing that monkeys are the closest relative to humans. You can trace the tree back further to the next node (node B) which separates humans and monkeys from dolphins and sheep, showing that humans are more closely related to monkeys than they are to dolphins and sheep. It's important to note that the last common ancestor of humans and monkeys occurs at node A.

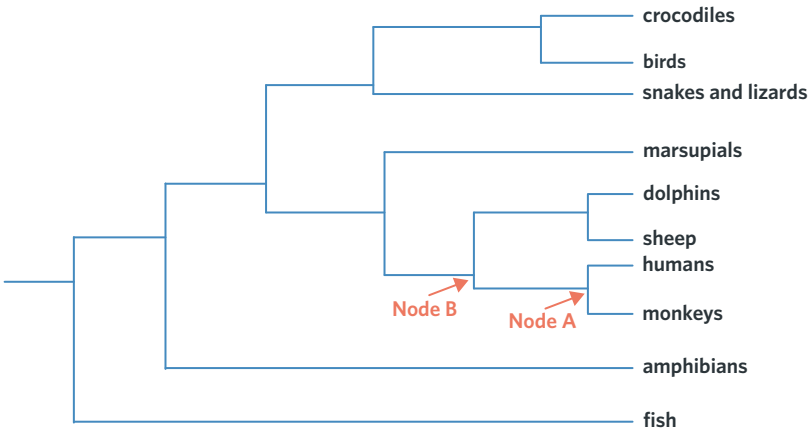


Figure 2 Phylogenetic tree of vertebrates. Node A represents the most recent divergence for humans and node B represents the second most recent divergence for humans.

Phylogenetic trees may include a timescale in order to show the time points of divergence events and adaptations. When a phylogenetic tree includes a timescale, the **branch length** represents time. You can see in Figure 3 that Ethiopian wolves diverged from dogs four million years ago.

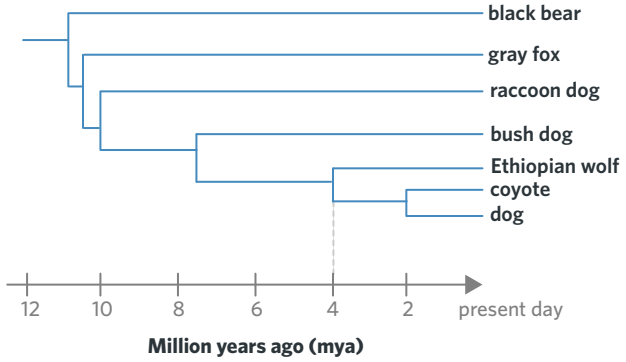


Figure 3 Phylogenetic tree of dogs and some of their relatives, including a timescale

root represents the most recent common ancestor for all members of the phylogenetic tree

branch a line on a phylogenetic tree that represents an evolutionary path

node the splitting point between two branches on a phylogenetic tree, representing a speciation event

taxon (pl. taxa) a term referring to a group of organisms (e.g. species, genus, family, phylum)

leaf the end of a branch that shows the current (or final) form of a species

branch length the length of a branch sometimes denotes evolutionary distance or time

Constructing phylogenetic trees

Phylogenetic trees illustrate the relatedness between organisms. Relatedness can be determined in a number of ways:

- using morphological data
- molecular homology
- DNA hybridisation.

Only morphological data will be covered in this lesson. Molecular homology and DNA hybridisation will be covered in the next lesson.

Closely related organisms are more likely to look similar (e.g. skull structure) and behave in similar ways (e.g. diet, reproductive strategies). These traits must be homologous in order to determine relatedness. In contrast, analogous structures cannot be used to determine relatedness (e.g. the dorsal fin of sharks and dolphins is an analogous structure and does not indicate they are closely related). In the phylogenetic tree below you can see the evolution of characteristics within vertebrates (Figure 4).

If you focus on a lineage such as placental mammals, you can distinguish between **derived traits** and **ancestral traits**. Derived traits are characteristics that have evolved in your taxon (e.g. fur, three middle ear bones, females feed offspring with milk). Ancestral traits are characteristics that are found in the ancestors of your taxon and are therefore shared with other taxa through homology (e.g. amniotic eggs, four legs, warm–blooded).

derived trait a trait that has been acquired in the time since two species diverged

ancestral trait a trait that is found in the ancestor of a species, but not necessarily in the species itself

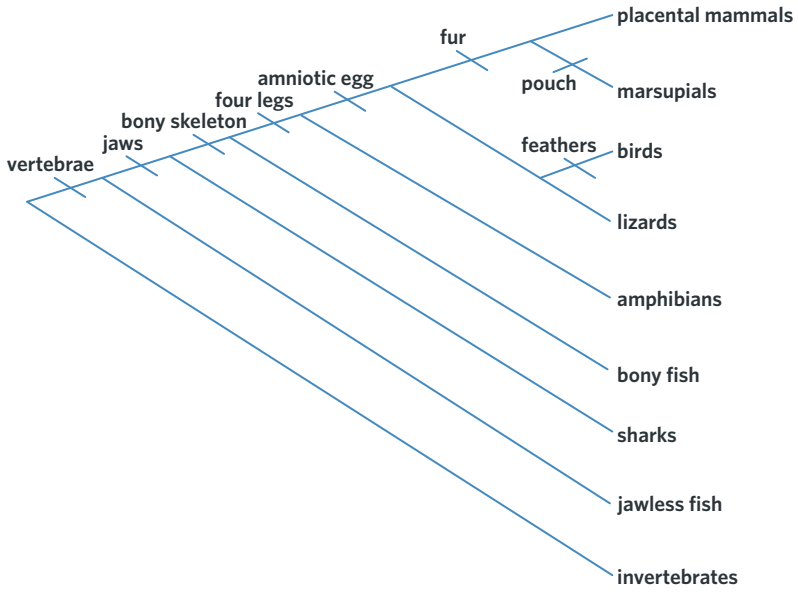


Figure 4 Phylogenetic tree showing the evolution of traits within vertebrates

Depicting uncertainties in phylogenetic trees

Often uncertainties occur when using fossil evidence, since dating techniques are not 100% precise. These uncertainties can be expressed using phylogenetic trees in several ways, as shown in Figure 5.

The lack of a node between species Y and Z means that the exact divergence time is unknown. The break between species W and X means that W is possibly an ancestor of X but there is no evidence of transitional fossils between these two species to support this hypothesis. The branch with species S does not reach the end of the tree, indicating that it is extinct.

Nodes usually only split into two lineages, but sometimes they can split into three or more, as can be seen between species T, U, and V. This kind of uncertainty is called a polytomy. This means that it's unclear which species diverged from the others first. This occurs if there is insufficient data or if two speciation events occurred closely together – such as with adaptive radiation.

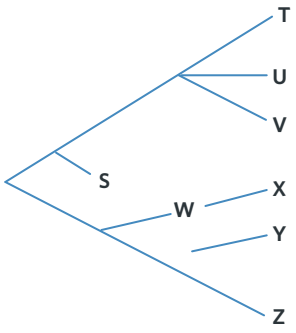


Figure 5 Phylogenetic tree showing evolution of species. This tree is based on fossil evidence and is full of uncertainties.

Exchanging genetic material between groups

Sometimes genetic material is passed between groups after they have diverged. For example, there is strong evidence that suggests that certain groups of modern humans (*Homo sapiens*) interbred with Neanderthals (*Homo neanderthalensis*), causing parts of their genomes to be passed between species. This is depicted using a horizontal line between branches (Figure 6).

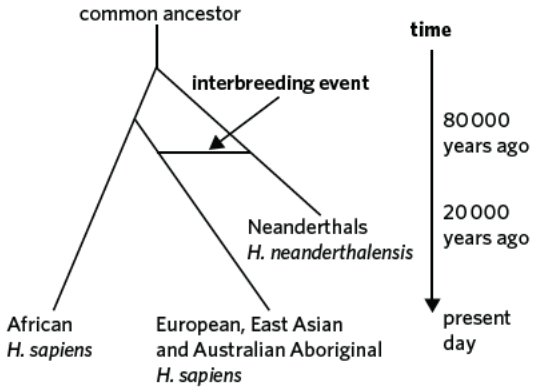


Figure 6 Phylogenetic tree depicting interbreeding between modern humans and Neanderthals

Theory summary

In this lesson you learned about the structure of phylogenetic trees and how to read them, including interpretation of timescales, derived and ancestral traits, uncertainties, and polytomies.

Phylogenetic trees are incredibly useful tools for illustrating relatedness between species and are used throughout this course. VCAA tests knowledge of phylogenetic trees in a range of contexts, including the fossil record, molecular homology, patterns of biological change, and hominin evolution.

13A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a characteristic of an organism that is not shared by closely related organisms

b _____ the science of evolutionary relationships

c _____ a diagram that is used to illustrate the evolutionary relationships between different organisms

d _____ a characteristic that was present in the ancestor of a species

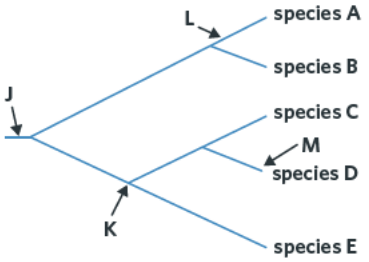
e _____ a line of species that evolved from a common predecessor

f _____ a group of related organisms (e.g. class, order, kingdom)

Question 2

Label structures J – M in the phylogenetic tree.

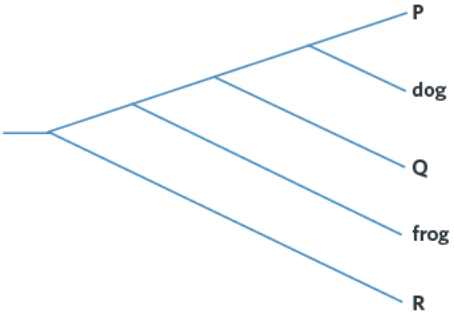
	J	K	L	M
A	Root	Node	Leaf	Branch
B	Root	Branch	Node	Leaf
C	Branch	Node	Root	Leaf
D	Root	Node	Branch	Leaf



Question 3

Based on homologous structures, which species belong in the spaces P, Q, and R of the phylogenetic tree?

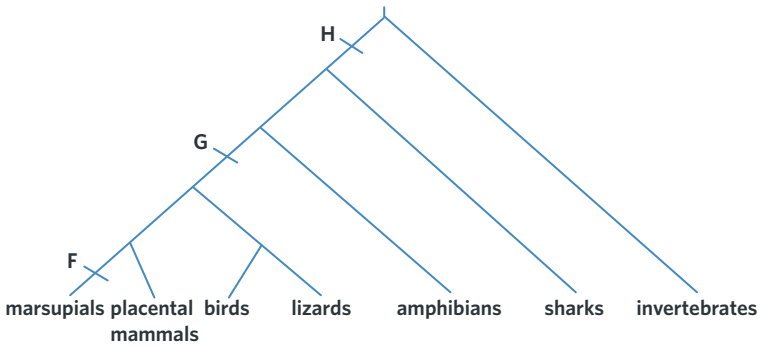
	P	Q	R
A	Cat	Lizard	Fish
B	Crocodile	Emu	Shark
C	Kangaroo	Eagle	Chimpanzee
D	Bear	Octopus	Spider



Question 4

Identify the following ancestral traits that belong in the spaces F, G, and H in the phylogenetic tree.

	F	G	H
A	Fur or hair	Amniotic eggs	Four limbs
B	Pouch	Four limbs	Vertebrae
C	Pouch	Amniotic eggs	Vertebrae
D	Pouch	Amniotic eggs	Bony skeleton



Question 5

Classify the following traits as either ancestral traits or derived traits of mammals.

I Hair or fur

II Bony skeleton

III Females feed offspring using milk

IV Four limbs

V Lungs

VI Three middle ear bones

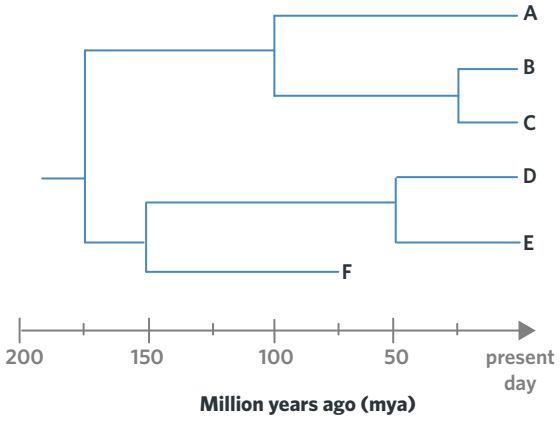
VII Amniotic eggs

	Ancestral trait	Derived trait
A	II, V, VI, VII	I, III, IV
B	II, IV, V, VII	I, III, VI
C	I, IV, V, VII	II, III, VI
D	II, IV, V, VI	I, III, VII

Question 6

Which of the following options contains all correct statements in regards to the phylogenetic tree shown?

A	Species F went extinct around 75 mya	Branch lengths indicate evolutionary time	Species A diverged from species B and C around 150 mya	Species D is more closely related to species F than it is to species C
B	Species A diverged from the ancestor of species B and C around 100 mya	Species F diverged from species D and E around 50 mya	Species D is the closest living relative of species E	Species D and F shared a common ancestor around 150 mya
C	The split between species D and E is the most recent divergence	Species B and C split around 25 mya	Species A – F shared a common ancestor around 175 mya	Species B is the closest living relative of species C
D	Branch lengths indicate evolutionary time	The split between species B and C is the most recent divergence	Species C is more closely related to species A than it is to species E	Species F is extinct

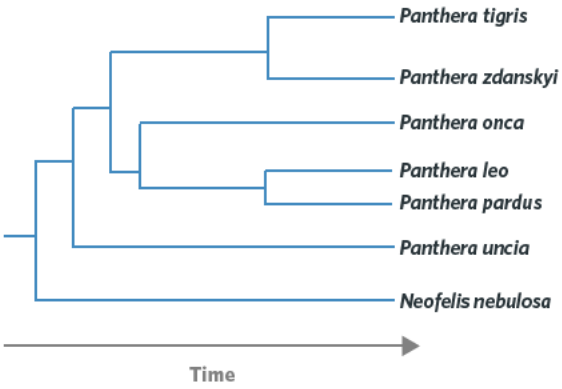


Exam-style questions

Within lesson

Question 7 (1 MARK)

Consider the following phylogenetic tree for different species in the *Panthera* genus. The tree has been constructed based on molecular and morphological data.



This information suggests that

A *Panthera uncia* is more closely related to *Panthera pardus* than it is to *Panthera zdanskyi.*

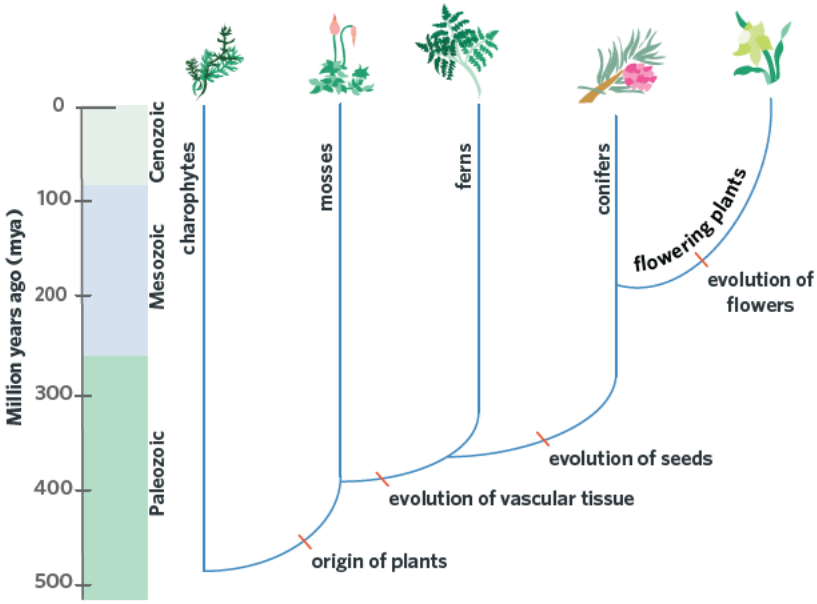
B *Panthera leo* shares a more recent common ancestor with *Panthera tigris* than with *Panthera onca.*

C *Panthera tigris* is more closely related to *Panthera pardus* than it is to *Panthera uncia.*

D *Neofelis nebulosa* is an ancestor of the other six species.

Use the following information to answer Questions 8 and 9.

In the evolution of plants there have been several major adaptations. These are shown in the image of the phylogenetic tree.



Question 8 (1 MARK)

Based on the diagram, which of the following statements is false?

A Seeds evolved in plants around 350 million years ago.

B Ferns are more closely related to conifers than they are to mosses.

C Mosses do not contain vascular tissue.

D Flowers evolved in charophytes around 160 million years ago.

Question 9 (1 MARK)

Scientists found a fossil impression of a now-extinct species of plant. This species was identified as a clubmoss, a class of vascular plants that do not contain seeds or flowers. Instead, clubmosses reproduce using spores found at the base of their leaves.

Based on this information, what time period would clubmosses most likely have first appeared in the fossil record?

A 470 – 400 mya

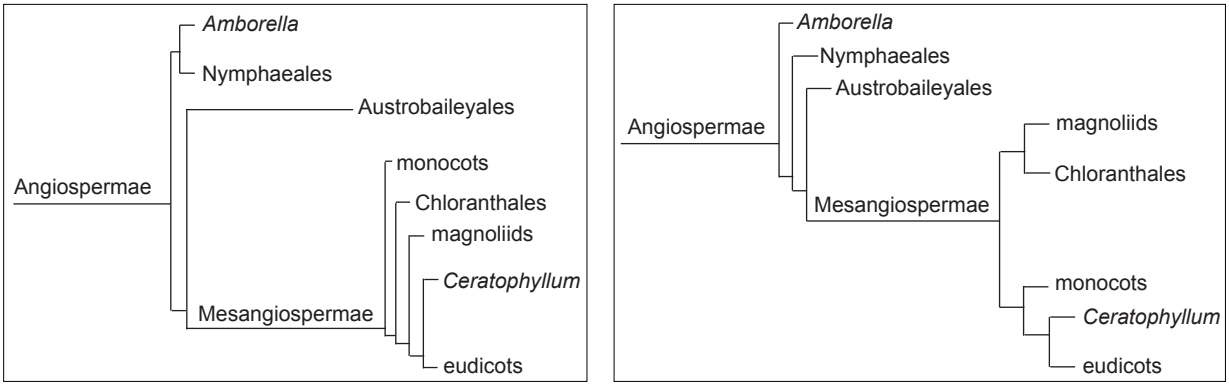
B 390 – 350 mya

C 350 – 160 mya

D 160 – 50 mya

Question 10 (4 MARKS)

Two possible phylogenetic relationships between eight groups of flowering plants are shown in the two diagrams.



a Identify two similarities between the two alternatives. (2 MARKS)

b Identify two differences between the two alternatives. (2 MARKS)

Adapted from VCAA 2011 Exam 2 Section A Q23

Multiple lessons

Question 11 (1 MARK)

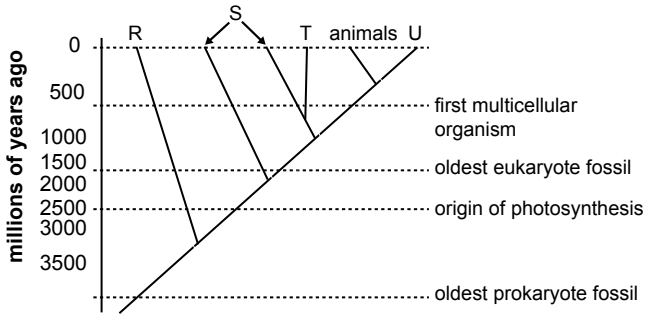
The phylogenetic tree represents one model of the order and approximate time of appearance of the major groups of living organisms, and includes four groups represented by the letters R, S, T, and U. Which of the following shows the correct placement of the organisms on the phylogenetic tree?

A R – bacteria, S – protists, T – plants, U – fungi

B R – bacteria, S – protists, T – fungi, U – plants

C R – protists, S – bacteria, T – plants, U – fungi

D R – bacteria, S – plants, T – protists, U – fungi

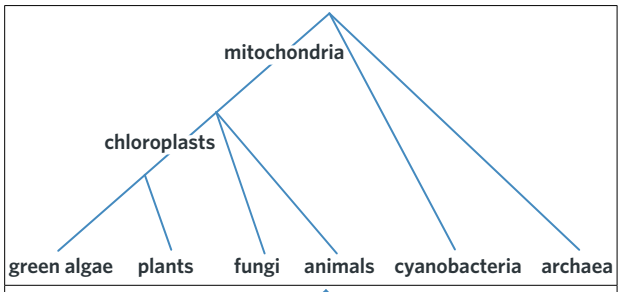


Adapted from VCAA 2017 Section A Q32

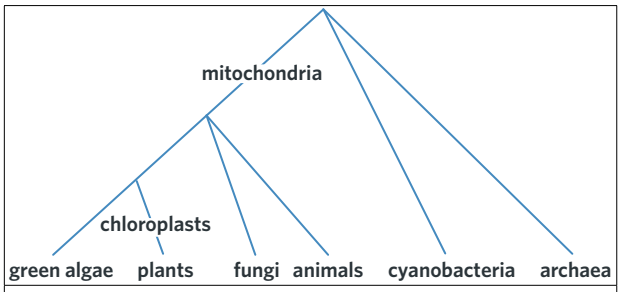
Question 12 (1 MARK)

Consider the theory of the evolution of mitochondria and chloroplasts. Which one of the following diagrams correctly represents this theory?

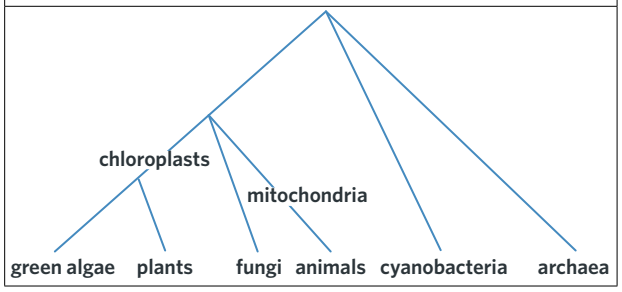
A



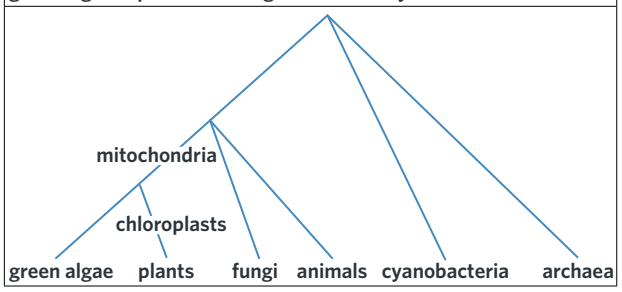
B



C



D



Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q23

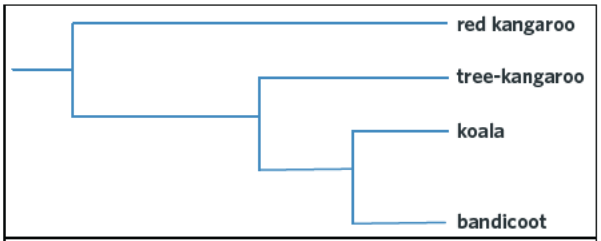
Question 13 (1 MARK)

The table shows a summary of three traits in four marsupials.

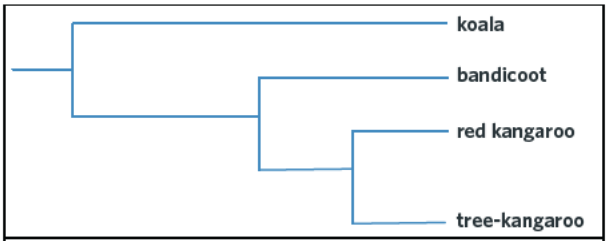
Animal	Pouch	Diet	Locomotion
red kangaroo	present	herbivore	bipedal
bandicoot	present	omnivore	quadrupedal
tree-kangaroo	present	herbivore	bipedal
koala	present	herbivore	quadrupedal

Using this information, which of the following phylogenetic trees shows the most likely evolutionary relationship between these four marsupials?

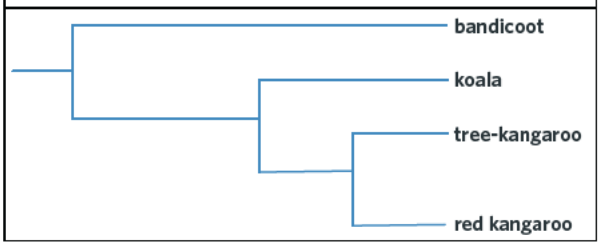
A



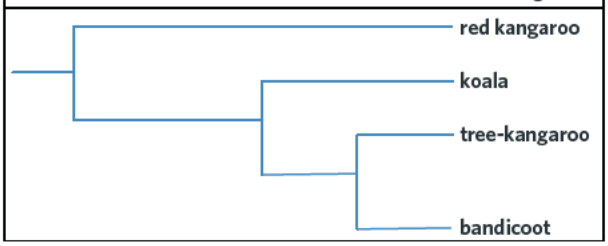
B



C

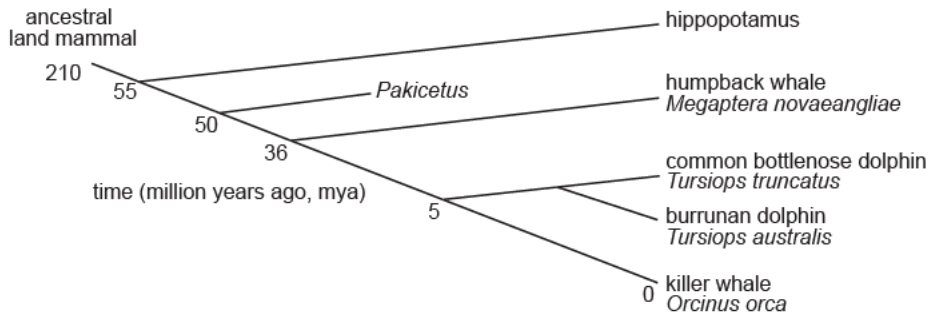


D



Use the following information to answer Questions 14 and 15.

Cetaceans (whales, porpoises, and dolphins) are marine mammals belonging to the order Artiodactyla (even-toed hoofed mammals). The closest living relatives of cetaceans are hippopotamuses. The following phylogenetic tree summarises the evolutionary relationships of four present-day cetacean species and the hippopotamus.



Question 14 (1 MARK)

Which of the following statements is false?

A The length of the branch of *Pakicetus* suggests it is extinct.

B The hippopotamus is most closely related to the ancestral land mammal.

C The killer whale diverged from the common bottlenose dolphin and the burrunan dolphin around 5 mya.

D The humpback whale is more closely related to dolphins than it is to *Pakicetus*.

Adapted from VCAA 2018 Section B Q9a

Question 15 (1 MARK)

A fossil named *Ambulocetus* was found in 1992 and dated at 49 million years old. Some palaeontologists believe that it is a transitional fossil between the ancestral land mammal shown in the phylogenetic tree and present-day cetaceans.

Given that *Ambulocetus* is a transitional fossil, you would expect it to have

A increased fur for better insulation.

B gills for underwater breathing.

C grasping ability in hands.

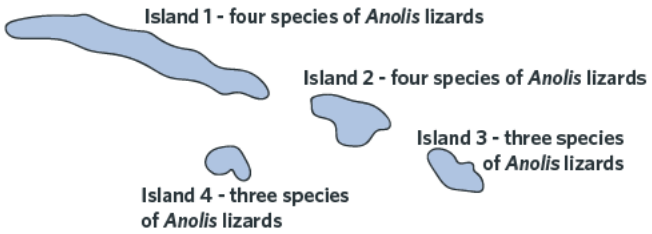
D eyes at top of head for surface vision.

Adapted from VCAA 2018 Section B Q9b

Question 16 (5 MARKS)

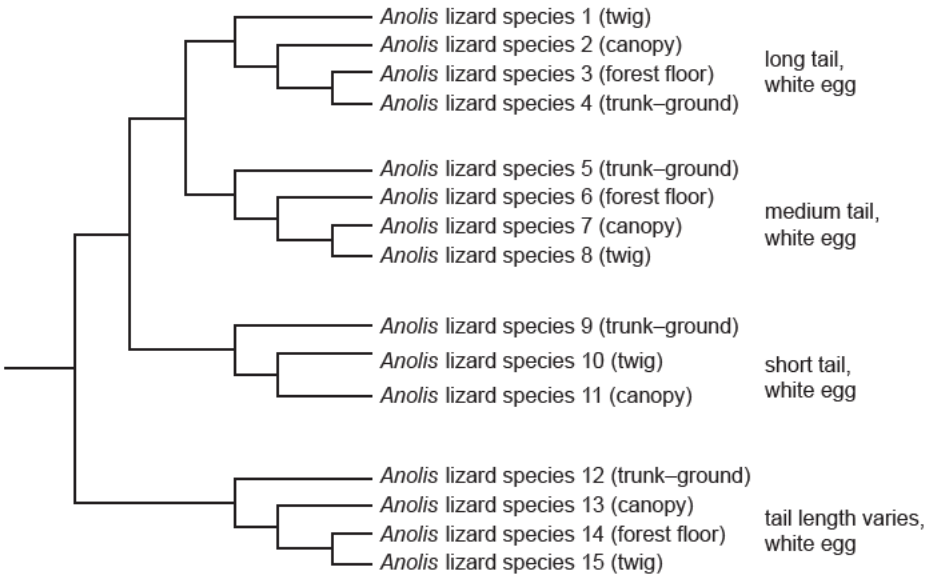
Scientists studied 15 species of lizards of the genus *Anolis* on four islands in the Caribbean Sea. On each island, there were up to four different species of these lizards. The lizards on each island tended to show similar morphology to other lizards on that island, including tail length and egg colour.

Habitat	Characteristics common to *Anolis* species living in each habitat
canopy (leafy section at the top of the tall trees)	large body, large toe pads, able to climb on the surface of broad leaves
twig (part-way up the trees on thin branches)	small body, very short legs, moves slowly, able to cling to twigs
trunk-ground (the trunks of the trees and the ground around the trunks)	chunky body, long legs, able to move very fast
forest floor (grassy areas and bushes between the trees)	long tail, slender body, short legs, able to cling to grasses and thin branches



a Each island is covered with large areas of forest. In the forests, there are four distinct habitats, as described in the table. The habitats correspond to different layers of the forest, from the canopy down to the forest floor. The scientists noticed that each of the habitats on each island was inhabited by just one of the species of lizards found on that island.
Explain how morphological data of various lizard species could be used to construct a phylogenetic tree. (1 MARK)

b The following phylogenetic tree was constructed by scientists for the *Anolis* genus of lizards based on tail length and egg colour. In brackets is the habitat type of each species.



One hypothesis is that *Anolis* lizard species with characteristics suitable for living on trunks and the ground (trunk–ground) have evolved separately on four occasions.

i Use the phylogenetic tree to justify whether *Anolis* lizard species 11 is more closely related to *Anolis* lizard species 3 or *Anolis* lizard species 12. (1 MARK)

ii Give an example of a characteristic that would be advantageous for a trunk–dwelling lizard. (1 MARK)

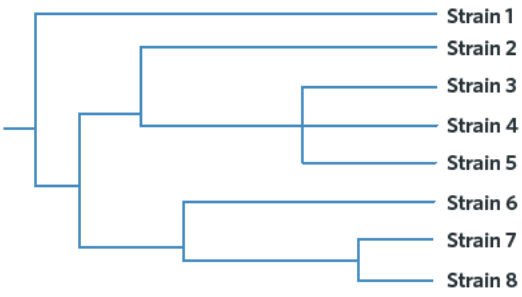
iii Explain how the phylogenetic tree supports the hypothesis that trunk–dwelling lifestyles evolved separately on four occasions. (2 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q8

Question 17 (7 MARKS)

In humans, severe acute respiratory syndrome (SARS) is a serious form of pneumonia. SARS is caused by a coronavirus that was first identified in 2003. Scientists suspected that the virus had been transmitted to humans from another animal. Testing was completed on several animal species.

Strains of the coronavirus similar to those found in humans were identified in different species of horseshoe bats (genus *Rhinolophus*) and palm civets (*Paguma larvata*). Morphological data, such as protein coat composition, was used to determine relatedness between strains of the virus.



a How can morphological evidence be used to explain divergent evolution between two strains of the virus? (2 MARKS)

b The morphological data enabled the scientists to draw an evolutionary tree for different strains of the virus. The following evolutionary tree was drawn. The branch length indicates time since divergence.

i Which two strains would you expect to be most morphologically similar? Justify your reasoning. (2 MARKS)

ii The branches for strains 3, 4, and 5 diverge at the same point. Explain how this can occur with reference to uncertainties in data. (1 MARK)

c Strains 3 and 4 are found in palm civets and strains 5 and 6 are found in humans. All other strains are found in different species of horseshoe bats.

i What conclusion can be drawn about the origin of the strains of virus that cause SARS in palm civets? (1 MARK)

ii What conclusion can be drawn about the origin of the strains of virus that cause SARS in humans? (1 MARK)

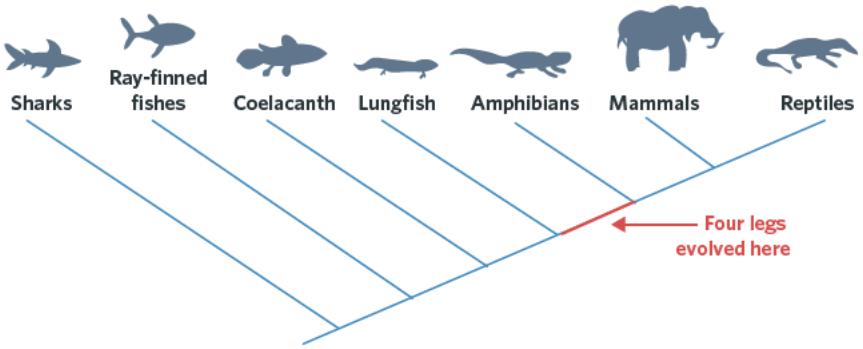
Adapted from VCAA 2013 Section B Q10

Key science skills

Question 18 (6 MARKS)

Tetrapods (meaning 'four legs') are a group of animals that have four limbs and includes amphibians, mammals, and reptiles. Tetrapods are predominantly terrestrial animals but evolved from a fish ancestor that lived in marine environments. The closest living marine relatives of tetrapods are lungfish, which have highly specialised lungs that allow them to take gulps of air for oxygen.

The phylogenetic tree summarises the evolutionary relationships of tetrapods among vertebrates.



a Based on the tree, what is the most recent divergence among vertebrates? (1 MARK)

b A fossil named *Tiktaalik,* that remains to be dated, was found by a group of scientists. A hypothesis among many paleontologists is that it is a transitional fossil between ancestral fish and tetrapods.

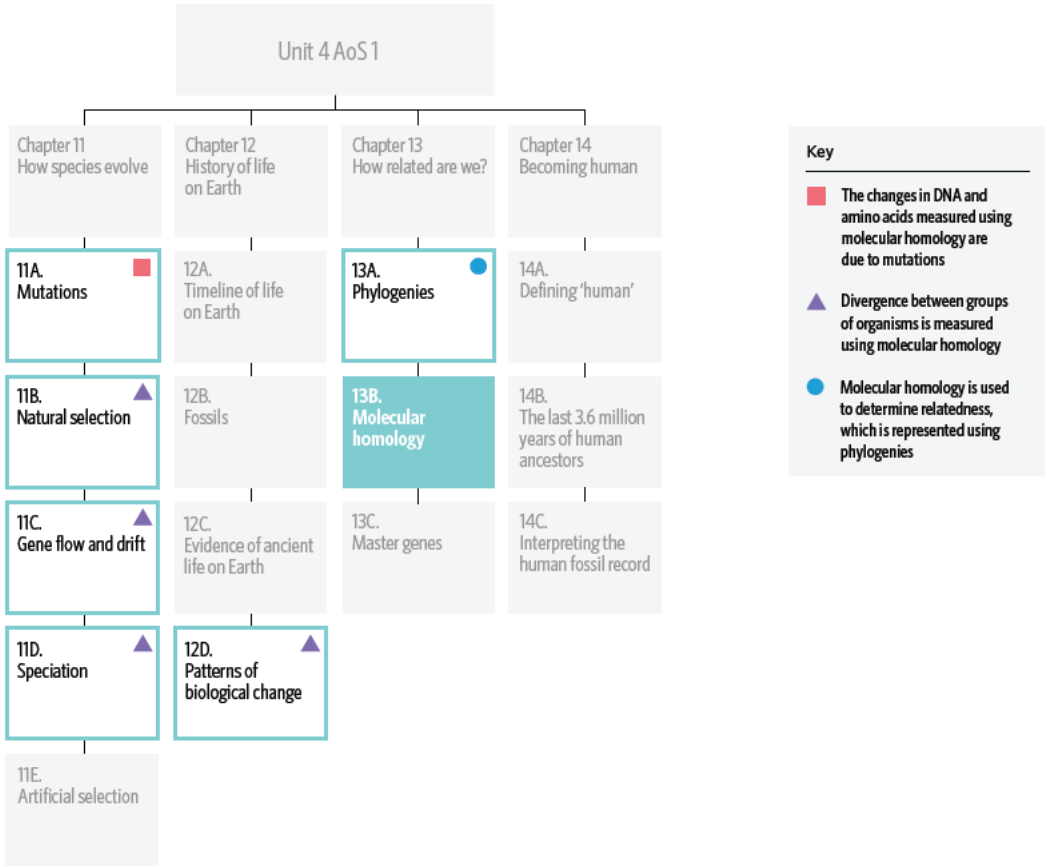
i Predict two structural features of the *Tiktaalik* fossil that would provide evidence to support the hypothesis that it is a transitional fossil and suggest a survival advantage on land of each feature. (3 MARKS)

ii Describe a piece of evidence that might refute the hypothesis that *Tiktaalik* is a transitional fossil between a fish ancestor and present-day tetrapods. (2 MARKS)

Adapted from VCAA 2018 Section B Q9b

13B MOLECULAR HOMOLOGY

Since the first living thing on Earth, mutations have arisen that make organisms different from each other. Scientists can use these slight mutations to distinguish between species and even people!



In this lesson you will learn how proteins and DNA are used to measure relatedness between organisms.

Study design dot point

- molecular homology as evidence of relatedness between species including DNA and amino acid sequences, mtDNA (the molecular clock), and the DNA hybridisation technique

Key knowledge units

DNA and amino acid differences	4.1.7.1
Mitochondrial DNA and the molecular clock	4.1.7.2
DNA hybridisation	4.1.7.3

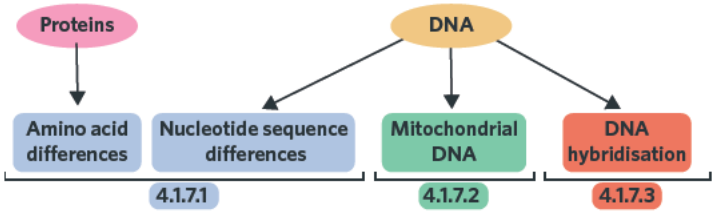


Figure 1 Overview of the different molecules used in each molecular homology technique, and their corresponding KU in this lesson

DNA and amino acid differences 4.1.7.1

OVERVIEW

Comparing the amino acid or DNA sequence of two individuals reveals how related they are.

THEORY DETAILS

mutation rate the average number of mutations that occur in a gene or genome over time

molecular clock a model that suggests the mutation rate can be used to determine relatedness between two organisms

DNA sequences in a species change over time due to the accumulation of heritable mutations in the germline. This is known as the **mutation rate**. Because of this, we know that two species that diverged millions of years ago will have more differences in their DNA than two species that diverged recently. The **molecular clock** model states that measuring the number of differences in DNA or amino acid sequences between organisms indicates how closely they are related.

A limitation of the molecular clock model is that the mutation rate is not constant. The mutation rate in DNA may vary:

- over time. The mutation rate is not constant over time since factors such as selection pressures, presence of mutagens, and population size can affect it.
- within the genome. Some regions of the genome are 'hotspots' for mutations, whilst other regions rarely accumulate mutations. Cytochrome c is an example of a conserved gene, meaning that it rarely accumulates mutations since they would usually be lethal or decrease fitness substantially and so these mutations are not inherited. Due to the very low mutation rate of conserved genes, they are often useful for determining relatedness between distantly related taxa.
- between species. Some species have much lower overall mutation rates than other species (e.g. turtles have a very low mutation rate).
- within species. In humans, the mutation rate in male gametes is much higher than the mutation rate in female gametes.

Amino acid sequences

Determining relatedness between two organisms by comparing amino acid sequences is easy. For cytochrome c, humans and rats share 91% of amino acid sites in common while humans and yeast have 64% of sites in common, indicating that rats and humans have a more recent common ancestor than yeast and humans. If you look at just a single segment of the amino acid sequence, you can see the same pattern (Figure 2). Humans and rats only have one amino acid difference between them, whereas humans and yeast have three amino acid differences, indicating that yeast is more distantly related than rats.

Human	*Ser*	*Tyr*	*Thr*	*Ala*	*Ala*	*Asn*	*Lys*	*Asn*
Rat	*Ser*	*Tyr*	*Thr*	*Asp*	*Ala*	*Asn*	*Lys*	*Asn*
Yeast	*Ser*	*Tyr*	*Thr*	*Asp*	*Ala*	*Asn*	*Ile*	*Lys*

Figure 2 Comparison of a section of the cytochrome c amino acid sequence between humans, rats, and yeast. Highlights indicate amino acid differences.

Nucleotide differences

Determining relatedness using DNA sequences is very similar to using amino acid sequences. Below is the same section of cytochrome c but instead the DNA sequence is shown (Figure 3). You can compare the number of nucleotide differences between organisms to determine relatedness. Humans and rats have three nucleotide differences whereas humans and yeast have seven nucleotide differences, indicating again that rats are more closely related to humans than yeast.

lesson link In **13A**, you learned how to analyse and interpret phylogenetic trees. Now you can use data from molecular homology within phylogenetic trees.

Human	5′ – AGA ATA TGA CGG CGA TTG TTC TTA – 3′
Rat	5′ – AGA ATA TGA CTG CGT TTG TTT TTA – 3′
Yeast	5′ – AGA ATG TGG CTG CGT TTG TAT TTC – 3′

Figure 3 Comparison of a section of the cytochrome c DNA sequence between humans, rats, and yeast. Highlights indicate nucleotide differences.

Building a phylogenetic tree

The whole point of this analysis is to determine relatedness so you can construct a phylogenetic tree. The evolutionary relationship between humans, rats, and yeast based on cytochrome c data is shown in Figure 4.

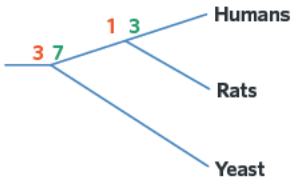


Figure 4 Phylogenetic tree of humans, rats, and yeast based on amino acid (orange) and nucleotide (green) differences in cytochrome c segment

Species identification

Sometimes, species are so morphologically similar that molecular markers such as DNA and amino acid sequences must be used in order to distinguish between them. In other cases, molecular markers may be used to identify unknown biological samples (e.g. in food-quality testing) or mummified specimens in which the morphology is difficult to discern. There is no specific number of changes in a sequence that indicates two samples are from different species so the results must be interpreted by experts in the field. Practically, scientists would look at multiple sites across the genome when determining relatedness between organisms.

Mitochondrial DNA and the molecular clock 4.1.7.2

OVERVIEW

Mitochondrial DNA may be used as a molecular clock to measure the time since divergence between two organisms.

THEORY DETAILS

Mitochondria, like chloroplasts, contain their own genome because they once existed as free-living organisms before being engulfed by our eukaryotic ancestors. Their DNA is referred to as **mitochondrial DNA (mtDNA)**. mtDNA is almost 17 000 nucleotides long in humans and contains 37 genes, compared to the over 24 000 genes in our **nuclear DNA**. Mitochondrial DNA is **maternally inherited**, meaning that it is only inherited from your mother, so your mtDNA is completely different from your father's.

mitochondrial DNA (mtDNA) circular DNA found in mitochondria

nuclear DNA DNA that is located in the nucleus of a cell

maternally inherited only inherited from the mother, not the father

There are two main advantages of using mtDNA over nuclear DNA as a molecular clock:

- The mutation rate in mtDNA is much higher than in the coding regions of nuclear DNA making it useful for more closely related species which have had less time to accumulate mutations.
- There is no recombination (mixing of DNA between homologous chromosomes during gamete development) in mtDNA because it's inherited from the mother, making it possible to trace unbroken lineages.

Tip Note that the coding regions of DNA mutate at a slow rate and the non-coding regions of DNA mutate at a fast rate. mtDNA usually mutates faster than the coding regions of nuclear DNA.

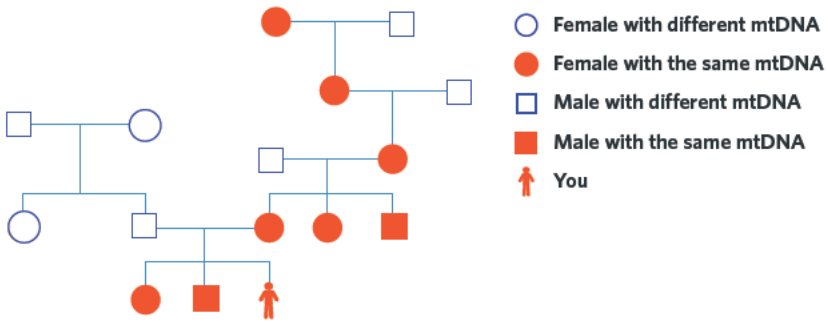


Figure 5 Pedigree diagram showing the inheritance of mtDNA over generations

lesson link In ***4B***, you learned about complementary base pairing. For this lesson, you will need to remember that adenine binds to thymine and cytosine binds to guanine.

For these reasons, mtDNA is incredibly useful for tracing human lineages. Researchers have been able to trace maternal lineages using mtDNA and have shown that modern humans share a common female ancestor that lived in Africa about 160 000 years ago – this is known as the Mitochondrial Eve Hypothesis.

DNA hybridisation 4.1.7.3

OVERVIEW

DNA hybridisation uses the principle of complementary base-pairing to measure the similarity of DNA sequences.

THEORY DETAILS

DNA hybridisation is a technique that scientists use to determine how similar two strands of DNA are – also known as their sequence homology. It doesn't require sequencing DNA like the above techniques do, but instead relies on the base pairing property of DNA. DNA hybridisation is useful for distinguishing different species but less effective for distinguishing between individuals of the same species, due to their genome sequences being too similar.

DNA hybridisation a technique that determines relatedness between DNA sequences by measuring the temperature at which they break apart and become single-stranded

melting temperature (T_m) the temperature at which half of the DNA strands in a sample become single-stranded

Humans, for example, share around 99.9% of their genome with each other, a difference too small to detect using DNA hybridisation. The process of DNA hybridisation is detailed below and in Figure 6.

1 Denaturation – DNA from two different species are heated to around 95°C to break all of the hydrogen bonds between strands to create single-stranded DNA.

2 Hybridisation – Single-stranded DNA from both species are mixed together and cooled. This allows complementary base pairs of DNA from each species to form hydrogen bonds with each other. The more related the species, the more homology there will be between the two DNA strands, and the more hydrogen bonds will form.

3 Melting – Samples are gradually heated to determine **melting temperature (T_m)**. As the temperature increases, more hydrogen bonds will break until ultimately all DNA in the sample is single-stranded (like in step 1). The melting temperature is the point where only 50% of the DNA strands in the sample have dissociated and become single-stranded. More hydrogen bonds between strands means that more heat will be needed to separate those two strands of DNA. Therefore, high T_m correlates with high sequence homology and closer relatedness.

Theory summary

Here you have learned about a few techniques that measure relatedness between organisms.

It's important to understand that these techniques are used for determining evolutionary relationships between and within species as well as for species identification.

Table 1 Summary of the different ways of determining relatedness

Piece of evidence	Explanation
Morphological data	Closely related species will have similar structural features
DNA sequence	Closely related species will have similar nucleotide sequences • Nuclear DNA is good for distantly related organisms • mtDNA is good for closely related organisms (e.g. humans)
Amino acid sequence	Closely related species will have similar protein sequences
DNA hybridisation	Closely related species will have a higher melting temperature

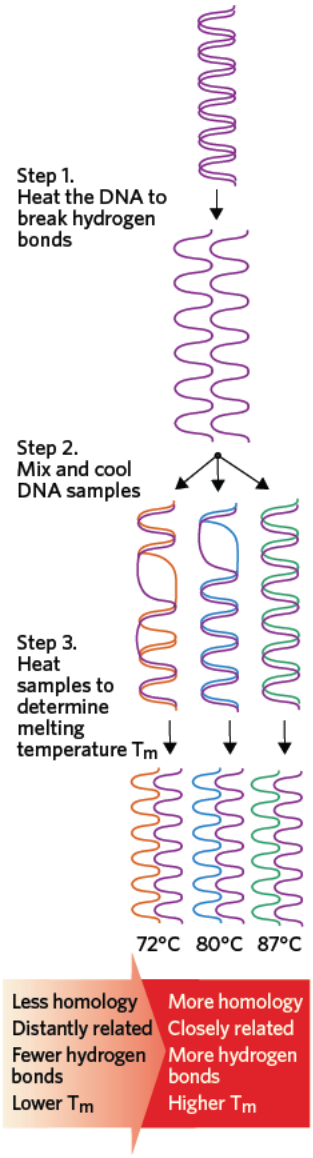


Figure 6 The process of DNA hybridisation. The two species whose hybrid DNA melted at 72°C are less related than the two species whose hybrid DNA melted at 87°C.

13B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ DNA that usually has a high mutation rate and is commonly used for determining human lineages

b _____ the temperature at which 50% of the DNA in a sample remains double-stranded

c _____ the number of mutations that occur in an organism's genome over time

d _____ a technique that determines relatedness based on the number of hydrogen bonds that form between DNA strands

e _____ the pattern of inheritance that mtDNA follows

f _____ a model that allows us to determine relatedness based on the number of mutations that accumulate over time

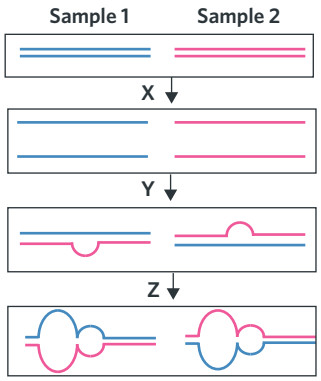
Question 2

Which option contains all true statements in regards to mitochondrial DNA?

A	Typically high mutation rate	Maternally inherited	Only found in females
B	Typically high mutation rate	Paternally inherited	Only found in females
C	Typically low mutation rate	Inherited from both parents	Found in males and females
D	Typically high mutation rate	Maternally inherited	Found in males and females

Question 3

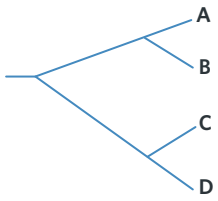
The diagram shows a procedure of a DNA hybridisation experiment. What occurs at the stages X, Y, and Z?



	X	Y	Z
A	heating	heating	cooling
B	heating	cooling	heating
C	cooling	heating	cooling
D	cooling	cooling	heating

Question 4

Which of the following statements is correct in regards to species A – D in the phylogenetic tree?



A The melting temperature between DNA from species C and D would be lower than the melting temperature between DNA from species B and C.

B The mtDNA sequence of species B is more similar to species A than species C.

C The amino acid sequence of species A is more similar to species D than species B.

D More hydrogen bonds would form between DNA from species B and D than between DNA from species B and A.

Question 5

Which of the following options shows the most homology to the amino acid sequence?

Met – Lys – Arg – Ala – Ala – Asn – Ser

A *Met – Thr – Arg – Ala – Ala – Asn – Ser*

B *Met – Lys – Arg – Thr – Ala – Asn – Tyr*

C *Met – Lys – Ser – Ala – Pro – Lys – Ser*

D *Met – Lys – Gly – Pro – Ala – Asn – Ser*

Question 6

Which of the following DNA sequences (A-D) is from a species that is most distantly related to the species with the DNA sequence? Bolded letters indicate a difference in the nucleotide sequence.

5′ – ATG GCC GAA AGA TGG TCA – 3′

A 5′ – ATG G**A**C GAA AGA TGG TCA – 3′

B 5′ – ATG GC**A** G**G**A AGA TGG TCA – 3′

C 5′ – ATG GC**A** G**G**A AGA TG**A** **A**CA – 3′

D 5′ – ATG GCC G**G**A AGA TG**T** TC**C** – 3′

Exam-style questions

Within lesson

Question 7 (1 MARK)

A source of DNA that could be used to determine evolutionary relationships among humans would be

A plasmids.

B mitochondria.

C ribosomes.

D chloroplasts.

Adapted from VCAA 2012 Exam 2 Section A Q20

Question 8 (1 MARK)

You do not have the same mitochondrial DNA as your

A mother.

B sibling.

C paternal aunt.

D maternal uncle.

Adapted from VCAA 2013 Section A Q22

Question 9 (1 MARK)

Which of the following explains how amino acid differences in proteins can indicate evolutionary relationships?

A Over time, mutations accumulate that may change the sequence of amino acids. The more differences in the amino acid sequence, the less related the two species are.

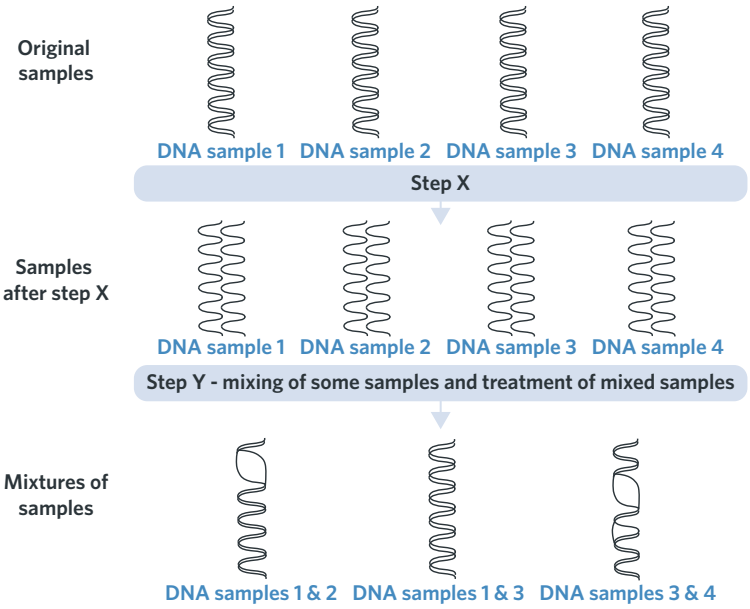
B Over time, silent mutations accumulate in DNA that don't change the amino acid sequence. The resultant proteins look the same and this similarity indicates closely related species.

C Mutations in amino acids accumulate over time, resulting in metabolic enzymes with different structures. The rate at which each enzyme catalyses reactions may be compared between species to determine relatedness.

D Mixing proteins of two species will cause them to bind together. The higher the temperature at which the proteins separate indicates they are more closely related.

Use the following information to answer Questions 10 and 11.

Samples of DNA were taken from four individuals. The samples went through a series of steps and the resulting DNA is shown.



Question 10 (1 MARK)

Using information from the diagram, which conclusion could be drawn?

A Samples 1 and 4 are from individuals belonging to the same species.

B Treatment at step X would have included heating each of the original samples.

C Treatment of mixed samples at step Y would have included the addition of DNA ligase.

D Individuals belonging to samples 3 and 4 are more closely related than individuals belonging to samples 1 and 2.

Adapted from VCAA 2013 Section A Q33

Question 11 (1 MARK)

Which of the following statements in regards to DNA samples 1 and 3 is incorrect?

A The melting temperature would be higher than the other mixtures of samples.

B More hydrogen bonds are formed between DNA from each sample compared to other mixtures.

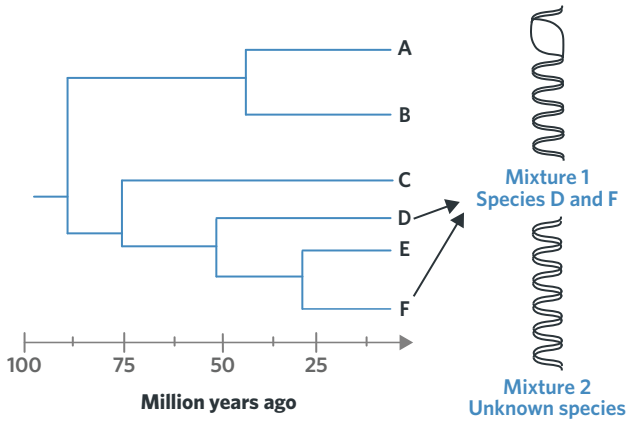
C Hydrogen bond formation between complementary bases requires DNA polymerase.

D Half of the DNA strands would be single-stranded when the mixture is heated to its melting temperature.

Question 12 (1 MARK)

DNA hybridisation experiments were conducted using six closely related species to construct the phylogenetic tree.

Two diagrams of what DNA samples look like after DNA hybridisation are shown. Mixture 1 contains DNA of both species D and F. Mixture 2 contains DNA from two of the species shown in the tree.



Given the information, DNA from which species are most likely to be in mixture 2?

A species A and F

B species B and F

C species C and F

D species E and F

Use the following information to answer Questions 13 and 14.

Cytochrome c is a protein that consists of 104 amino acids. Many of these 104 sites on cytochrome c contain exactly the same amino acid across a large range of organisms. There are, however, some differences at certain sites. Underlying these amino acid differences are changes in the DNA sequence. It is hypothesised that different organisms, all containing cytochrome c proteins, descended from a primitive microbe that lived over 2 billion years ago.

The table shows the corresponding DNA sequences for various amino acids found at specific sites for each organism.

Organism	Site 1	Site 4	Site 11	Site 15	Site 22
pig	GGT	GAG	GTA	GCA	AAA
human	GGT	GAG	**A**TA	GCA	AAA
dogfish	GGT	**A**AG	GTA	GCA	AA**T**
chicken	GGT	**T**AG	GTA	**T**CA	AAA
Drosophila	GGT	GAG	GTA	GCA	**GC**A
yeast	GGT	GAG	GTA	G**A**A	AAA
wheat	GGT	GA**G**	**AA**A	GCA	**GC**A

Question 13 (1 MARK)

Using only the data for the molecular homology of cytochrome c, which one of the following organisms is most closely related to the chicken?

A *Drosophila*

B Pig

C Human

D Yeast

Adapted from VCAA 2016 Section A Q39

Question 14 (1 MARK)

Using only the data for the molecular homology of cytochrome c, which pair of organisms is most distantly related to wheat?

A Dogfish and chicken

B Human and *Drosophila*

C *Drosophila* and pig

D Chicken and yeast

Adapted from VCAA 2016 Section A Q40

Multiple lessons

Question 15 (1 MARK)

Which of the following cannot be used as evidence that two lizard populations are from a different species?

A comparison of amino acid sequences

B comparison of homologous structures

C DNA hybridisation

D DNA replication is similar in both species

Question 16 (1 MARK)

Measuring the accumulation rate of random genetic changes in the genomes of chimpanzees and humans is called

A phylogeny.
B a molecular clock.
C DNA hybridisation.
D relative dating.

Adapted from VCAA 2013 Section A Q37

Question 17 (1 MARK)

Research has shown that in a number of genes the sequence of nucleotides is unique to humans and is not found in chimpanzees.

Gene with sequence unique to humans	Functional role of gene with sequence unique to humans
HAR1	active in the brain, necessary for development of the cerebral cortex
FOXP2	facilitates formation of words by the mouth
AMY1	facilitates digestion of starch
ASPM	controls brain size
LCT	permits digestion of milk sugar in adulthood
HAR2	drives gene activity in the wrist and thumb during development

Using the information in the table, it is reasonable to conclude that chimpanzees
A have a similar ability to form words by mouth as humans.
B are unable to digest starch.
C are able to digest milk sugar in adulthood.
D process and remember more complex information than humans.

Adapted from VCAA 2013 Section A Q38

Question 18 (4 MARKS)

Six different snake species have been studied by scientists. Five of the species are presently found in the Amazon rainforest, and one extinct species was recovered from a fossil found in the Amazon. All six species belong to the genus *Bothrops*.

Scientists wanted to classify the evolutionary relationships between the six species in order to construct a phylogenetic tree. Scientists used amino acid sequences to help classify the six snake species.

a Describe two other pieces of evidence the scientists could use to construct a phylogenetic tree. (2 MARKS)
b Explain how amino acid sequences may be used to determine relatedness between species. (2 MARKS)

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q10c

Question 19 (8 MARKS)

The Mitochondrial Eve Hypothesis suggests that the mitochondrial DNA of all living people can be traced back to a few women in Africa.

a Give two reasons why mitochondrial DNA is useful for tracking human evolutionary history. (2 MARKS)

Adapted from VCAA 2011 Exam 2 Section B Q7ai

b In the table is data taken from seven sites of mtDNA that are known to identify different phylogenetic groups of humans. mtDNA from five modern-day humans of different backgrounds were sequenced and their sequences at these seven sites are shown.

Individual	Site A	Site B	Site C	Site D	Site E	Site F	Site G
Individual 1	ATT	GA**C**	CCA	TGG	AAG	CCC	TTG
Individual 2	ATT	GA**C**	CCA	TGG	AAG	CC**T**	TTG
Individual 3	ATT	GAG	C**A**A	TGG	**C**AG	C**G**C	TT**A**
Individual 4	ATT	GAG	CC**T**	TG**A**	AAG	CCC	TTG
Individual 5	ATT	**T**AG	C**A**A	TGG	**C**AG	CCC	T**CA**

i Based on the data, which two individuals are the most closely related? Explain your reasoning. (2 MARKS)

ii Identify the type of mutations that have accumulated in mtDNA that make it useful for determining relatedness. (1 MARK)

iii The sequence TGA found in individual 4 at site D encodes a stop triplet, whereas TGG does not encode a stop triplet. Name this type of mutation and explain the consequences this would have on gene expression if the mutation was found in a protein-coding gene. (3 MARKS)

Key science skills

Question 20 (8 MARKS)

Angus wants to use DNA to determine the relatedness between him and his pets, which include a dog, lizard, mouse, tarantula, and goldfish. He decides to use DNA hybridisation to compare his DNA to DNA from each of his five pets individually, resulting in five mixtures of samples. He also includes a sixth sample containing just his own DNA.

a Outline the steps involved in the DNA hybridisation technique following the isolation of DNA. (3 MARKS)

Adapted from VCAA 2017 Section B Q6a

b Angus performed the experiment, resulting in six tubes containing mixtures of DNA. The melting temperatures (T_m) are measured for each of the six samples and are shown in the table.

Sample mixed with Angus's DNA	Melting temperature (T_m)
Angus	95°C
Goldfish	87°C
Tarantula	86°C
Mouse	92°C
Lizard	89°C
Dog	90°C

i With reference to melting temperature, what is the general hypothesis of a DNA hybridisation experiment? (1 MARK)

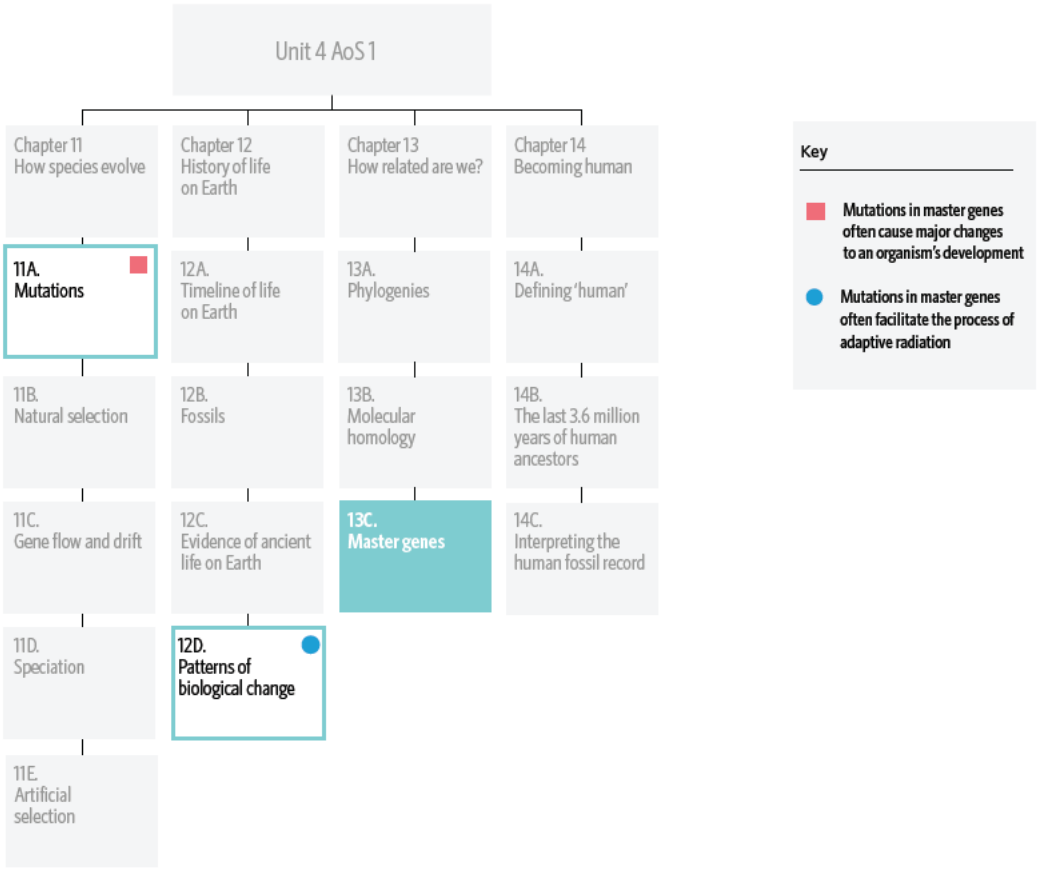
ii With reference to the data, identify which of his pets Angus is most closely related to. (1 MARK)

iii With reference to the data, identify which of his pets Angus is most distantly related to. (1 MARK)

c Give an example of a suitable factor to control for in this experiment. Justify your response. (2 MARKS)

13C MASTER GENES

Master genes have a huge impact on the phenotype of an organism. A mutation in a single master gene in fruit flies can cause them to grow legs on their heads!



In this lesson you will learn about master genes and how they work. You will be looking specifically at *BMP4* and how it influences beak formation in Galápagos finches and jaw formation in African cichlid fish.

Study design dot point

- the evolution of novel phenotypes arising from chance events within genomes, specifically sets of genes that regulate developmental processes and lead to changes in the expression of a few master genes found across the animal phyla, as demonstrated by the expression of gene *BMP4* in beak formation of the Galápagos finches and jaw formation of cichlid fish in Africa

Key knowledge units

Master genes	4.1.9.1
How the *BMP4* gene works	4.1.9.2

Master genes 4.1.9.1

OVERVIEW

Master genes have vital roles in the development of animals by switching other genes on or off.

THEORY DETAILS

Regulatory genes control the expression of other genes by switching them either on or off. These genes encode regulatory proteins that bind to specific sequences in the genome in order to influence gene expression. There are several regulatory genes that control gene expression during **embryonic development.**

regulatory gene a segment of DNA responsible for producing proteins that control the expression of other gene(s)

embryonic development process that occurs during the gestation period where structures of the animal are formed under the direction of molecular signals

Since embryos represent such a crucial stage in early development, gene expression during this period can have massive impacts on the phenotype of an animal, including jaw shape, leg size, and leg location. Regulatory genes that have such a massive impact on the development of animals are known as **master genes**.

Master genes may control the expression of other genes by:

- Controlling the timing of gene expression. For example, switching a gene on early will have a different effect on development compared to switching the same gene on later.
- Controlling the cells in which gene expression occurs. For example, master genes might switch a gene on in one part of the body and not another. *Hox* genes are a group of master genes that control the body plan of animals during embryonic development. In fruit flies, the *Antp* gene is a *Hox* gene that promotes leg growth and is therefore only expressed in the abdomen. A mutation can occur that causes *Antp* to be expressed in the head, resulting in flies growing legs instead of antennae on their heads (Figure 2).

Imagine a hypothetical master gene that is responsible for nose growth during embryonic development. Increased expression of this master gene during development would increase nose growth, creating an organism with a large nose such as a proboscis monkey. Decreased expression of this master gene would limit nose growth, creating an organism with a smaller nose such as a golden snub-nosed monkey (Figure 3).

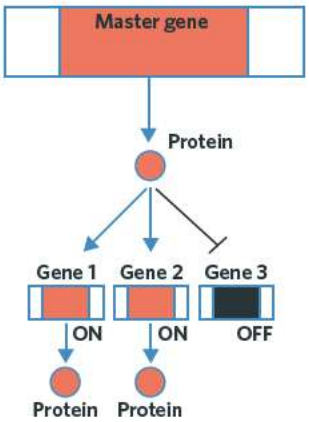


Figure 1 Diagram showing the general regulatory function of master genes. Master genes produce a protein that switches other genes on or off.

Figure 2 A fly with a mutation causing expression of the *Antp* master gene in the head results in the growth of legs instead of antennae from the head.

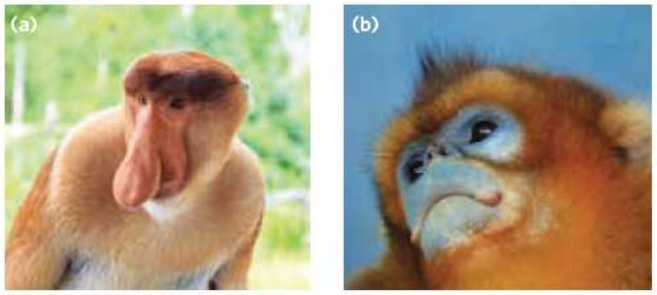


Image: Yusnizam Yusof/Shutterstock.com

Figure 3 **(a)** Proboscis monkey with a large nose and a **(b)** golden snub-nosed monkey with a small nose

master gene a gene that controls the expression of a large number of genes in early development

structural gene a segment of DNA that doesn't code for regulatory proteins, but codes for proteins that will be used functionally or structurally throughout a cell or organism

bone morphogenetic protein 4 (*BMP4*) a master gene that is important for beak formation in Galápagos finches and jaw formation in African cichlid fish

How the *BMP4* gene works 4.1.9.2

OVERVIEW

BMP4 is a great example of a master gene controlling facial development in a number of animal groups including Galápagos finches and African cichlid fish.

THEORY DETAILS

Bone morphogenetic protein 4 (BMP4) is a protein encoded by the master gene ***BMP4***. BMP4 is a signalling protein found in all vertebrates that controls cartilage, bone, and muscle development in embryos. Its precise role changes between different vertebrate species. Here we will look at two examples.

Tip To refer to a gene scientists often italicise its name. So, if *BMP4* is italicised, we are talking about the gene that encodes the BMP4 protein.

African Cichlid fish

Cichlids are an astonishingly diverse family of fish found across the world. There are over 1650 species found worldwide, with around 1600 of these being found in Africa. Scientists have studied species found in three African lakes: Lake Victoria, Lake Malawi, and Lake Tanganyika. Within each of these lakes, adaptive radiation of cichlid species has occurred in an incredibly short period of time. For instance, in Lake Victoria there are 500 species of cichlid that all evolved from a common ancestor living a mere 10 000 to 15 000 years ago. Scientists were puzzled: how did so many different cichlid species with vastly different phenotypes evolve so quickly?

It may have happened like this: 15 000 years ago, the ancestral Lake Victoria cichlid lived in a habitat with many unoccupied dietary niches. That is, there was an abundance of many different types of food. But the ancestral cichlid could only consume one food type. Then, small mutations to *BMP4* drastically changed the jaw shape of individuals, which meant they were able to eat different prey items. Jaw shape was heritable, and eventually cichlids with different jaw shapes speciated. In essence, cichlids were able to diversify in such a short period of time because tiny mutations in *BMP4* can result in large phenotypic changes.

This evidence is supported by the fact that the same jaw shape has arisen in distantly related cichlids that occupy different lakes - indicating that the same mutations to *BMP4* may have occurred in different locations. For example, algae-scraping and scale-eating fish have more muscular, larger jaws and a stronger bite due to overexpression of BMP4 protein in embryonic development. Low expression of BMP4 protein in the developing jaw of cichlids results in decreased muscle mass and a weaker bite (better for plankton-eating fish). You can see in Figure 4 that cichlids labelled 'a' have very similar jaw shapes in all the lakes, despite being distantly related.

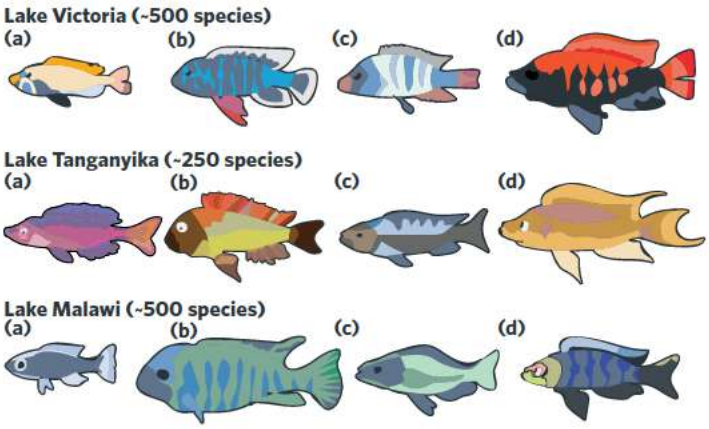


Figure 4 Comparison of cichlid species from Lakes Victoria, Tanganyika, and Malawi. **(a)** Plankton-eaters, **(b)** algae-scrapers, **(c)** scale-eaters, **(d)** reef plankton-eaters. Adapted from Wagner et al. (2014).

Galápagos finches

The finches of the Galápagos Islands *(Geospiza spp.)*, also known as Darwin's finches, have a great array of beak shapes and sizes. This is another clear example of mutations in master genes facilitating adaptive radiation.

The variety of beak shapes in *Geospiza* is explained by mutations in *BMP4* and calmodulin *(CaM)* master genes (Figure 5). High levels of the BMP4 protein in the upper beak of developing finches results in a wider and deeper beak whereas low levels of BMP4 results in low beak width and depth. The signalling molecule CaM controls beak length. High CaM expression results in an elongated beak whereas low CaM expression results in a short beak.

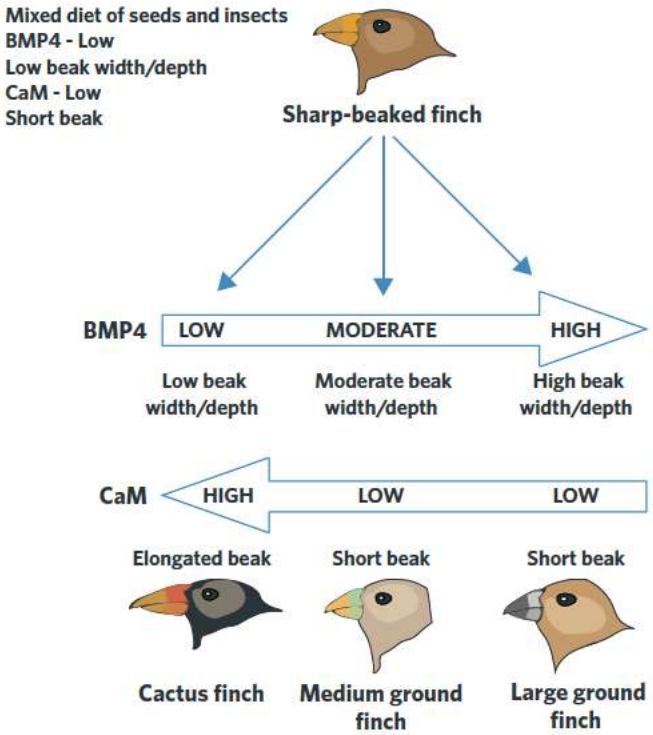


Figure 5 Variations in beak depth, width, and length among *Geospiza* species is explained by varying levels of BMP4 and CaM proteins. Adapted from Wagner et al. (2007).

Tip High BMP4 levels during embryonic development in cichlid fish usually lead to increased muscle mass and larger jaws. However, because multiple genes are involved it is pretty complex, so VCAA examination reports often just state that different levels of BMP4 result in different jaw shapes.

Analogy

A sports coach is like a master gene. Coaches tell players what to do, and master genes tell genes what to do. If a team gets a new coach, the players may train harder or become lazy. Similarly, if a single mutation arises in a master gene, the genes it controls may be upregulated or downregulated. As multiple genes are affected, there can be massive changes to phenotype in a short space of time. Under the right selection pressures, large phenotypic changes can quickly lead to speciation. In the same way, a new coach can turn a losing team into a winning team.

Tip VCAA expect you to memorise the function of *BMP4* in controlling jaw formation in African cichlids and beak formation in Galápagos finches. VCAA does not expect you to memorise other master genes such as *Hox* genes, but you should be able to understand and describe the function of other master genes when given a scenario.

Theory summary

Here you have learned about how master genes control the timing and levels of gene expression during embryonic development. Importantly, you have learned about the *BMP4* master gene, which controls beak formation in Galápagos finches and jaw formation in African cichlids.

Table 1 The functions of *BMP4* and *CaM* covered in this lesson.

Species	Master gene	Low levels	High levels
African cichlids	*BMP4*	Generally smaller jaws, less muscle mass	Generally larger jaws, more muscle mass
Galápagos finches	*BMP4*	Low beak depth/width	High beak depth/width
	CaM	Shortened beak	Elongated beak

13C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a gene responsible for regulating cartilage, bone, and muscle growth in both cichlids and finches

b _____ an early period of growth in vertebrates

c _____ a gene responsible for altering the expression of other genes during early development

d _____ a gene that encodes a protein that alters gene expression

Question 2

Which master gene expression levels belong in the spaces M and N?

Pelagic plankton eater, weak bite

M

Rock-dwellling algae scraper, strong bite

N

	M	N
A	high *BMP4*	low *BMP4*
B	high *CaM*	low *BMP4*
C	low *BMP4*	high *BMP4*
D	low *CaM*	high *CaM*

Question 3

Fill in the blanks in the following sentences.

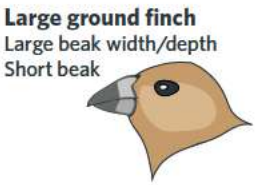
Master genes are genes that are important for regulating gene expression during _____**I**_____. One way they influence gene expression is by _____**II**_____. This occurs in jaw formation in _____**III**____ where levels of ____**IV**_____ determine muscle mass in jaws.

	I	II	III	IV
A	embryonic development	changing the timing of gene expression	African cichlid fish	CaM
B	early development	increasing the level of gene expression	African cichlid fish	BMP4
C	puberty	changing the location of gene expression	Galápagos finches	CaM
D	gestation	causing mutations in important structural genes	Galápagos finches	BMP4

Question 4

Which levels of master gene expression would correctly match the large ground finch shown?

A	high *BMP4*	low *CaM*
B	moderate *BMP4*	low *CaM*
C	low-moderate *BMP4*	high *CaM*
D	high *BMP4*	high *CaM*



Question 5

Which of the following genes would be considered a master gene?

A A gene that switches on genes needed for finger development.

B A gene that responds to high lactose levels by upregulating genes for lactose breakdown.

C A gene that encodes a structural protein used to build muscle fibres.

D A gene that repairs DNA mutations in the genome.

Exam-style questions

Within lesson

Question 6 (1 MARK)

Master genes control the jaw formation of cichlid fish by

A causing mutations in the structural genes for jaw formation.

B altering gene expression during embryonic development.

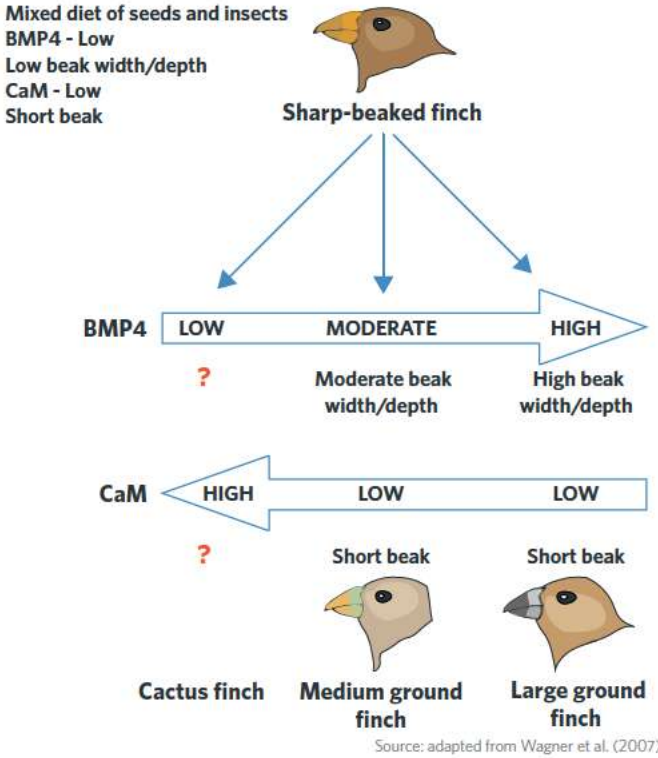
C interfering with protein folding, preventing gene expression.

D preventing mRNA from leaving the nucleus.

Adapted from VCAA 2017 Section A Q31

Use the following information to answer Questions 7 and 8.

Two proteins, BMP4 and CaM, act in the developing embryo and are responsible for the variations in beak size and shape among Galápagos finches. Variations in beak size and shape and the levels of the proteins in different types of Galápagos finches are shown in the diagram.



Source: adapted from Wagner et al. (2007)

Question 7 (1 MARK)

Consider the cactus finch. Based on the protein levels, which of the following would be the most likely beak shape of this finch?

A moderate beak depth/width, elongated beak
B moderate beak depth/width, short beak
C low beak depth/width, elongated beak
D low beak depth/width, short beak

Question 8 (1 MARK)

The differences in the levels of proteins in the different finches can be explained by

A different gestation times between species affecting embryonic development.
B mutations in the genes vital for beak formation.
C natural selection selecting for beak types due to different diets.
D mutations in *BMP4* and *CaM* causing changes in gene expression.

Adapted from VCAA 2017 Sample Exam Section A Q27 and Q28

Question 9 (5 MARKS)

The *Hox* genes are master regulatory genes that influence cells in a particular location of an animal embryo in order to develop structures for that part of the body.

In the brine shrimp, *Artemia*, the expression of the *Hox* genes *Ubx* and *Scr* results in the growth of either a swimming appendage or a feeding appendage, depending on whether the genes are expressed in cells that are in the mid-region of the body or near the mouth. These specialised appendages are labelled in the diagram.

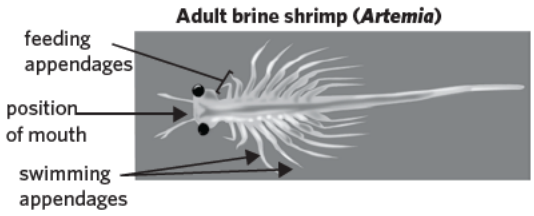


Image: patrimonio designs ltd/Shutterstock.com

a Describe one way that genes are regulated so that the same genes can produce different appendages when expressed in different locations in the *Artemia* embryo. (1 MARK)

b Outline one possible phenotypic consequence of a mutation in the *Ubx* and *Scr* genes in *Artemia*. (2 MARKS)

c Explain how mutations in master genes such as *Hox* genes could result in adaptive radiation among brine shrimp. (2 MARKS)

Adapted from VCAA 2018 Section B Q6

Multiple lessons

Question 10 (5 MARKS)

Beak shape variation in Galápagos finches is a classic example of divergent evolution. The genetic basis of beak shape is hypothesised to be due to a master gene called *BMP4*.

a Explain how *BMP4* controls beak formation in Galápagos finches. (2 MARKS)

b Different beak shapes in finches allow them to specialise on different foods. For example, finches with long thin beaks are better adapted to probing flowers and fruit. Describe a selective advantage of having a wide, deep beak. (2 MARKS)

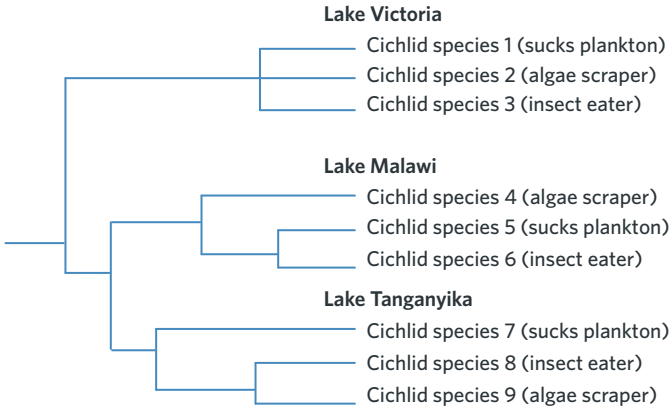
c Scientists bred a line of chickens that expressed reduced levels of the BMP4 protein during the beak formation stage of embryonic development. Identify what kind of beak shape you would expect this line of chickens to have. (1 MARK)

Question 11 (7 MARKS)

Cichlids are an incredibly diverse family of over 1650 species of tropical and freshwater fish. Scientists investigating cichlids found the fish in three lakes in Africa: Lake Victoria, Lake Malawi, and Lake Tanganyika. Scientists noticed that similar dietary niches were being filled in each lake by unrelated cichlid species, and that corresponding to each of these niches were characteristic jaw shapes. These observations are shown in the table.

Diet	Jaw shape
Sucks plankton from water column	Protruding lower jaw with weak bite
Scrapes algae from rocks	Reduced lower jaw with strong bite
Insects	Lobe-shaped lips

The phylogenetic tree shows the evolutionary relationships among various cichlid fish species. It was observed that jaw shape varies between individuals and does not seem to be due to a common ancestor.



a Explain whether or not jaw shape could be used to determine relatedness between cichlid fish species. (2 MARKS)

b Scientists hypothesise that jaw shape varies between cichlid species in the three lakes due to a master gene. Explain how the phylogenetic tree suggests a master gene is responsible for jaw shape variation in cichlid fish. (2 MARKS)

c Outline the function of the *BMP4* gene and explain its evolutionary significance in the African cichlid fish. (3 MARKS)

Key science skills

Question 12 (7 MARKS)

Cells of the bacterium *Pseudomonas fluorescens* each have a flagellum that enable them to move. Scientists removed a master gene in *P. fluorescens* that controls the expression of genes responsible for the formation of the flagellum. Scientists then measured the movement of this new strain of *P. fluorescens* compared to a strain that contains the master gene.

a Identify the independent and dependent variable in this experiment. (2 MARKS)

b Removal of the master gene produced a strain of the bacterium (called *Free*) that did not grow flagella and was unable to move. Scientists placed these bacteria in the centre of 20 dishes containing a supply of food. They also placed bacteria containing the master gene (called *Master*) in the centre of another 20 dishes containing a supply of food. The results of the experiment are shown in the table.

Strain	Day 1	Day 4
Free	Only food next to bacteria was consumed	Food further from bacteria was consumed. Almost all bacteria in dish contained flagella
Master	Food further from bacteria was consumed. All bacteria in dish contained flagella	Unchanged from Day 1

Scientists proposed two hypotheses to explain these results:

Hypothesis 1: a mutation in another gene enabled it to function as a master gene for flagella growth.

Hypothesis 2: each of the genes involved in flagella growth mutated so that they were expressed without the presence of a master gene.

i Explain which hypothesis is more likely. Justify your response. (3 MARKS)

ii Suggest two measures that should be taken to ensure the results of this experiment are reliable. (2 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q17

ACTIVITIES

Constructing phylogenetic trees

One way that scientists construct phylogenetic trees is by sequencing DNA from various species and comparing their sequences. The more differences between the sequences, the less related the two species are and the longer the amount of time since they shared a common ancestor.

Four nuclear DNA sequences of the same intron from four different species are shown.

1 Examine the four sequences and count the number of differences between samples. Record your results in the table. The differences between species 1 and 2 have been calculated for you and are shown in the second cell as 7.

Species 1: C T A T T T A A A A C G C G C T C A A T

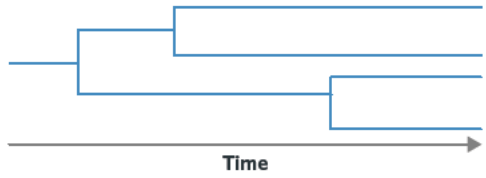
Species 2: C A A T A T A G A A T G G G C G C T A T

Species 3: C T A T T G A A A A C G C T C T C A A T

Species 4: C A A T A T A A G A T G G G C G G A A T

	Species 1	Species 2	Species 3	Species 4
Species 1	0	7		
Species 2		0		
Species 3			0	
Species 4				0

2 Redraw the phylogenetic tree on a separate piece of paper and use your results from the table to determine the evolutionary relationships between the four species.



3 What other tools could be used to determine species relatedness and ultimately construct a phylogenetic tree?

4 Is the adenine nucleotide at site 3 of the nucleotide sequence helpful for constructing a phylogenetic tree? Explain.

5 What type of DNA mutations have occurred in the intron between the four species that allow us to determine relatedness using the molecular clock?

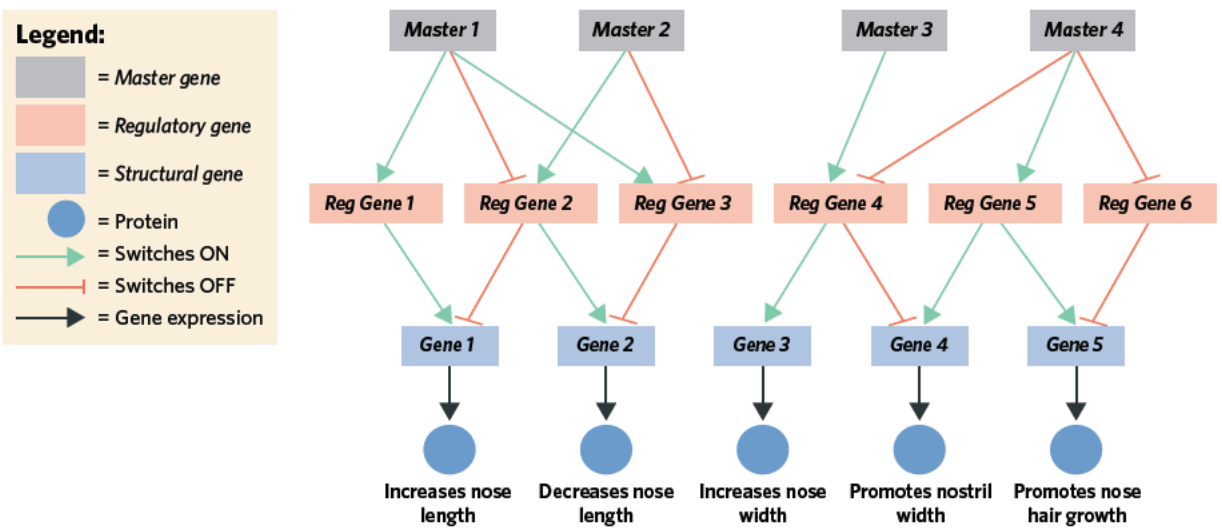
6 What types of mutations are NOT useful for determining species relatedness using the molecular clock?

7 Explain the challenges involved in determining relatedness between distantly related species using a highly mutable region of DNA.

How master genes influence other genes

Master genes control the expression of multiple genes during embryonic development. As a result they have large phenotypic consequences on an organism. They influence the phenotype of an organism by regulating multiple other genes, which has a cascade effect.

The signalling pathways of four hypothetical master genes that are important for nose shape in humans are shown. These master genes are expressed during embryonic development and have different effects on the phenotype of the embryo.



Questions

1. Identify the effect each regulatory gene has on nose shape.
2. Identify the effect each master gene has on nose shape.
3. Sometimes master genes and regulatory genes can have opposite effects on the individual's phenotype from one another. Identify the pair of master genes and the three pairs of regulatory genes from the diagram that have opposing effects from each other.
4. Dom has a long and hairy nose with wide nostrils. Which master genes do you think would be most active during the embryonic development of Dom?
5. Bridie has a very wide and short nose with small nostrils. Which master genes do you think would be most active during the embryonic development of Bridie?
6. Imagine that there is a 5th master gene that promotes nose length, nostril width, and nose hair growth. State which regulatory and structural genes would need to be switched ON and OFF by this master gene to produce this phenotype.
7. Julia has a mutation that causes a complete loss of function of *Reg Gene 2*.
   - **a** Which structural genes would be expressed in Julia if master genes 1, 2, and 4 were all active during embryonic development?
   - **b** What nose shape would you expect Julia to have?
8. Explain why a mutation in a master gene would have a larger effect on phenotype than a mutation in a structural gene.

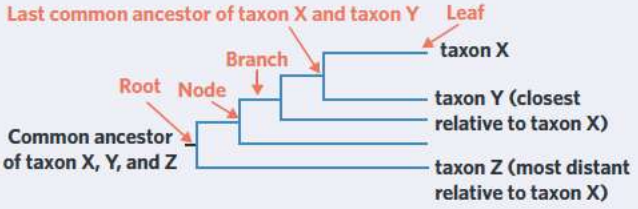
CHAPTER SUMMARY

This chapter is about how we determine relatedness between species.

13A

How do we show relatedness?

Phylogenetic trees show the **evolutionary relationships** between taxa. They are constructed using morphological and/or molecular data



13B

How do we determine relatedness?

1. Morphological structure - homologous structures show relatedness

2. Amino acid sequences

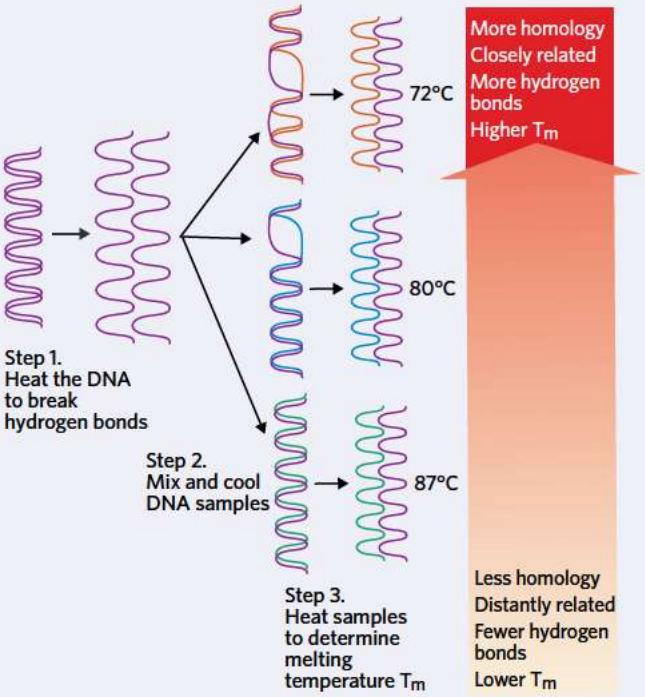
Human	*Ser*	*Tyr*	*Thr*	*Ala*	*Ala*	*Asn*	*Lys*	*Asn*
Rat	*Ser*	*Tyr*	*Thr*	*Asp*	*Ala*	*Asn*	*Lys*	*Asn*
Yeast	*Ser*	*Tyr*	*Thr*	*Asp*	*Ala*	*Asn*	*Lle*	*Lys*

3. DNA sequences

Human	5′ – AGA ATA TGA CGG CGA TTG TTC TTA – 3′
Rat	5′ – AGA ATA TGA CTG CGT TTG TTT TTA – 3′
Yeast	5′ – AGA ATG TGG CTG CGT TTG TAT TTC – 3′

nuclear DNA	**mtDNA**
• inherited from both parents	• maternally inherited
• lower mutation rate	• higher mutation rate
• recombination	• no recombination
• better molecular clock for larger timespans	• better molecular clock for shorter timespans (e.g. human evolution)

4. DNA hybridisation

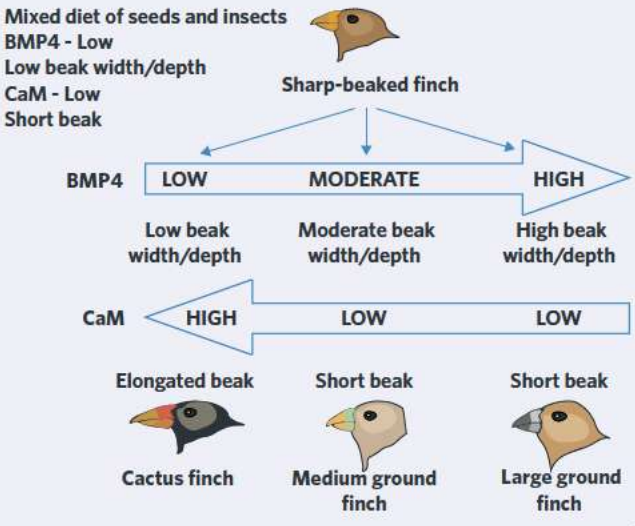


13C

Master genes - an exception to the rule

Mutations in **master genes** create novel phenotypes in a short period of time, making it difficult to use morphological or molecular data to determine relatedness.

Master genes control the expression of other genes during embryonic development and have massive impacts on the phenotype of an organism. ***BMP4*** is an example of a master gene that controls jaw formation in cichlid fish and beak formation in Galápagos finches. Mutations in master genes can lead to **adaptive radiation**.

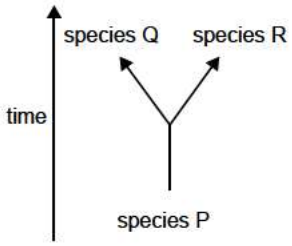


CHAPTER REVIEW QUESTIONS

SECTION A (13 MARKS)

Question 1 (1 MARK)

Consider the following diagram that represents one type of evolution.



It could be concluded that

A species Q and R could have arisen through a process of convergent evolution.
B species Q and R evolved as the result of a mass extinction event.
C species Q and R could be the result of adaptive radiation.
D species Q would appear in the fossil record before species P.

Adapted from VCAA 2008 Exam 2 Section A Q24

Question 2 (1 MARK)

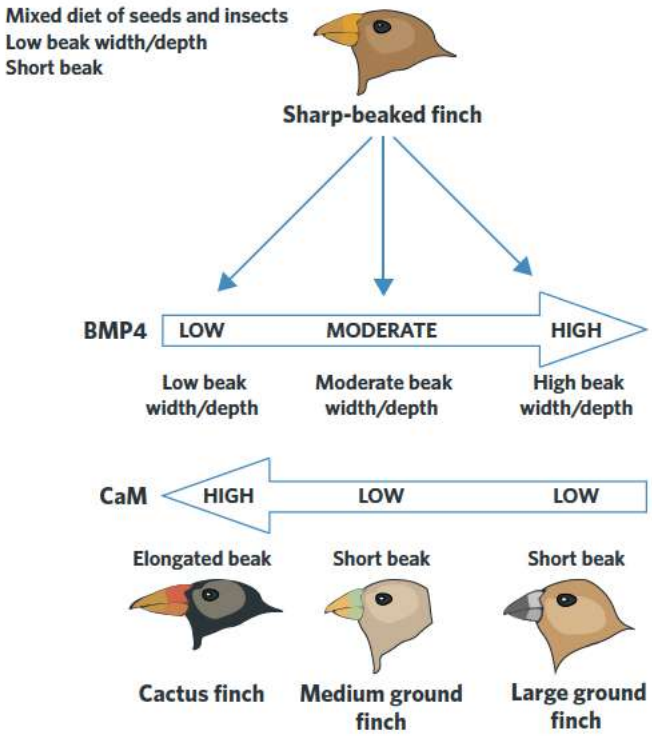
Mitochondrial DNA may be used to determine relatedness between species by

A comparing mtDNA sequences and looking for similarities and differences.
B comparing the structure of mitochondria.
C comparing the rate of cellular respiration.
D comparing the melting temperature between mtDNA strands.

Use the following information to answer Questions 3–5.

The sharp-beaked finch is a common ancestor of the cactus finch, medium ground finch, and the large ground finch.

Two proteins, BMP4 and CaM, act in the developing embryos of finches and are responsible for the variations in beak size and shape among the Galápagos finches. Variations in beak size and shape, and the levels of the proteins in different types of Galápagos finches are shown in the diagram.



Question 3 (1 MARK)

Consider the sharp-beaked finch digram. Which of the following would be the most likely levels of proteins to produce the beak shape of this finch?

	BMP4	CaM
A	high	low
B	low	high
C	low	low
D	high	high

Adapted from VCAA 2017 Sample Exam Section A Q27

Question 4 (1 MARK)

What process of evolution would have led to the evolution of the four finch species from the sharp-beaked finch ancestor?

A divergent evolution
B convergent evolution
C artificial selection
D gene flow

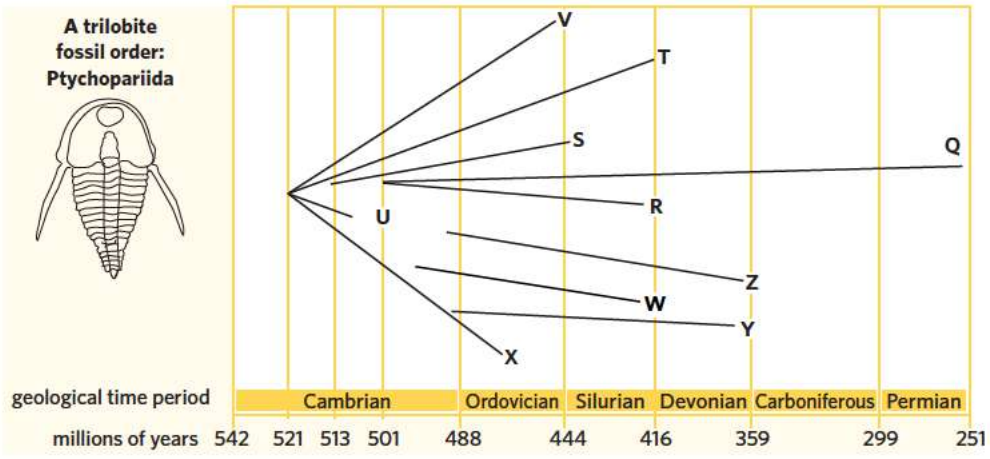
Question 5 (1 MARK)

Which of the following statements correctly describes the mechanism of action of *BMP4* in Galápagos finches?

A *BMP4* is not expressed in the beaks of finch species with smaller beaks, resulting in a beak with low depth/width.
B *BMP4* silences expression of *CaM*, resulting in a deep/wide beak.
C The longer the duration of *BMP4* expression during embryonic development, the higher the beak depth/width.
D *BMP4* is expressed for a brief window during early development, triggering a pathway that causes the development of a deep/wide beak.

Use the following information to answer Questions 6 and 7.

Trilobites existed from the Early Cambrian period (521 million years ago) until the end of the Permian period (250 million years ago). The chart, based on fossil evidence, shows the phylogeny of some trilobite orders (Q – Z) present in Earth's oceans over this time.



Question 6 (1 MARK)

Trilobite fossils in a particular layer of rock were used to date a fossil shell in the same layer. A palaeontologist dated the fossil shell to 432 – 444 million years old. Which order is the trilobite fossil likely not to come from?

A R
B V

C Y

D Z

Adapted from VCAA 2014 Section A Q34

Question 7 (1 MARK)

Scientists discovered another trilobite fossil that they placed in the order T based on molecular and morphological data.

Which geological time period is the trilobite fossil likely to come from?

A Permian

B Carboniferous

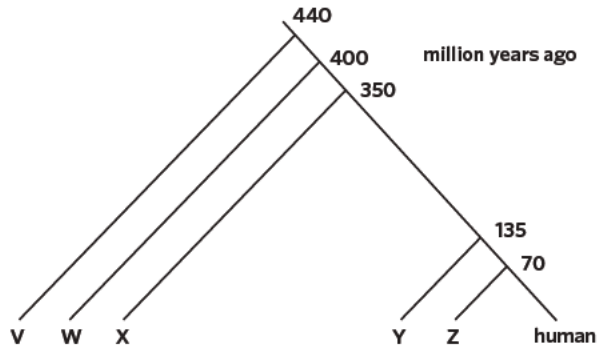
C Devonian

D Silurian

Question 8 (1 MARK)

Comparisons of the amino acid sequences of the α-globin polypeptide have been made between humans and a number of other vertebrates. The number of differences is shown in the table.

Organism	Stingray	Rabbit	Wombat	Frog	Clownfish
Amino acid differences in α-globin compared to humans	78	14	26	66	71



Based on the information provided, the correct placement of each animal on the phylogenetic tree to show the evolutionary relationship is

A V = rabbit, W = wombat, X = frog, Y = clownfish, Z = stingray

B V = stingray, W = clownfish, X = frog, Y = wombat, Z = rabbit

C V = clownfish, W = stingray, X = frog, Y = rabbit, Z = wombat

D V = wombat, W = rabbit, X = frog, Y = stingray, Z = clownfish

Adapted from VCAA 2006 Exam 2 Section A Q25

Question 9 (1 MARK)

Comparison of sequences in mitochondrial DNA is often used to establish the degree of relatedness between organisms and thus to suggest evolutionary relationships, particularly in complex, higher-level organisms. Mitochondrial DNA is used because it

A is only inherited in males.

B is a longer DNA sequence than nuclear DNA.

C mutates more rapidly than nuclear DNA.

D has the exact same sequence in distantly related individuals.

Adapted from VCAA 2007 Exam 2 Section A Q7

Using the following information to answer Questions 10 – 12.

Eucalypts, commonly known as gum trees, are found throughout Australia and other countries in Southeast Asia. They have been recently classified into seven different genera. A proposed phylogeny for the seven genera is shown in the diagram, along with the countries in which they are found.

Key Numbers in brackets ( ) refer to the numbers of species in the genus.

Adapted from VCAA 2012 Exam 2 Section A Q19

Question 10 (1 MARK)

It would be reasonable to conclude that

A DNA sequences in *Corymbia* would be more similar to those in *Arillastrum* than to those in *Angophora*.

B the fewer the number of species in a genus, the older the genus.

C speciation within the genus *Corymbia* was assisted by different selection pressures.

D the genus that evolved most recently was *Allosyncarpia*.

Question 11 (1 MARK)

The table displays DNA hybridisation results between five species of the genus *Eucalyptus*.

	Species 1	Species 2	Species 3	Species 4	Species 5
Species 1	95°C	86°C	92°C	86°C	84°C
Species 2		95°C	86°C	89°C	84°C
Species 3			95°C	86°C	84°C
Species 4				95°C	84°C
Species 5					95°C

Based on this data, which species is most closely related to species 3?

A Species 1

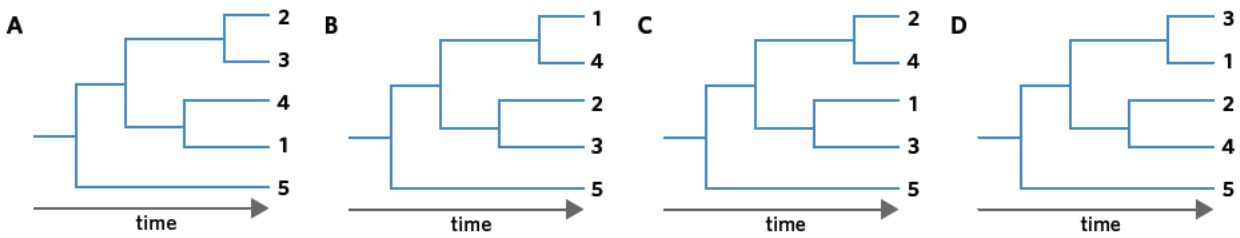
B Species 2

C Species 4

D Species 5

Question 12 (1 MARK)

Which of the following phylogenetic trees is most likely to represent the evolutionary relationships among these five *Eucalyptus* species?



Question 13 (1 MARK)

A comparison was made between the following human, rabbit, mouse, and chimpanzee sequences:

- DNA coding sequence of the β-*globin* gene
- DNA sequence in the introns of the β-*globin* gene
- amino acid sequence of the β-globin polypeptide.

The data is shown in the table.

	Sequence similarity (%)		
Organisms being compared	**Coding DNA**	**Intron**	**Amino acid sequence**
human β-globin/chimpanzee β-globin	100	98.4	100
human β-globin/rabbit β-globin	89.3	67	90.4
human β-globin/mouse β-globin	82.1	61	80.1

It is possible to conclude from this data that

A the divergence between humans and rabbits is greater than the divergence between humans and mice.

B the variation between chimpanzees and humans occurs in a region of the β-*globin* gene which would code for amino acids.

C differences in DNA sequences always have an effect on the amino acid sequence.

D mutations accumulate more readily in non-coding regions of the genome than in coding regions.

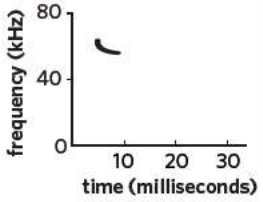
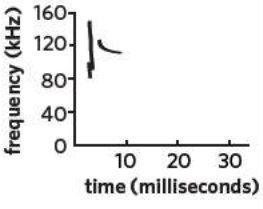
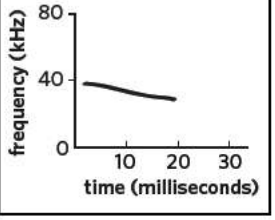
Adapted from VCAA 2002 Exam 2 Section A Q18

SECTION B (27 MARKS)

Question 14 (8 MARKS)

Barro Colorado Island is a small island covered by tropical forest in Central America. Seventy-four different species of bats live in this forest.

Bats are nocturnal, flying mammals. To find their way around in the darkness, many bat species emit high-frequency sound pulses that bounce off obstacles and prey. These pulses enable them to judge the distance to an object. A longer pulse allows bats to detect insects that are further away, whereas a shorter pulse is good for shorter distances. This behaviour is called echolocation. Three of the Barro Colorado Island species are described in the table.

Species name	Facial appearance of bat	Diet	Feeding location	Echolocation signal
Black myotis bat (*Myotis nigricans*)		Insects	Around trees at forest's edge and in clearings	
Mexican long-tongued bat (*Choeronycteris mexicana*)		Nectar and pollen flowers that open at night, for example cactus, agave	Narrow gaps and small spaces	
Velvety free-tailed bat (*Molossus molossus*)		Insects	Above trees, in open spaces	

a Referring to the information, explain how selection pressures may lead to changes in allele frequencies in bat populations. (3 MARKS)

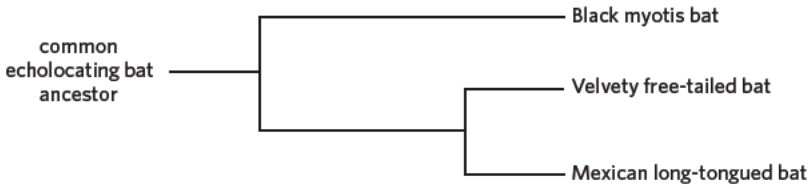
b Analyse the data in the table.

i In terms of time, which of the three species emits the shortest echolocation signal? (1 MARK)

ii Explain how a short echolocation signal could be a selective advantage for this bat species. (1 MARK)

c A world-renowned biologist found that the three bat species share a recent common ancestor.

To establish the order in which each species had evolved from this common ancestor, the biologist compared amino acid differences for several proteins between the various species. After analysing the results, the scientist drew the following phylogenetic tree.



Based on the diagram, which species would have the fewest amino acid differences when compared with the Mexican long-tongued bat? (1 MARK)

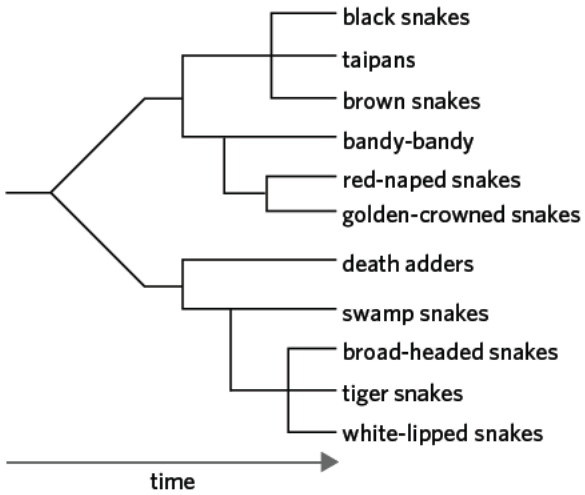
d A long-time fan of the biologist donated a DNA sample taken from an unknown species of bat she accidentally hit with her car. This bat is found in the forests of southern Mexico and feeds on insects at night. The fan asked the biologist to determine if it was a different species from the other bats.

Describe two methods the biologist could use to determine if the DNA sample from the unknown bat species is from a different species to the other bats. (2 MARKS)

Adapted from VCAA 2012 Exam 2 Section B Q5

Question 15 (4 MARKS)

DNA hybridisation was used to determine the evolutionary relationships between some Australian elapid snakes. This data was used to construct a phylogenetic tree.



a Which species are most closely related to bandy-bandy snakes? (1 MARK)

Adapted from VCAA 2002 Exam 2 Section A Q15

b Between which species did the most recent divergence occur? (1 MARK)

c Explain how the melting temperature given by DNA hybridisation enables scientists to determine evolutionary relationships between species. (2 MARKS)

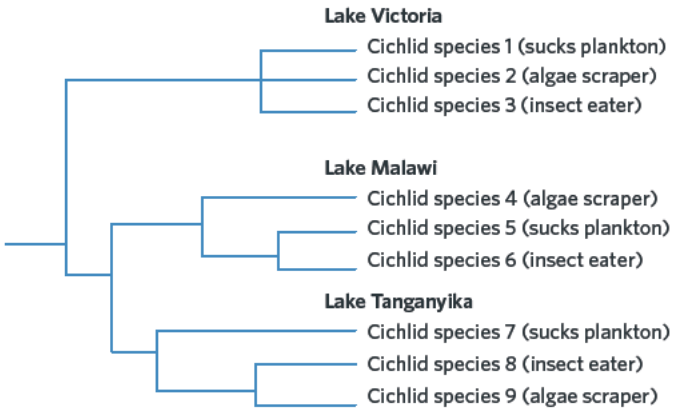
Adapted from VCAA 2017 Section B Q6b

Question 16 (8 MARKS)

In African cichlid fish, mutations in the *BMP4* master gene are responsible for rapid adaptive radiation, creating over 500 species in less than 15 000 years.

a Describe one type of evidence that biologists could use to estimate an approximate time of divergence between these species. (2 MARKS)

b Nine of these African cichlid species are shown in the phylogenetic tree. The three lakes (Victoria, Malawi, Tanganyika) are isolated populations and show evidence of convergent evolution in similar dietary niches.



i What is adaptive radiation? (1 MARK)

ii Explain what effect rapid divergence would have on the use of molecular homology techniques in determining evolutionary relationships among African cichlid fish. (2 MARKS)

iii Outline the molecular mechanisms by which *BMP4* affects African cichlid fish development and explain how this is an example of adaptive radiation. (3 MARKS)

Question 17 (7 MARKS)

The table shows the number of nucleotide differences between humans and six vertebrate species for a single gene found in the nucleus.

Species	DNA differences from humans
Pan troglodytes	4
Ceratotherium simum	7
Perca fluviatilis	14
Ichthyosaura alpestris	14
Homo rudolfensis	2
Isurus paucus	17

a Based on this data, which species is most distantly related to humans? (1 MARK)

b Scientists often use mitochondrial DNA for determining relatedness between closely related species, such as the hominin relatives of humans.

i What is the molecular clock? (1 MARK)

ii Describe two advantages of using mitochondrial DNA over nuclear DNA for determining relatedness between closely related species. (2 MARKS)

c Humans are actually more closely related to *Ichthyosaura alpestris* than to *Perca fluviatilis,* despite both species having 14 nucleotide differences from humans.

Explain these unexpected results by referring to the molecular clock model and the limitations of using nuclear DNA differences alone to determine relatedness between species. (2 MARKS)

d One way to improve the reliability of this experiment would be to calculate the nucleotide differences of multiple genes across the genome between each species.

Explain why this is a good suggestion. (1 MARK)

Adapted from VCAA 2018 Section B Q11e

UNIT 4 AOS 1, CHAPTER 14

Becoming human

14

14A Defining 'human'

14B The last 3.6 million years of human ancestors

14C Interpreting the human fossil record

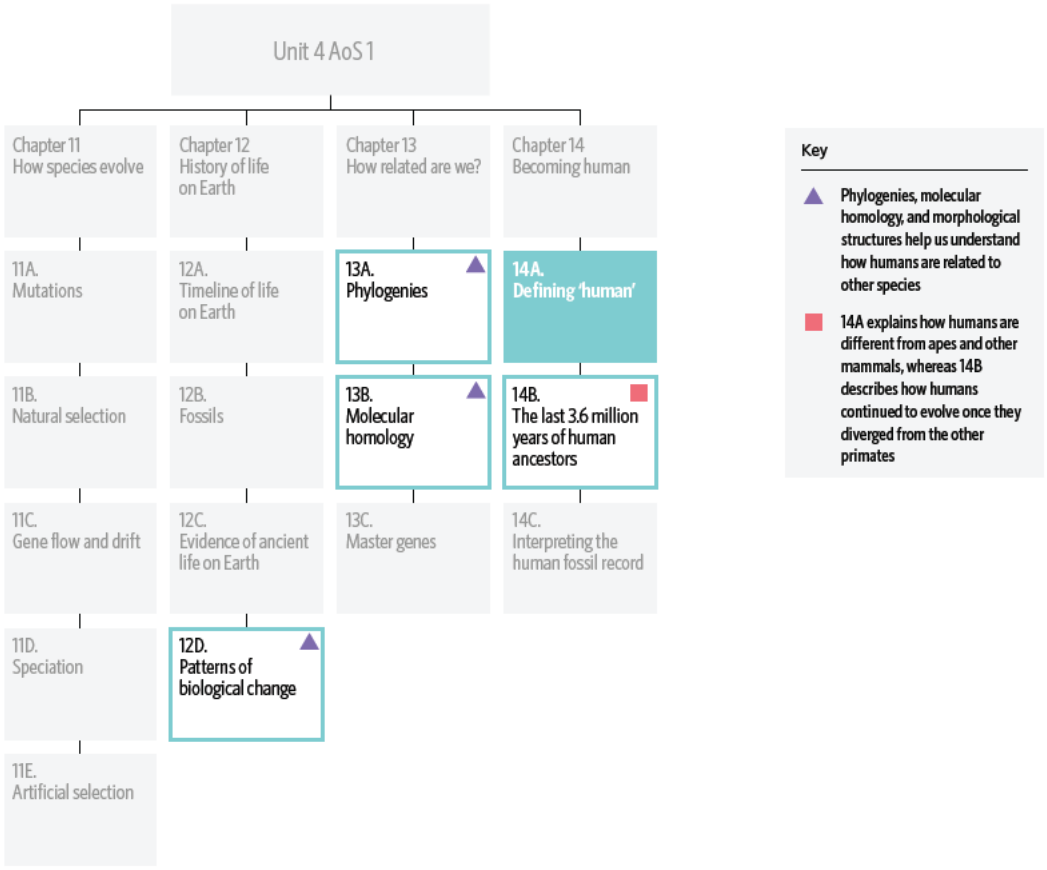
Key knowledge

- shared characteristics that define primates, hominoids, and hominins
- major trends in hominin evolution from the genus *Australopithecus* to the genus *Homo* including structural, functional, and cognitive changes and the consequences for cultural evolution
- the human fossil record as an example of a classification scheme that is open to interpretations that are contested, refined or replaced when new evidence challenges them or when a new model has greater explanatory power, including whether *Homo sapiens* and *Homo neanderthalensis* interbred and the placement of the Denisovans into the *Homo* evolutionary tree

Image: Ari Wid/Shutterstock.com

14A DEFINING 'HUMAN'

Have you ever looked at your family and thought, 'How are we related?' Next time you're at the primate exhibit at the zoo you should be thinking the exact same thing!



In this lesson you will be learning about how humans are related to other species. More specifically, you will learn about primates, hominoids, and hominins and how humans fit into the classification of species.

Study design dot point

- shared characteristics that define primates, hominoids, and hominins

Key knowledge unit

Comparing primates, hominoids, and hominins	4.1.10.1

Comparing primates, hominoids, and hominins 4.1.10.1

OVERVIEW

Using the biological taxonomy we can define humans in relation to other species.

THEORY DETAILS

If you were to ask a philosopher 'what is a human being?' you might get a long-winded answer that leaves you more confused than you were to begin with. Asking a biologist 'what is a human being?', however, will probably get you a more straightforward answer – modern humans, ***Homo sapiens***, are the last remaining member of the tribe Hominini.

One way to determine what makes us human is to look at how we fit in with all other species and how we relate to and differ from them. The easiest way to do this is by looking at the features we do and don't share with other species (Figure 2).

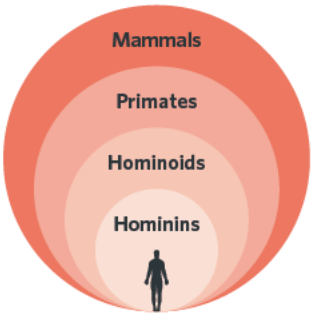
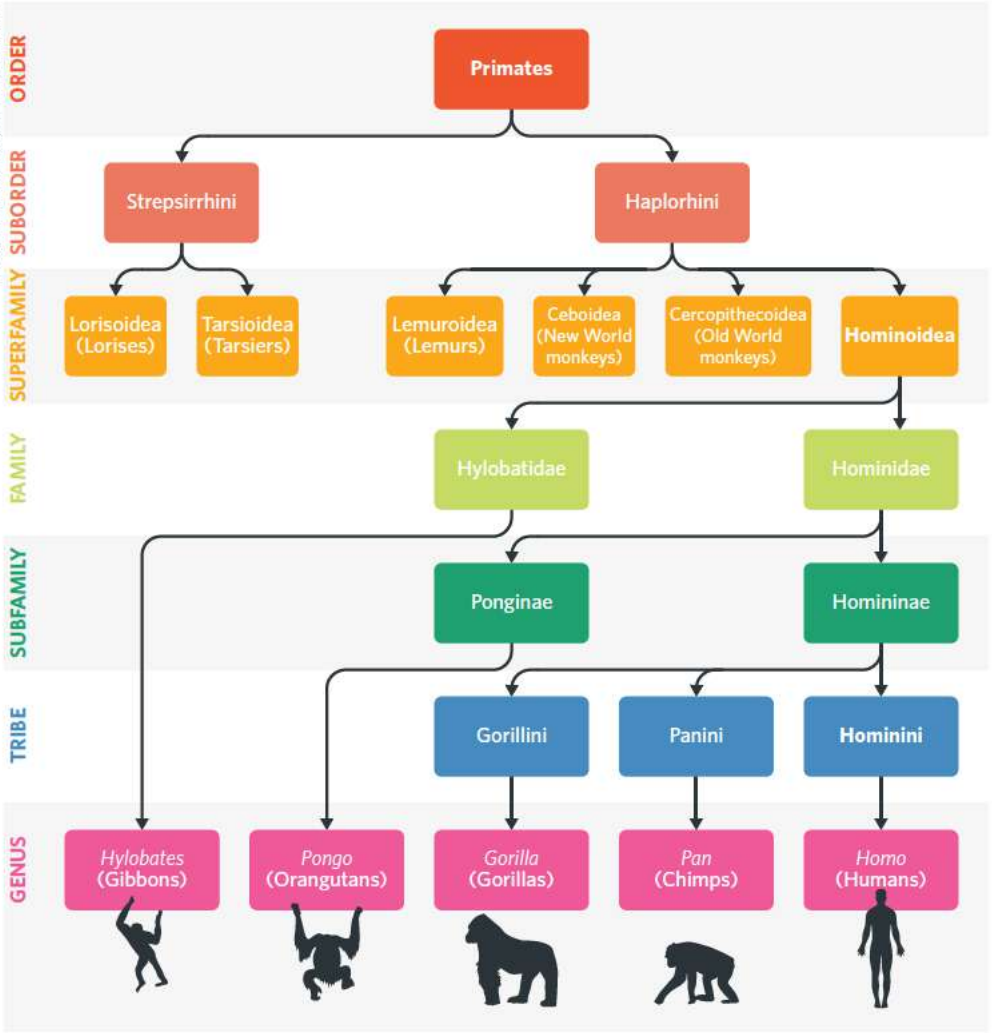


Figure 1 Overview of where humans fit in the taxonomy of life



Images: Hein Nouwens/Shutterstock.com

Figure 2 Classification of primates

To get an understanding of what makes us unique within the animal kingdom we can look at the defining characteristics of the bolded groupings in the taxonomy shown in Figure 2. By starting further up the taxonomy with more general classifications and gradually making our way down we'll hone in on the precise features that make us 'human'. We'll do this now, starting off with traits that define **mammals**.

Characteristics of mammals

'Mammals' refers to animals that belong to the taxonomic class Mammalia, within which lies the order **Primates**. There are over 5,000 species in the class Mammalia, however there are some key characteristics they all share. These are:

- Milk–producing mammary glands – mammals use the milk produced by these glands to feed their offspring (Figure 3a).
- Hair/fur – whilst some adult mammals have lost their hair/fur, all mammals at some stage of their life have various amounts of hair/fur on their bodies (Figure 3b).
- Three bones in the middle ear – all mammals have three bones in their middle ear to help with hearing (Figure 3c).
- One lower jawbone – in mammals the lower jawbone is one single bone that attaches directly to the skull, giving them an extremely powerful bite (Figure 3d).

Tip VCAA won't assess your knowledge of mammals, but it's good to know the features they have in common with the subsequent groups we'll look at in this lesson.

Characteristics of primates

Like mammals, there are a number of traits that **Primates** share. In order to be classified as a primate, a species must exhibit a number of these features in combination.

Homo sapiens the species name for modern humans

mammal warm–blooded vertebrates belonging to the taxonomic class Mammalia that have mammary glands, hair/fur, three middle ear bones, and one lower jawbone

primate a member of the order Primates that's comprised of about 400 different living species and that share a number of features including opposable digits and binocular vision

Image: JNix/Shutterstock.com

Image: maxcreatnz/Shutterstock.com

Figure 3 Defining characteristics of mammals: **(a)** milk–producing mammary glands, **(b)** hair/fur, **(c)** three middle ear bones, and **(d)** one lower jaw bone.

These features can be grouped into body features, skull features, and functional features as below:

- Body features:
  - **Prehensile** hands and feet with five digits, with one **opposable digit** (either the thumb in the hand or the hallux in the foot) and flat fingernails – these help primates grasp objects with power ('power grip') and precision ('precision grip') (Figure 4a).
  - Large number of sensitive touch receptors in fingertips – primates are able to use their hands to gather information.
  - Flexible spines and a large degree of rotation around the hips and shoulders – this increased flexibility has allowed primates to adapt to living in trees.
- Skull features:
  - Relatively large **cranium** for their body weight – this is due to an increased brain size.
  - 3D colour vision and forward facing eyes – these allow primates to see things in three dimensions, which makes life much easier when jumping from tree to tree! (Figure 4b)
- Functional features:
  - Social animals – primates typically live in groups (Figure 4c).

prehensile the ability to grasp objects

opposable digit a digit (either the thumb or the big toe) that is able to touch all the other digits on the same appendage

cranium the part of the skull that covers the brain

hominoid a member of the superfamily Hominoidea that includes apes and humans

hominin a member of the taxonomic tribe Hominini that includes modern humans and our direct ancestors

bipedal using two legs for walking upright

Figure 4 Some of the defining characteristics of primates: **(a)** prehensile hands and feet with opposable digits, **(b)** 3D colour vision and forward facing eyes, and **(c)** social lifestyles.

Characteristics of hominoids

The next highlighted step down the taxonomy in Figure 2 is the superfamily Hominoidea. Species belonging to this superfamily are called **hominoids** (or apes) and includes modern humans. All other primate species, such as lemurs and Old World monkeys, belong to different superfamilies.

Hominoids tend to have the following features:

- Body features:
  - Shorter spine between the rib cage and pelvis – this helps hominoids sit upright (Figure 5a and 5b).
  - Lack of tail – further contributes to hominoids ability to sit upright (Figure 5a and 5b).
  - Broader rib cage and pelvis – these also help hominoids sit upright (Figure 5a and 5b).
  - Typically longer arms than legs and shoulder blades that sit further back – gives hominoids the ability to use their arms in a number of ways (Figure 5a and 5b). *Homo sapiens*, however, are an exception to this and don't have longer arms than legs.
- Skull features:
  - Distinctive molar teeth in lower jaw – teeth that have five cusps arranged in a 'Y5' pattern (Figure 5c).
  - Increased cranium size – hominoid brains tend to be larger than other primates.

Characteristics of hominins

We've finally arrived at the point on the taxonomy in Figure 2 where humans are separated from the rest of the animal kingdom! Current taxonomic classification defines human as any member of the genus *Homo*, within the tribe Hominini – this includes modern humans (*Homo sapiens*) as well as many of our evolutionary ancestors.

The definitive feature of **hominins** amongst primates is our ability to walk upright on our hind legs. This ability, termed '**bipedalism**', is unique to hominins (Figure 6a).

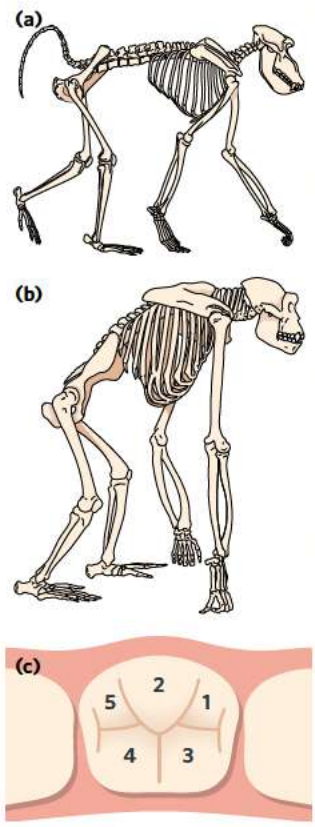


Figure 5 Defining characteristics of hominoids: comparing the skeleton of a **(a)** baboon with a **(b)** gorilla highlights the absence of a tail, shorter spine, broader rib cage, and longer arms than legs typical of hominoids, whilst **(c)** shows the distinctive Y5 molar teeth pattern of hominoids.

While some other primates are able to briefly walk on two legs (Figure 6b), hominins are able to move in this position for an extended period of time. Other primates tend to walk on all four limbs – gorillas, for example, usually walk with their knuckles on the ground (Figure 6c).

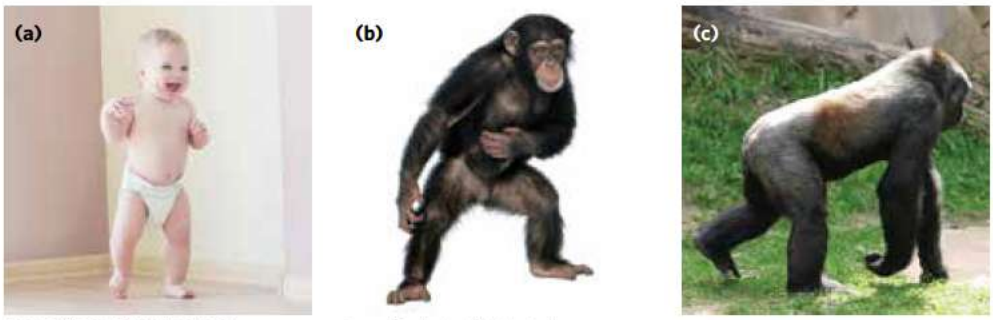


Image: UvGroup/Shutterstock.com

Image: Eric Isselee/Shutterstock.com

Figure 6 Hominins are bipedal: **(a)** hominins walk upright, whereas **(b)** other primates can only stay upright for short periods of time and **(c)** a gorilla displaying knuckle-walking.

canine teeth a type of tooth in mammals that is relatively long and pointed

foramen magnum the hole in the base of the skull through which the spinal cord passes

brow ridge a bony ridge above the eye sockets. It is found in all primates, but is greatly reduced in Homo sapiens

sagittal crest a ridge of bone running from front-to-back along the top of the skull

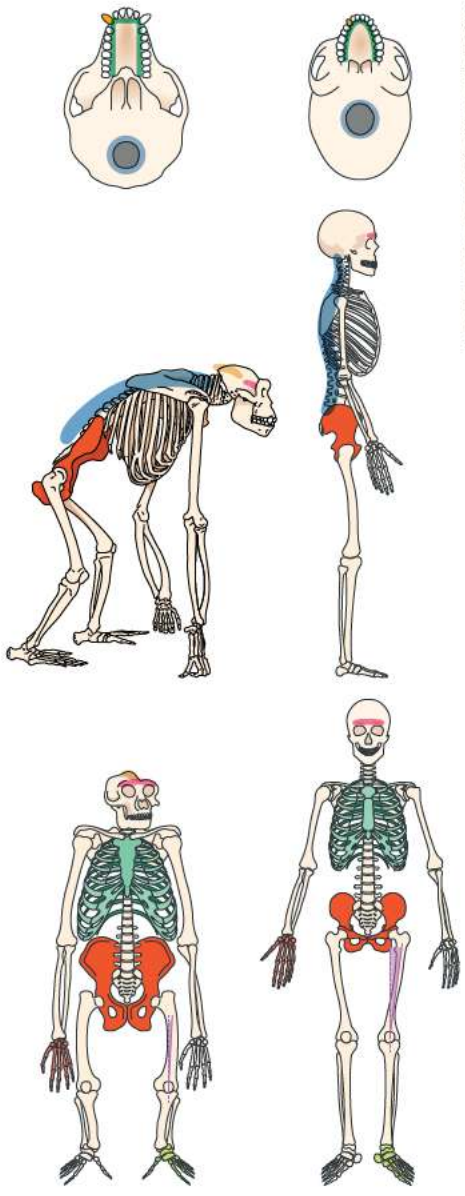
femur angle the angle between the top and bottom of the femur when standing. It is greater in hominins when compared to other primates

Becoming bipedal has resulted in a number of structural changes that have come to distinguish hominins from other primates. To illustrate these clearly we'll compare a gorilla skeleton and a *Homo sapiens* skeleton. These are shown in Figure 7 and the key differences are summarised in Table 1.

Table 1 Structural differences between modern hominins and gorillas

Canine teeth	Humans have much smaller **canine teeth** than gorillas.
Dental arch	The dental arch of humans is more parabolic than gorillas who have a U-shaped/rectangular jaw.
Foramen magnum*	The **foramen magnum** is more central in human skulls, allowing the head to sit forwards while resting on top of the spinal column. In gorillas, however, the foramen magnum is closer to the back of the skull.
Brow ridge	Humans tend to have a much smaller **brow ridge** than gorillas.
Sagittal crest	The **sagittal crest** that is present on the top of the skull in gorillas is absent in humans. This crest is where jaw muscles attach. Having a big sagittal crest means large muscles can attach to it, increasing jaw strength.
Spine curve*	Gorillas have a 'C-shaped' spine that curves forwards. Human spines, however, are 'S-shaped' with a curve in the lower spine and another in the upper spine. These curves help support weight vertically and aid with upright mobility.
Rib cage*	The rib cage in humans is more barrel-shaped than gorillas who have funnel-shaped rib cages instead. This helps humans to maintain an upright posture for a lengthy period of time.
Hand	Human hands have shorter, straighter fingers and longer thumbs compared to gorillas, making it possible for humans to have a further refined precision grip.
Pelvis*	Human pelvises are more shallow and bowl-shaped than other primates, whose pelvises tend to be vertically long and narrow. The bowl-shaped pelvis helps provide support for the upper body whilst standing and walking upright.
Femur angle*	Humans have a relatively large **femur angle** compared to gorillas. This helps to increase stability in humans while walking upright by ensuring the knee and foot are more centrally placed below the body.
Foot*	The human foot no longer has prehensile capabilities, and the big toe is in line with the other toes. Human feet also have two arches and a wide heel, making bipedalism more energy efficient and less impactful on the foot.

*denotes a feature indicating bipedalism



Images: Emre Terim/Olga Bolbot/Shutterstock.com

Figure 7 Structural features of gorillas (left) compared to hominins (right)

As you can see, many of the key structural differences between hominins and other primates arose due to our bipedalism. Other differences, such as the reduction in canine teeth size, aren't directly related to bipedalism but are still important as evidence of other influences that drove our evolution – in this case, changes in hominin diet.

There are also many other non–structural differences between hominins and other taxa. Hominins have the ability to speak and communicate with one another, and tend to form large, complex societies. They also have increased cognitive abilities, meaning they can think about abstract concepts and create language as well as create tools and pass knowledge on from generation to generation. Many of these traits will be looked at in more detail in the next lesson as we trace the evolution of hominins more closely.

Theory summary

By understanding the characteristics of primates, hominoids, and hominins we can see exactly what it is that defines us as 'human'.

Table 2 Summary of the defining characteristics of the taxonomic groups covered in this lesson

Classification	Defining characteristics
Mammals	• Mammary glands • Hair/fur • Three middle ear bones • One jawbone
Primates	• Prehensile hands and/or feet with five digits • Opposable thumb/big toe • Binocular colour 3D vision • Social animals
Hominoids	• Broad rib cage • No tail • Long arms • Y5–shaped molar teeth • Large cranium
Hominins	• Bipedalism • Communication and formation of complex social groups • Structural consequences of bipedalism – centralised foramen magnum, S–shaped spine, broader rib cage, bowl–shaped pelvis, increased carrying angle of femur

14A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the term used to describe individuals that walk upright

b _____ animals that have mammary glands and fur

c _____ the order of mammals to which humans belong

d _____ capable of grabbing an object

e _____ members of the taxonomic tribe to which humans belong

Question 2

Which of the following statements is false?

A A distinctive feature of primates is an opposable digit.

B A distinctive feature of hominoids is a broad rib cage.

C A distinctive feature of hominins is prehensile hands.

D A distinctive feature of primates is colour vision.

Question 3

Which of the following options correctly shows the unique defining characteristics of the taxonomic categories shown in the table?

	Mammals	Primates	Hominoids	Hominins
A	Y5-shaped molar teeth	Prehensile hands	One jaw bone	Bipedalism
B	One jaw bone	Prehensile hands	Y5-shaped molar teeth	Bipedalism
C	Prehensile hands	One jaw bone	Y5-shaped molar teeth	Bipedalism
D	Fur	Y5-shaped molar teeth	Prehensile hands	Bipedalism

Question 4

Classify each of the following features as being characteristics of primates, hominoids, and/or hominins.

I Large cranium

II Bipedalism

III Broad rib cage

IV 3D colour vision

V Mammary glands

VI Opposable thumb

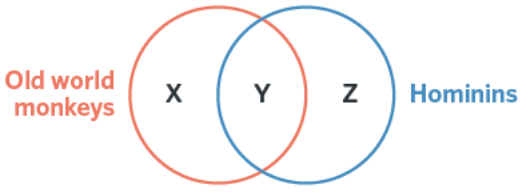
	Hominins	Hominoids	Primates
A	I, II, III, IV, V, VI	I, III, IV, V, VI	I, IV, V, VI
B	I, II, III, IV, V, VI	III, IV, VI	I, IV
C	II	III	IV, VI
D	II	I, II,III	IV, V, VI

Question 5

Examine the Venn diagram.

Which of the following is correct?

	X	Y	Z
A	Fur	Tail	Broad rib cage
B	No tail	Mammary glands	Bipedalism
C	Tail	Broad rib cage	Bipedalism
D	Tail	Binocular vision	Broad rib cage



Exam-style questions

Within lesson

Question 6 (1 MARK)

What is a defining trait of hominins?

A Colour vision

B An opposable thumb

C Bipedalism

D Sensitive fingertips

Question 7 (1 MARK)

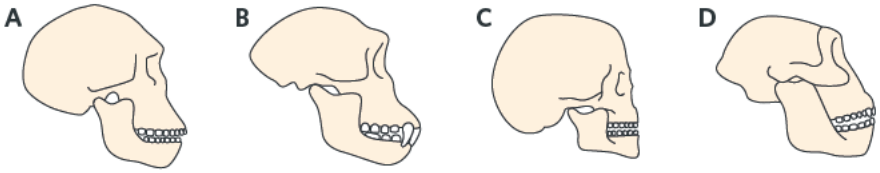
Consider the evolution of hominins. Which one of the following statements about hominin classification is true?

A All hominoids are also hominins
B No primates have a tail
C All hominins are also primates
D *Homo sapiens* are the only present-day hominoid species

Adapted from VCAA 2018 Section A Q38

Question 8 (1 MARK)

Consider the following skulls. Which is likely the most distantly related to *Homo sapiens*?



Adapted from VCAA 2006 Exam 2 Section A Q22

Question 9 (1 MARK)

A key characteristic of primates is the presence of an opposable thumb.

The development of an opposable thumb in primate evolution

A distinguished hominins from all other primates.
B was a necessary step in the development of bipedalism in hominins.
C influenced the arm-to-leg ratio of hominoids.
D was an important anatomical development that allowed for a precision grip.

Adapted from VCAA 2014 Section A Q40

Question 10 (1 MARK)

While transporting artifacts between museums, a young conservator mixes up the skulls and labels from a primate exhibit with those from an Old World monkey exhibit.

Which of the following would distinguish the chimpanzee skull from the skulls of the Old World monkey exhibit?

A A small braincase
B Y5 molar teeth
C A flat face and small teeth
D The presence of three middle ear bones

Adapted from VCAA 2002 Exam 2 Q23

Question 11 (1 MARK)

Which of the following classifications is correct?

	Primate	Hominoid	Hominin
A	Gibbon	Chimpanzee	*Homo sapiens*
B	*Homo sapiens*	Gibbon	Chimpanzee
C	Gorilla	Tarsier	*Homo sapiens*
D	Chimpanzee	Gibbon	Gorilla

Question 12 (1 MARK)

Members of the order Primates are mammals.

Which combination of features is common to all primates and distinguishes them from other mammals?

	Feature 1	Feature 2	Feature 3
A	binocular vision	fur or hair	opposable thumbs
B	fully rotating shoulder joints	opposable thumbs	large brains relative to body size
C	milk-producing mammary glands	fully rotating shoulder joints	nails instead of claws
D	large brains relative to body size	binocular vision	milk-producing mammary glands

Adapted from VCAA 2018 Section A Q37

Question 13 (4 MARKS)

Shown here are two photographs of a hominoid skull. Scientists compared this skull to that of species belonging to a different primate superfamily.

Photo A

Photo B

Images: ivanpavlisko/Shutterstock.com

a Describe two features that could allow scientists to determine that this skull belonged to the hominoid superfamily. (2 MARKS)

b Describe two other structural features (other than skull features) of hominoids that indicate they are more closely related to *Homo sapiens* than other primates. (2 MARKS)

Adapted from VCAA 2016 Section B Q10

Question 14 (5 MARKS)

A team of scientists has been presented with a recently discovered species and are trying to classify it according to biological taxonomy.

a List three features that could be used to classify the species as a primate. (3 MARKS)

b If the species had one of these features, but no other features of primates, would it be classified as a primate? Explain your answer. (2 MARKS)

Question 15 (7 MARKS)

The skeletons of two primates are shown. One is a hominoid skeleton, the other is a hominin skeleton.

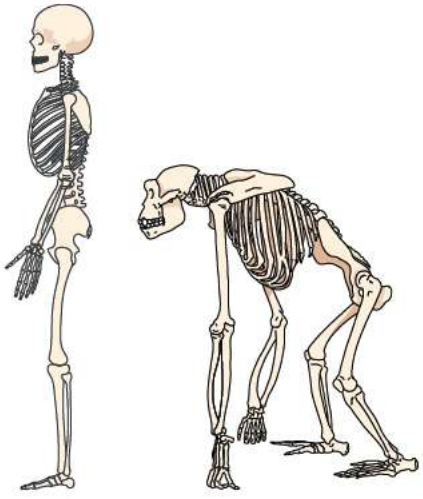
a Which is the hominin skeleton? (1 MARK)

b Redraw the table on a piece of paper.

Skeletal structure	Differences	Significance
1.		
2.		

Identify two non-skull skeletal structures in the hominin, describe how they differ from the same structure in the hominoid, and state the functional significance of these differences. (6 MARKS)

Adapted from VCAA 2013 Section B Q11



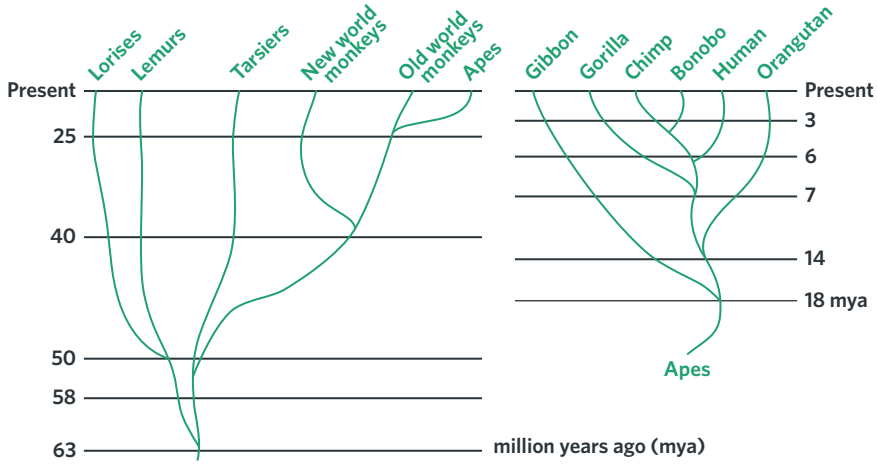
Skeleton 1 **Skeleton 2**

Images: Emre Terim/Olga Bolbot/Shutterstock.com

Multiple lessons

Question 16 (1 MARK)

Examine the following primate evolutionary tree.



Which of the following statements is false?

A Chimps and humans are more closely related than gorillas and chimps.

B Lorises and New World monkeys shared a common ancestor approximately 63 mya.

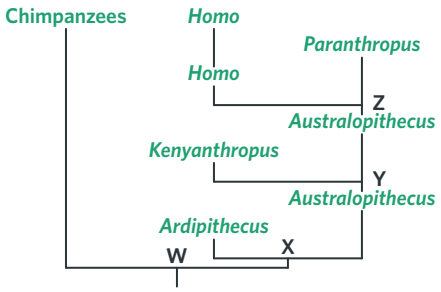
C Bonobos and chimps are more closely related than humans and chimps.

D Lemurs and apes are unrelated.

Adapted from VCAA 2009 Exam 2 Section A Q21

Question 17 (1 MARK)

The figure here shows the possible evolutionary relationships between chimpanzees and humans. The common ancestor of *Homo* and Chimpanzees is represented on the diagram at



A W.

B X.

C Y.

D Z.

Adapted from VCAA 2002 Exam 2 Q22

Key science skills

Question 18 (5 MARKS)

The table shows the number of nucleotide differences between a region of mitochondrial DNA in humans, chimpanzees, and tarsiers.

	Human	Chimpanzee	Tarsier
Human		15	30
Chimpanzee			20

a Based on the data in the table, which species is most closely related to humans? (1 MARK)

b Explain how nucleotide differences can be used to determine relatedness between primate species. (2 MARKS)

c The DNA used in the tests was extracted from skeletons of the three species in the table.

What other type of information could be obtained from the skeletons to assist in determining the relationships between the three species? (1 MARK)

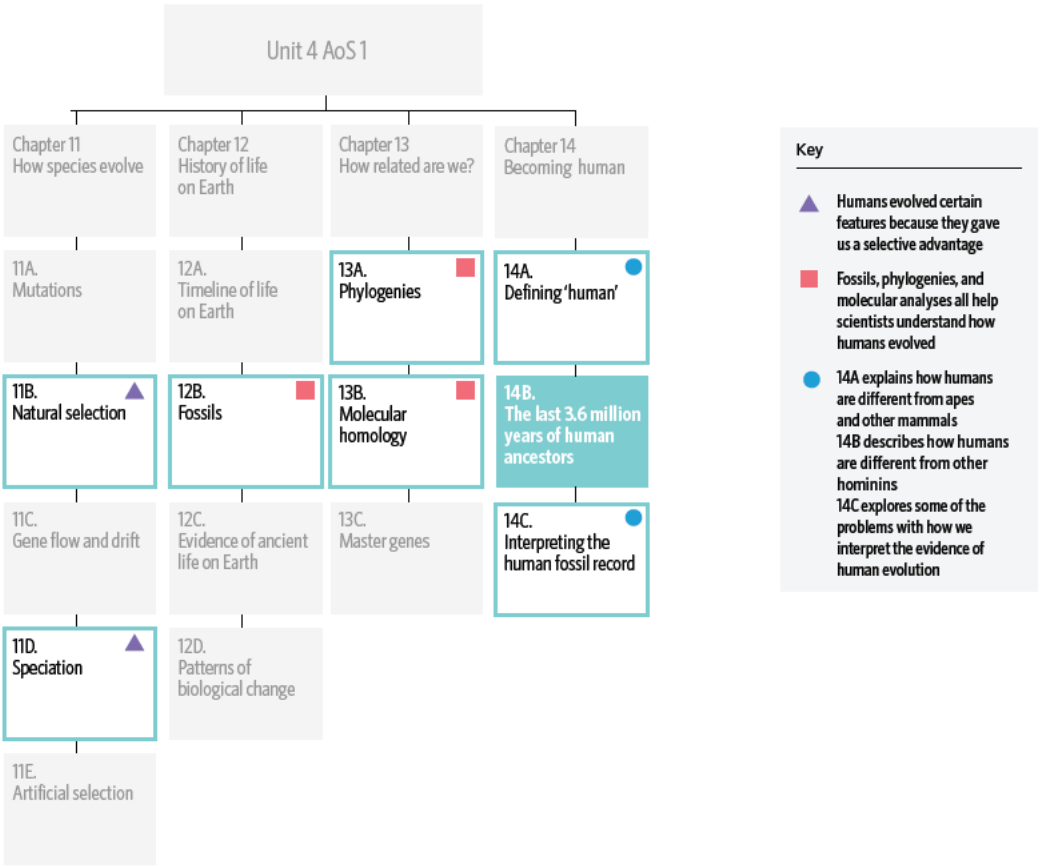
d In an effort to further explore the relatedness between the three species, scientists used the technique of DNA hybridisation. They used an uncalibrated thermometer and overheated the DNA to 105°C.

What kind of error has taken place? (1 MARK)

Adapted from VCAA 2003 Exam 2 Section B Q6

14B THE LAST 3.6 MILLION YEARS OF HUMAN ANCESTORS

The story of human evolution is just like Pokémon, with Australopithecines being the Charmander to *Homo sapiens'* Charizard.



In this lesson you will learn about the major trends in hominin evolution.

Study design dot point

- major trends in hominin evolution from the genus *Australopithecus* to the genus *Homo* including structural, functional, and cognitive changes and the consequences for cultural evolution

Key knowledge units

Meet the hominins	4.1.11.1
Structural changes	4.1.11.2
Functional changes	4.1.11.3
Cognitive changes	4.1.11.4
Consequences for cultural evolution	4.1.11.5

Meet the hominins 4.1.11.1

OVERVIEW

Hominins are species classified in the taxonomic tribe Hominini and include all the ancestors and close relatives of humans up until our last common ancestor with chimpanzees.

THEORY DETAILS

As you learnt in the last lesson, the term hominin refers to species that are more closely related to humans than to chimpanzees. Hominins are unique amongst primates in that they are primarily bipedal. It is thought that bipedalism evolved at least 4 mya with ***Australopithecus***. Prior to *Australopithecus* we aren't entirely sure how hominin species moved – most likely it was a combination of bipedalism and knuckle–walking.

A number of different hominin species have come and gone since they first separated from the chimps, however we – ***Homo sapiens*** – are the only ones left. Some hominin species such as *Australopithecus*, ***Homo habilis***, and ***Homo erectus***, are our direct ancestors; whilst species such as ***Homo neanderthalensis*** are non–ancestral and could be thought of more as our evolutionary 'cousins.'

Sahelanthropus tchadensis may have been our last common ancestor with chimps (Figure 1), however there is not enough evidence for us to be entirely certain of this.

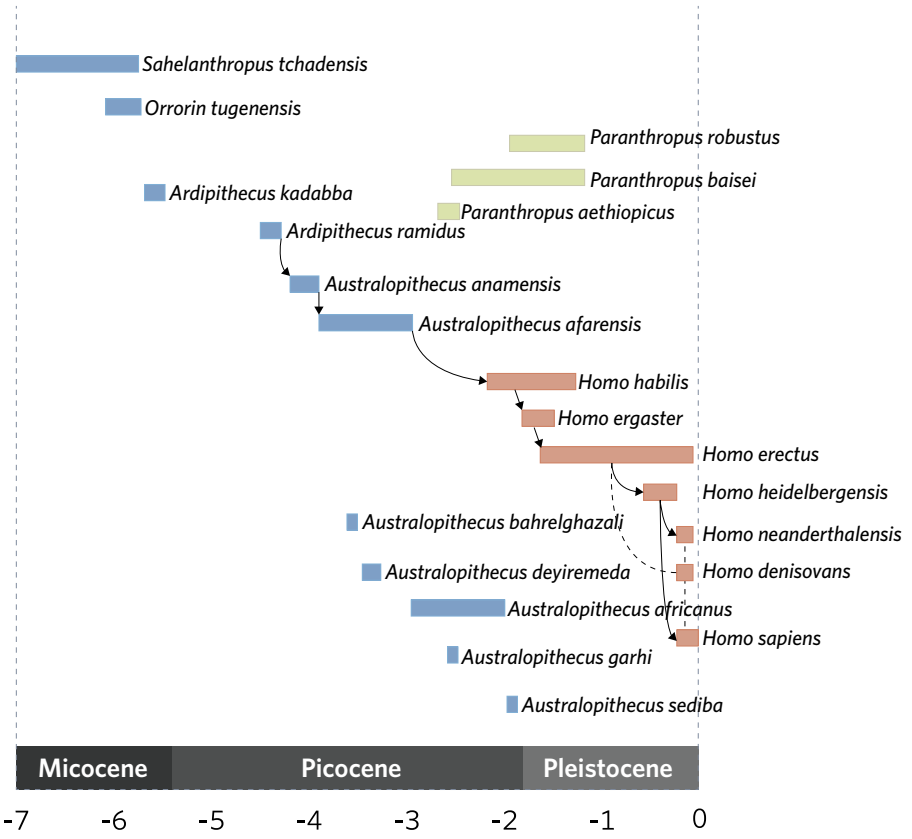


Figure 1 A family tree of hominin species showing when each species existed. VCAA tests you on patterns of hominin evolution from *Australopithecus* to *Homo sapiens*.

> ***Tip*** VCAA only tests you on general trends in hominin evolution from the genus *Australopithecus*, which existed around 3.6 mya. Note how *Homo neanderthalensis* and *Homo sapiens* share a common ancestor – ***Homo heidelbergensis*** – but aren't directly related.

Structural changes 4.1.11.2

OVERVIEW

Over time, hominins have undergone a number of structural changes, many of which are a direct consequence of their bipedal form of movement.

THEORY DETAILS

As you've already seen in lesson 14A, the defining feature of hominins that distinguishes them from other primates is their sustained bipedal form of locomotion. A number of structural changes have taken place throughout hominin evolution as a result of this.

Australopithecus the genus name for an ancient hominin ancestor from which the genus *Homo* evolved

Homo sapiens the species name for modern humans

Homo habilis an extinct hominin species that existed around 2.3 mya

Homo erectus an extinct hominin species that existed around 2 mya

Homo neanderthalensis commonly called Neanderthals, they are an extinct hominin species that lived in cold climates alongside *Homo sapiens* with whom they are believed to have interbred

Sahelanthropus tchadensis an early hominin species that is thought to be the last common ancestor of modern humans and chimpanzees

Homo heidelbergensis an extinct hominin species that existed around 500 000 years ago and was the common ancestor of Neanderthals and modern humans

robust having a larger and stronger build

gracile having a slender or fine build

sexual dimorphism a difference in appearance between sexes of the same species

cranial capacity the volume of the braincase, usually measured in cubic centimetres (cc or cm^3)

brow ridge a bony ridge above the eye sockets. It is found in all primates, but is greatly reduced in *Homo sapiens*

foramen magnum the hole in the base of the skull through which the spinal cord passes

arm to leg ratio the ratio of arm length to leg length. Tree–dwelling hominids have longer arms and shorter legs, or a larger arm to leg ratio

bowl–shaped pelvis the description of the shape of a *Homo sapiens* pelvis. Non– or partially–bipedal primates have comparatively flat pelvises

Figure 2 is a diagram featuring skeletons from three different hominin species that existed at three different points in hominin evolutionary history. On each of the skeletons, key pieces of anatomy that have changed throughout hominin evolution have been highlighted. Table 1 summarises the information shown in the diagram and explains the key structural features that have changed during hominin evolution. Some general trends to note are that hominin bodies increased in height over time and became less **robust** and more **gracile**, and **sexual dimorphism** decreased from early to late hominin species.

Table 1 Trends of structural changes over time

Cranial capacity	**Cranial capacity** increases from 460 cubic centimetres (cc) to around 1350cc throughout successive hominin species.
Brow ridge	Over time the **brow ridge** decreases in size. This is possibly due to the increasing size of the cranium, or that it once helped to disperse the mechanical stresses generated by our ancestors having to bite and chew tough raw meat, but as cooking made food easier to chew this was no longer necessary.
Face shape	Hominin faces become flatter over time due to jaw size decreasing and becoming less protruding/prognathic. This has been linked to the reduction in teeth size and dietary changes that have happened throughout hominin evolution.
Chin	*Homo sapiens* are the only hominin species to have evolved a chin. Interestingly, scientists are still unsure about why this has occurred!
Teeth	The dental arch changes from a U-shape to a shorter V-shaped or parabolic arch. Canine and molar teeth size also tended to decrease through time. These trends have been linked to the changing hominin diet, which became more based on softer, cooked foods.
Foramen mangum	The **foramen magnum** gradually becomes more central throughout hominin evolution as a consequence of hominin species becoming increasingly upright.
Spine curve	The spine shape of hominins changes from 'C-shaped' to 'S-shaped' with curves in both the upper and lower spine. These curves help support weight vertically and aid with upright mobility.
Rib cage	The rib cage shape in hominins changes over time from funnel-shaped to barrel-shaped. This helped later hominin species to maintain an upright posture for a lengthy period of time.
Arm to leg ratio	The **arm to leg ratio** decreases in hominin species over time as legs became used more for bipedal locomotion.
Pelvis	As time progresses hominin pelvis shape becomes shorter and more **bowl-shaped**. This shape provided hominins with more support for the upper body whilst standing and walking upright. In later hominin species the leg attaches to the pelvis at an angle, allowing more recent species to walk upright more easily. The legs of earlier hominin species attached to the pelvis in more of a straight line, meaning they had to swing their legs wide when walking which made them slower.
Big toe	The big toes of hominins change over time, becoming more protruding. Additionally, the other toes of the foot become increasingly aligned because there was no longer a need to grasp.
Foot arch	Over time the foot arch of hominin species increases, making bipedal locomotion more efficient.
Heel size	Heel size increases in hominins throughout time, making bipedalism more energy efficient and less impactful to the foot.

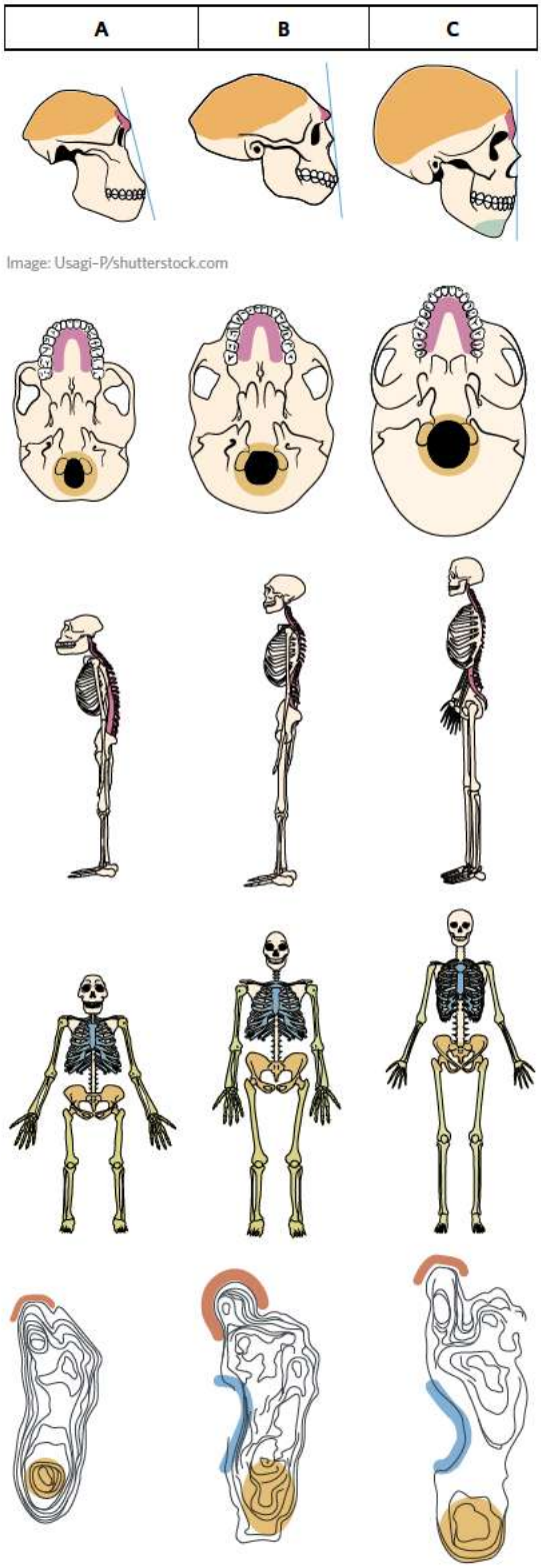


Image: Usagi-P/shutterstock.com

Figure 2 Tracing the structural changes in hominins: **(a)** *Australopithecus afarensis* (3.9 – 2.9 mya), **(b)** *Homo erectus* (1.8 mya – 70 000 ya), and **(c)** *Homo sapiens* (350 000 ya – present).

Tip VCE Biology exams usually only test your knowledge of general trends, but some specifics are good to remember. You should know that *Australopithecus* existed nearly 4 mya, the *Homo* genus emerged with *H. habilis* around 2 million years ago, and that Neanderthals and *Homo sapiens* coexisted until quite recently.

Image: prdyapin/Shutterstock.com

Figure 3 A collection of tools used by *Homo sapiens* during the Stone Age

Functional changes 4.1.11.3

OVERVIEW

Bipedalism led to hominins being able to use their hands in different ways and resulted in the development of tools that fundamentally altered hominin existence.

THEORY DETAILS

Becoming bipedal meant hominins developed increasingly flexible, precise, and dexterous hands. That might not sound like much, but in terms of evolution, this is a huge development – hands are one of the most useful and handy tools in the whole animal kingdom (pun intended). With free hands, hominins were able to create and use tools, build, and hunt in ways that other species could not (Figure 3).

Tools gave hominins access to new types of food. Whilst early hominin species were most likely vegetarian, later hominins were omnivores and obtained meat and plants through scavenging or hunting. They were also able to cook these foods using their hands to make and control fire. Cooking sterilises food, and also unlocks a vast array of nutrients. This meant hominins were less likely to get sick and obtained more energy from their food. All this extra energy helped increase the cognitive functioning of hominin species.

Having free hands also changed other aspects of hominin life. For example, hominins were able to carry their young and reach higher food. Additionally, having hands meant hominins could engage in different artistic and cultural activities such as art and jewellery making.

Finally, bipedalism had a number of other functional impacts on hominins that weren't related to hands. Being bipedal meant hominins could raise their head up high and scan for predators and prey. Walking on two legs is also more energy–efficient than walking on four legs, which meant that hominins had more energy to devote to other tasks. Additionally, bipedalism reduced the surface area of hominin skin that was exposed to the sun, so they could spend longer periods of time in the open foraging and hunting.

Image: Aldona Griskeviciene/Shutterstock

Figure 4 The brain of *Homo sapiens* has many more folds than other species.

Cognitive changes 4.1.11.4

OVERVIEW

Hominin brains increased in size over time, resulting in the evolution of higher cognitive processes such as planning, speech, and abstract thinking.

THEORY DETAILS

You learnt in 14A that hominoids have large brains for their body size. This trend increases throughout the evolution of hominin species, with the brain sizes of subsequent hominin species, in general, increasing over time. As discussed earlier, one of the primary drivers of this change was the improved diet of hominin species.

With an increase in hominin brain size comes an increase in the complexity of brain structure. Specifically, the **cerebrum** of hominin brains became more folded, which increased the total surface area of the brain, theoretically enhancing cognitive ability (Figure 4).

cerebrum the part of the brain responsible for complex functions, such as language and learning

With this increase in folding came the ability to do a number of unique activities including speech, feel complex emotions, higher order decision making, enhanced self–control, abstract thinking, and planning.

You should know that Neanderthals had larger brains than humans, but scientists think they used them differently. Human brains have evolved extensive networks to promote socialisation, whereas Neanderthal brain power may have been spent on superior vision and maintaining their large, stocky bodies in cold climates.

Consequences for cultural evolution 4.1.11.5

OVERVIEW

The structural, functional, and cognitive changes that took place in hominin evolution allowed hominins to create sophisticated cultures and transmit them to their offspring. Over time these cultures would change through the process of cultural evolution.

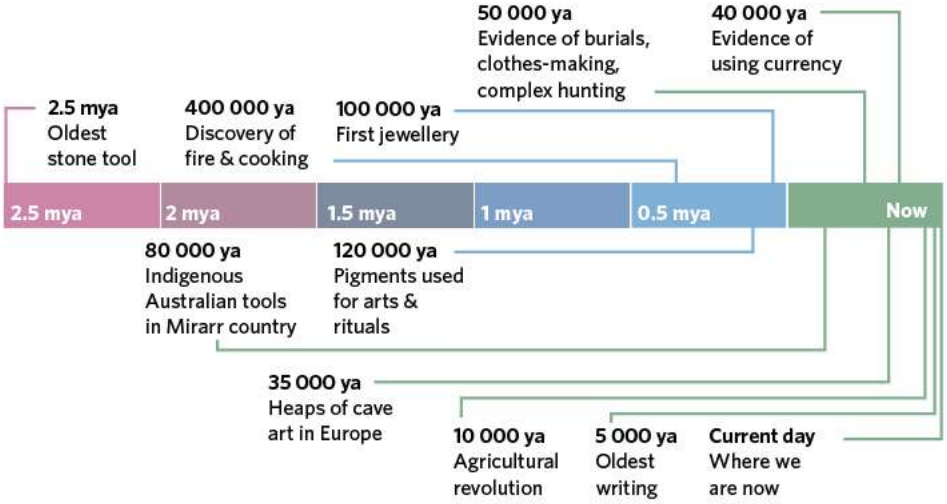


Figure 5 Timeline of key events in cultural evolution

THEORY DETAILS

A culture is the collective knowledge, ideas, beliefs, and customs of a society. Like genes, culture is passed on from generation to generation, changing (or mutating) over time. This process is called **cultural evolution**.

cultural evolution the change in socially-transmitted information, beliefs, language, attitudes, or skills over time

Hominins were able to use their written and verbal language skills to pass their cultural on to one another and to their offspring. This made language a core component of culture development and evolution, as subsequent generations inherited knowledge from their ancestors and built upon it.

This transmission of cultural information would not have been possible without the underlying structural, functional, and cognitive changes described earlier. For example, without tool development, hominins wouldn't have been able to hunt and gather enough food to live in large communities. Without fire, hominins wouldn't have been able to cook their food, extracting more nutrients from it to allow their brains to grow and develop. When looked at in this way, all the different areas of hominin evolution can be seen to interact with each other.

Just like how we can find a fossilised bone and learn about how the organism that left it behind lived, we can look at evidence of hominin cultural evolution and similarly come up with theories about how hominins evolved. VCAA expects you to know about some key aspects of hominin culture that clearly display the process of cultural evolution (Table 2).

Table 2 Examples of hominin cultural evolution

Area of culture	Evidence of cultural evolution
Tool use	Over time, the tools used by hominins became increasingly complex. This suggests that knowledge of tools and tool use was transferred between generations and was altered over time as hominin intelligence increased (Figure 6b).
Fire	The use of fire became increasingly more intricate, as fire went from being purely a source of warmth to becoming crucial to the way hominins made tools and cooked, enabling them to extract more nutrients from their food.
Social organisation	Hominin societies became more layered and complex over time, indicating that social structures and hierarchies were established and passed on to newer generations who then subsequently continued to alter them. As hominin social groups increased in size, abstract entities, such as governments, were created to maintain order and peace.

cont'd

Images: Jannarong & muratart/ Shutterstock.com

Image: Bborriss.67/Shutterstock.com

Figure 6 Evidence of cultural evolution is present in hominin **(a)** art and **(b)** tool use.

Food sources	Whilst early hominins largely foraged for their food, there is evidence that later hominin species worked together to hunt large prey. This shows that knowledge pertaining to hunting and planning was transferred between individuals and was passed on to subsequent generations who refined and improved upon the process. Eventually, through the development of agriculture, hunting became no longer necessary, as hominins now had a constant supply of food.
Art	Evidence of early hominin artwork reveals that it was relatively simple in nature. Over time, however, hominin art became increasingly more detailed, indicating that the knowledge and skills required to create it were passed on and improved upon between generations (Figure 6a).

In general, as the structural, functional, and cognitive changes brought about by bipedalism took place, hominin culture expanded and evolved.

Theory summary

The changes in hominin structure, function, cognition, and culture over time influenced each other. In particular, bipedalism – identifiable by bowl–shaped pelvis, a central foramen magnum, and longer legs compared to arms – was key for freeing the hands for tool–making and hunting. This led to improved cognition and subsequently enabled cultural development and evolution to take place.

Case study

This book is a great example of the ways in which the processes of structural, functional, and cognitive evolution influence hominin cultural evolution. Bipedalism led to a number of structural changes that gave rise to free hominin hands. These hands were used to get access to better food, which increased the energy intake of hominins. This extra energy aided the expansion of the hominin brain, allowing it to invent tools such as paper and ink.

These inventions were shared between generations and improved upon over time through the process of cultural evolution. Simultaneously, the improved cognition of hominins facilitated their understanding of abstract concepts such as biology. Over time these separate inventions of paper, ink, printing, and biology were expanded upon and improved. Then, one day, they were all combined into this textbook!

14B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the oldest hominin genus that was certainly bipedal

b _____ term used to describe organisms that walk on two feet

c _____ a facial feature above the eyes commonly larger in older hominin species

d _____ the hole at the base of the skull through which the spine passes

e _____ the shape of the *Homo sapiens* pelvis compared to ancient hominins

f _____ a hominin species that had a larger cranial capacity than *Homo sapiens*

g _____ the process of passing on and refining knowledge through time

Question 2

Identify which statements describe members of *Australopithecus* or *Homo sapiens*.

I Has a larger cranial capacity

II Has a smaller heel

III Has a more central foramen magnum

IV Smaller canines than apes

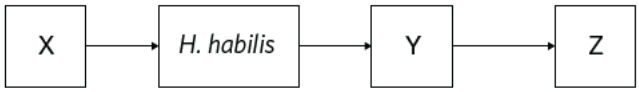
V Has a more prominent brow ridge

VI Barrel–shaped chest

	Australopithecus	*Homo sapiens*
A	II, IV	I, II, III, IV, VI
B	II, IV, V, VI	I, III, IV
C	II, IV, V	I, III, IV, VI
D	II	I, III, IV, V, VI

Question 3

Fill in the blanks.



	X	Y	Z
A	*Australopithecus*	*H. erectus*	*H. sapiens*
B	*H. erectus*	*H. neanderthalensis*	*H. sapiens*
C	*Australopithecus*	*H. sapiens*	*H. neanderthalensis*
D	*H. sapiens*	*Australopithecus*	*H. sapiens*

Question 4

Which of the following statements is false?

A *Homo erectus* had a larger cranial capacity compared to *Homo neanderthalensis*.

B Species with larger brain-to-body mass ratio tend to have a higher cognitive capacity.

C Australopithecine brains were less than half the size of modern human brains.

D *Homo neanderthalensis* had a larger brain size than modern *Homo sapiens*.

Question 5

From *Australopithecus* to modern humans, did the following structures generally increase or decrease?

I Brow ridge

II Cranial capacity

III Canines and molars

IV Robustness

V Sexual dimorphism

VI Jaw size

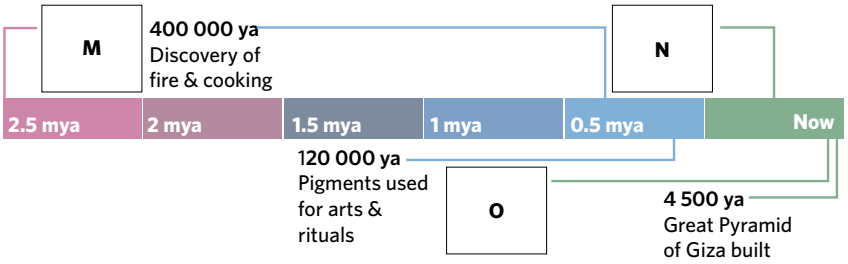
VII Brain size

VIII Body height

	Increase	Decrease
A	V, VII, VIII	I, II, III, IV, VI
B	II, VII	I, III, IV, V, VI, VIII
C	VII, VIII	I, II, III, IV, V, VI
D	II, VII, VIII	I, III, IV, V, VI

Question 6

Which moments in cultural evolution are missing in the timeline?



	M	N	O
A	Agriculture	Cave art	Religion
B	Stone tools made	Burials	Agriculture
C	Discovery of fire / fire control	Clothes-making / rituals	Sophisticated stone tools widely used
D	Stone tools made	Agriculture	Complex hunting techniques

Exam-style questions

Within lesson

Question 7 (1 MARK)

The name *Homo habilis* means 'handy man'. Scientists have discovered members of this species buried with a number of different stone tools. This suggests that *H. habilis*

A had bigger brains than previously thought.
B had a developed culture.
C could use fire for cooking.
D used a written language.

Adapted from VCAA 2017 Section A Q36

Question 8 (1 MARK)

Which feature would indicate fossil bones belong to the genus *Australopithecus* rather than *Homo*?

A A less parabolic jaw
B A flatter face
C A chin
D A larger braincase

Adapted from VCAA 2017 Section B Q7a

Use the following information to answer Questions 9 and 10.

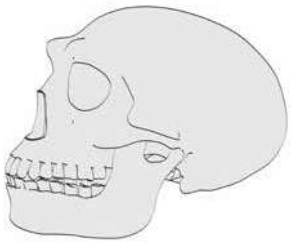


Image: 3drenderings/Shutterstock.com

Question 9 (1 MARK)

Which features of the skull shown in the diagram allow scientists to determine that this is a much earlier species of the genus *Homo* than modern humans *(H. sapiens)*?

A Brow ridge and more parabolic jaw
B Large canines and no brow ridge
C Brow ridge and a flat face
D Brow ridge and more protruding jaw

Adapted from VCAA 2016 Section B Q10b

Question 10 (1 MARK)

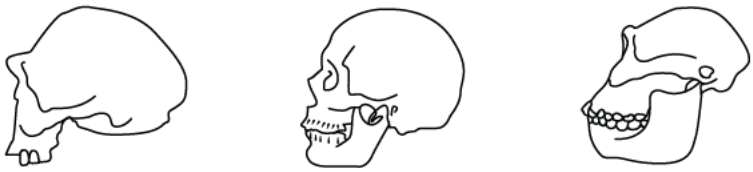
Which features of the skull shown in the diagram allows scientists to determine that this is a more modern species than members of the genus *Australopithecus*?

A Smaller braincase
B Flatter face
C More sloping forehead
D Less central foramen magnum

Adapted from VCAA 2016 Section B Q10c

Question 11 (1 MARK)

Here are three images of fossil hominin skull.



Skull 1 **Skull 2** **Skull 3**

Image: 3drenderings/Shutterstock.com

Which sequence best shows the order from the most modern fossil skull to the most ancient fossil skull?

A Skull 1, Skull 2, Skull 3
B Skull 3, Skull 1, Skull 2
C Skull 2, Skull 1, Skull 3
D Skull 3, Skull 2, Skull 1

Adapted from VCAA 2015 Section A Q37

Use the following information to answer Questions 12 and 13.

Fossil remains of a number of individuals from a hominin species were found at various sites in the eastern half of Africa and have been dated to between 3 – 4 million years old.

Question 12 (1 MARK)

These fossil remains are likely

A from the genus *Homo*.
B some of the earliest examples of the hominin super-family.
C *Australopithecus afarensis.*
D from a species that used fire to cook.

Adapted from VCAA 2015 Section A Q38

Question 13 (1 MARK)

Compared to *Homo sapiens*, these fossil remains would have a

A more bowl-shaped pelvis.
B shorter arm to leg ratio.
C more S-shaped spine.
D smaller heel bone and broadly spread feet.

Adapted from VCAA 2015 Section A Q38

Question 14 (1 MARK)

Which of the following is not an example of how culture is passed on to other members of a species?

A Genetically
B Cave art, rituals, and ceremonial dances
C Orally
D Socially

Adapted from VCAA 2017 Exam Section B Q8c

Question 15 (1 MARK)

Which of the following statements outlines the general trend shown by hominin fossils?

A The older the fossil, the more central the position of the foramen magnum in the skull.
B The more recent the fossil, the larger and more prognathic the jaw.
C The older the fossil, the larger the braincase that surrounds the cerebral cortex.
D The more recent the fossil, the shorter the arm to leg ratio.

Adapted from VCAA 2018 Section A Q39

Question 16 (1 MARK)

The following image shows three views of the skeleton of a hominin species.

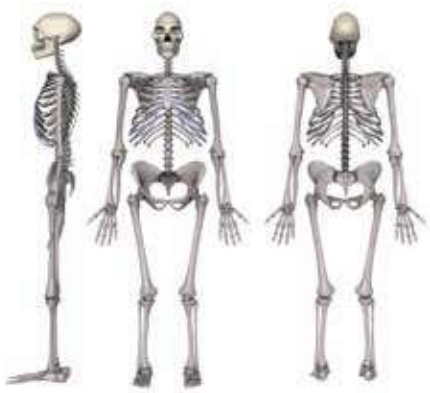


Image: 3drenderings/Shutterstock.com

Based on your knowledge and the information provided in the image, which one of the following is a correct statement?

A The species shown in the image has a C-shaped spine similar to ancient hominins.
B The species shown in the image has a central foramen magnum indicative of a tree-based habitat.
C The species shown in the image has a protruding jaw, similar to modern *Homo sapiens*.
D The species shown in the image has a funnel-shaped rib cage, similar to older *Homo* and *Australopithecus* fossils.

Adapted from VCAA Exam 2017 Northern Hemisphere Exam Section AQ39

Question 17 (7 MARKS)

In 2013, about 1500 fossil bones of a hominin species were found in a cave in South Africa. From these bones, scientists have managed to construct an almost complete skeleton. The fossil bones have some features in common with those of the genus *Australopithecus*; however, they have enough similarities to the genus *Homo* that scientists have classified the fossil skeleton as belonging to a new species, *Homo naledi*.

a What are two features that would classify the fossil skull in the genus *Australopithecus* and not the genus *Homo*? (2 MARKS)

b Scientists estimate that the fossil is approximately 2 million years old.
  i Given this information, would you expect this species to be bipedal? Explain. (1 MARK)
  ii Describe two features the scientists would need to find on the skeleton to prove that the species was bipedal and explain how these helped with bipedal locomotion. (2 MARKS)
  iii Describe two effects of bipedalism on hominin behaviour. (2 MARKS)

Adapted from VCAA 2014 Section B Q11d and VCAA 2017 Section B Q7a

Multiple lessons

Question 18 (1 MARK)

Members of the genus *Homo* are hominins. Which combination of features is common to all hominins and distinguishes them from other primates?

	Feature 1	Feature 2	Feature 3
A	Forward-facing eyes	Less fur and hair	Opposable thumbs
B	Higher sexual dimorphism	Larger braincase	Narrower, more bowl-shaped pelvis
C	No brow ridge	Bipedal	Large braincase
D	Shorter arm to leg ratio	Large braincase	S-shaped spine

Question 19 (8 MARKS)

A hominin species, *Homo floresiensis,* was identified from fossils found on an isolated Indonesian island. These fossils were dated to be 18 000 years old.

The adult skull of this upright, bipedal hominin had a cranial volume less than one-third the average cranial volume of a modern adult human. It had harder, thicker eyebrow ridges than *Homo sapiens,* a sharply sloping forehead, and no chin. *H. floresiensis* was just over one metre tall and their arm to leg ratio was slightly larger than modern humans. They weighed approximately 16 kg.

The fossils were found in sediment that also contained stone tools and fireplaces for cooking. The fireplaces contained the burnt bones of animals, each animal weighing more than 350 kg. The stone tools included blades, spearheads, and cutting and chopping tools.

a The fossils of *H. floresiensis* showed that they had opposable thumbs. Explain why developing opposable thumbs was an important step in primate evolution. (2 MARKS)

b *H. floresiensis* are unusually small for such a recent hominin species. Using the theory of natural selection, describe how this species evolved to be so small compared to *Homo sapiens* and *Homo neanderthalensis*. (4 MARKS)

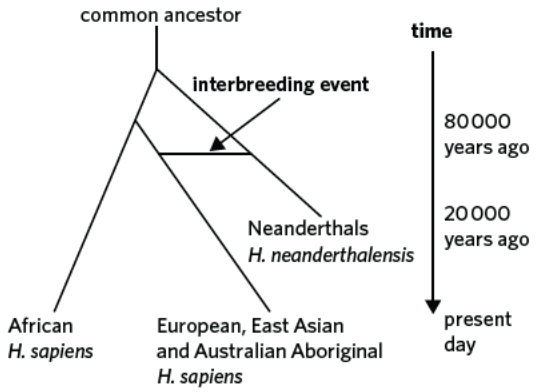
c Using two pieces of evidence from the text, explain why scientists theorise that *H. floresiensis* had well-developed communication skills and social cooperation. (2 MARKS)

Key science skills

Question 20 (5 MARKS)

Fossil evidence indicates that between 30 000–80 000 years ago, populations of modern humans (*Homo sapiens*) and the extinct Neanderthals (*Homo neanderthalensis*) lived close to one another in parts of the Middle East, Asia, and Europe.

Using molecular and structural homology analyses, researchers have constructed a theory about the relationships between ancient populations. This is represented in the diagram.



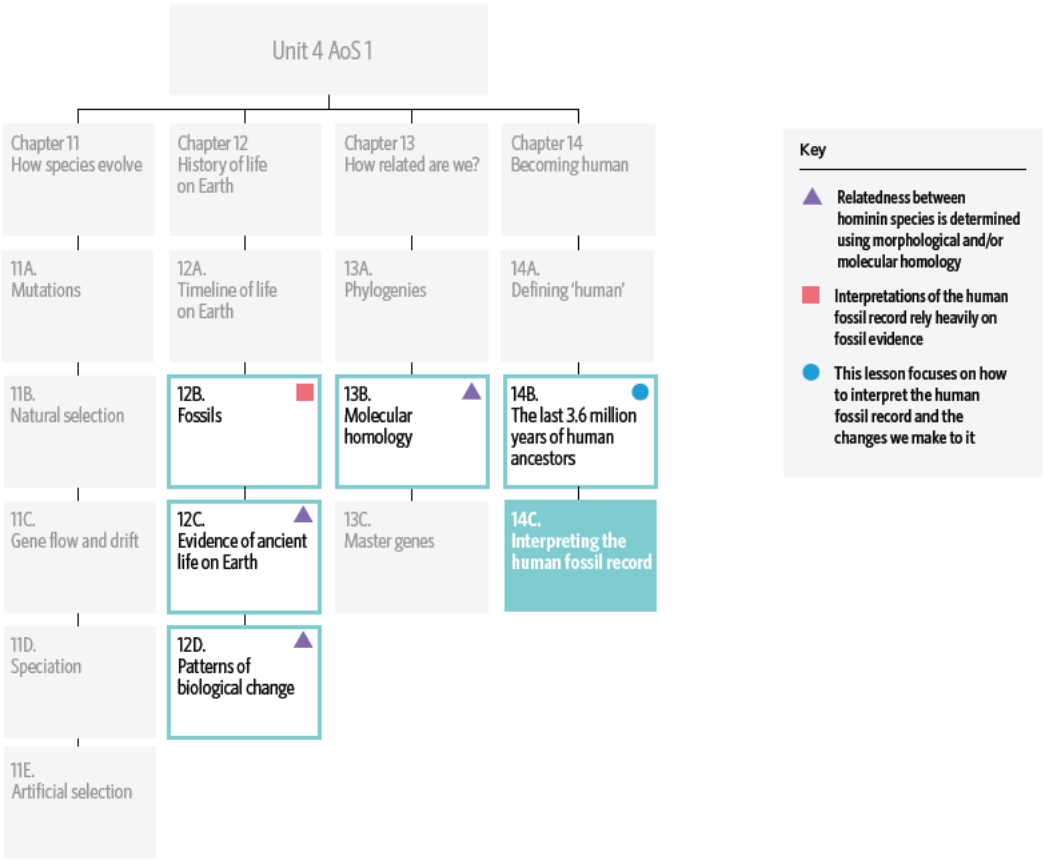
a Given the phylogenetic tree, would you expect *Homo sapiens* of African descent to have Neanderthal DNA in their genome? Justify your response. (2 MARKS)

b Explain how scientists could construct this tree from DNA samples of Neanderthals and modern humans. (3 MARKS)

Adapted from VCAA 2015 Section B Q11ai

14C INTERPRETING THE HUMAN FOSSIL RECORD

Would you believe that ~65 000 years ago humans did the deed with another species? And would you believe that ~15 000 years ago, humans did it again?



In this lesson you will learn about how scientists identify new hominins, and our recent interbreeding with Neanderthals and Denisovans.

Study design dot point

- the human fossil record as an example of a classification scheme that is open to interpretations that are contested, refined, or replaced when new evidence challenges them or when a new model has greater explanatory power, including whether *Homo sapiens* and *Homo neanderthalensis* interbred and the placement of the Denisovans into the *Homo* evolutionary tree

Key knowledge units

Why is interpreting the human fossil record so difficult?	4.1.12.1
Did we breed with Neanderthals?	4.1.12.2
Where do Denisovans belong?	4.1.12.3

Why is interpreting the human fossil record so difficult? 4.1.12.1

OVERVIEW

The human fossil record is like a puzzle that is slowly being filled in as new fossils are discovered. Ultimately, it is still incomplete and different interpretations can be made from the few pieces of evidence we have.

THEORY DETAILS

Why do scientists have different interpretations of the fossil record? The fossil record, by its nature, is incomplete and the human fossil record is no different. In order to find the truth behind how we evolved and what other hominin species existed, we need to discover more fossils and build up the evidence.

The case studies in this lesson are not explicitly tested by VCAA but serve as examples of how VCAA expects you to think about hominin evolution.

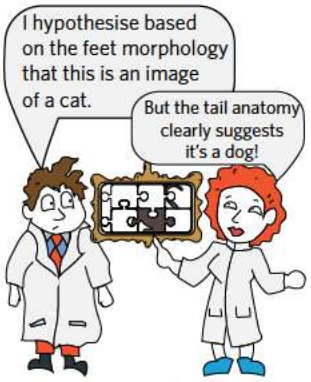


Figure 1 Cartoon representing how biologists interpret the human fossil record differently

Case study

Homo naledi is a hominin species that biologists often disagree over. In 2013, fossils from a new hominin species, called *Homo naledi*, were discovered in a cave in South Africa (Figure 2). It has features resembling both modern humans and older hominins (Table 1) and some scientists have suggested it may be a transitional fossil between *Australopithecus* and *Homo*. The fossils were not dated upon their initial discovery, so a crucial piece of the puzzle was missing. The fossils were only covered by a shallow layer of dirt and were arranged in a peculiar pattern, suggesting that they may have been intentionally arranged as some sort of burial rite. This finding could be groundbreaking if *H. naledi* really is older than the genus *Homo* since it would mean complex behaviour such as burial rituals would have evolved much earlier than expected. Figure 3 shows each of the possible ages for *H. naledi* and their implications for hominin evolution.

Table 1 Features of *H. naledi* grouped by genus resemblance

Australopithecus	*Homo*
More primitive shoulders	Skull shape
Fingers are long and curved, suggesting tree-climbing lifestyle	Hands well suited for object manipulation
Skull size is small	Legs, feet and ankles
Pelvis shape	
Wide rib cage	

Figure 2 Fossils from *Homo naledi*

Later in 2017, the fossils were dated to around 250 000 years ago, matching up with outcome 3 in Figure 3. This indicates *H. naledi* isn't as old as earlier scientists had suspected and actually lived alongside modern humans, adding another piece to the puzzle of hominin evolution.

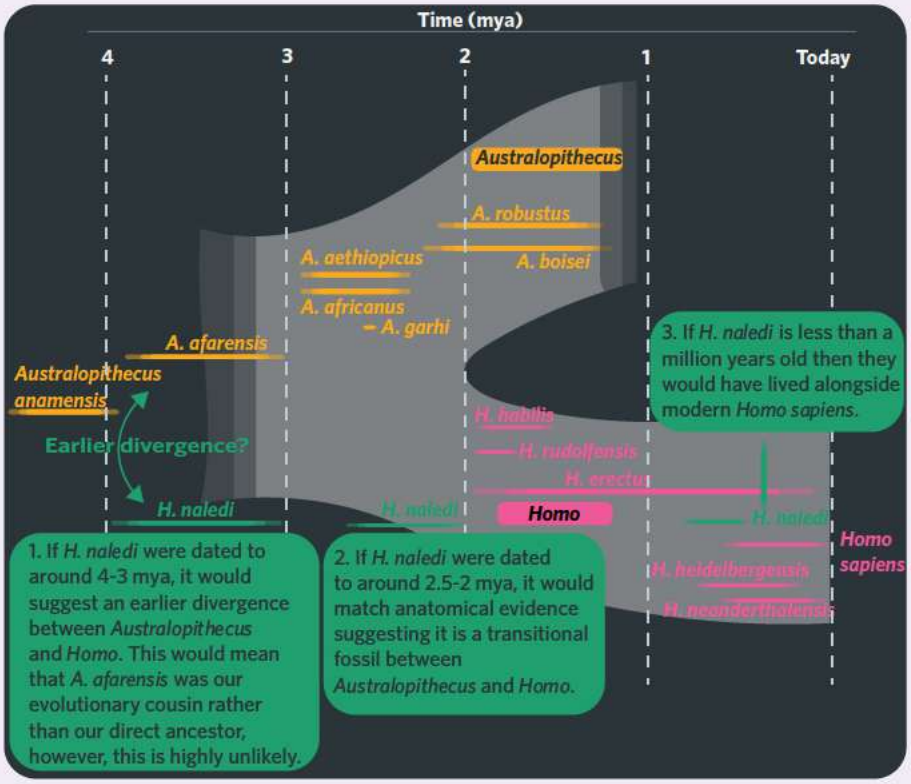


Figure 3 The implications on hominin evolution of three potential outcomes of *H. naledi* dating. Each outcome is dependent on how old the *H. naledi* fossils are based on dating data.

Out of Africa hypothesis
a well-supported model for human migration that suggests *Homo sapiens* moved out of Africa in several waves and replaced other hominin species in Eurasia

Case study

How hominins spread – two competing hypotheses

The **Out of Africa hypothesis** helps explain how modern humans came to be so widespread across the globe. It states that early *Homo sapiens* lived solely in Africa and spread out across the world later in time. Exactly when and how this spread of humans across the globe occurred is still very contentious and is constantly being revised in light of newer evidence.

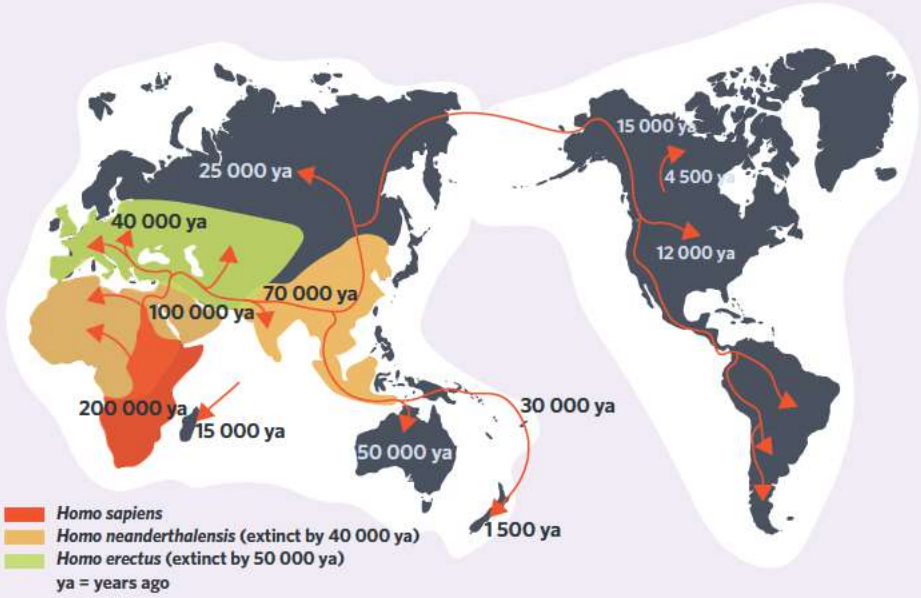


Figure 4 Map showing the multiple human migration events suggested by the Out of Africa hypothesis

Three key pieces of evidence supporting Out of Africa hypothesis include:

- The majority of older hominin fossils are found in Africa
- Use of the molecular clock to deduce divergences between human populations points to Africa as the origin of humans
- Neanderthals in Eurasia interbred with European and Asian *Homo sapiens* but not African *Homo sapiens*.

An alternative hypothesis to Out of Africa is the multiregional hypothesis, which proposes that an ancestor of modern humans such as *Homo erectus* became widespread across the globe first and evolved into *Homo sapiens* independently in several different human populations (Figure 5).
This hypothesis is quite controversial due to racial and scientific implications.

Two pieces of evidence supporting the multiregional hypothesis include:

- Low genetic diversity in modern humans suggests gene flow between populations
- Phenotypic variation between groups of modern humans suggests a long time since a common ancestor.

Currently, the Out of Africa hypothesis is more widely accepted due it to having more supporting evidence. However, the details of exactly how human migration occurred are gradually being uncovered as new evidence comes to light.

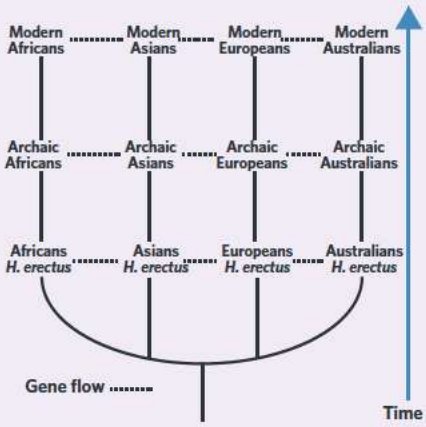


Figure 5 Diagram showing how multiple human populations could be separate but still speciate together, as proposed by the multiregional hypothesis

Tip VCAA typically tests this topic by giving a scenario of a new hominin fossil that is discovered and providing evidence and different opinions on its classification. You should be able to interpret which evidence supports which hypothesis about the fossil. *Homo naledi*, The Out of Africa hypothesis, and the multiregional hypothesis are not explicitly stated in the study design but have appeared in previous exams and are good examples of hypotheses that are constantly being updated based on new evidence.

Did we breed with Neanderthals? 4.1.12.2

OVERVIEW

How do we know that Neanderthals and humans interbred 50 000 years ago? Here we will look at the evidence supporting this hypothesis.

THEORY DETAILS

Homo neanderthalensis, commonly known as the Neanderthals, were our close cousins that existed in Europe and Asia between 400 000 and 40 000 years ago. They are known from fossil evidence that has accumulated over time since the first Neanderthal fossils were discovered in the Neander Valley in Germany in 1856. The mtDNA taken from Neanderthal fossils and compared with *H. sapiens* mtDNA indicates our two species are significantly different, suggesting we are separate species that shared a recent common ancestor around 400 000 years ago.

Being closely related to humans, Neanderthals share a lot of features with us but differ in a few important ways by having:

- an enlarged brow ridge
- a sloping forehead
- a wide nose
- a larger cranial capacity of 1500 cc
- a flared rib cage
- a stockier build
- shorter limbs
- better resistance to colder climates.

Humans and Neanderthals lived in the same regions as each other in Eurasia around 100 000 to 40 000 years ago, and there is compelling evidence to suggest that crossbreeding occurred between our two species (Table 2).

Table 2 Recent evidence supporting Human-Neanderthal interbreeding

Evidence for interbreeding	Hypothesis
Nuclear DNA studies in 2010 show around 1–4% of the human genome is identical to DNA found in Neanderthals. This 1–4% similarity was only found in the genomes of non-African populations and not in sub-Saharan African genomes.	Suggests Neanderthals may have interbred with humans as they left Africa somewhere in the Middle East around 65 000 years ago and did not interbreed with African humans.
100 000 year old DNA from Neanderthal fossils found in Siberia in 2016 found that it contained a significant amount of ancient human DNA not found in other Neanderthal populations.	Suggests a population of Neanderthals in Siberia may have interbred with an early form of humans around 100 000 years ago. This suggests a second **interbreeding** event with humans.

Although around 1–4% of some human genomes are made up of Neanderthal DNA, the part of the Neanderthal genome found in each person differs quite a lot. In fact, around 20% of the Neanderthal genome is represented in the human population!

Figure 6 **(a)** A reconstruction of a Neanderthal skull originally discovered in 1909 and **(b)** a model based on 40 000 year old male Neanderthal remains

Homo neanderthalensis commonly called Neanderthals, they are an extinct hominin species that lived in cold climates alongside *Homo sapiens* with whom they are believed to have interbred

interbreeding refers to the mating between different species (e.g. between *Homo sapiens* and other closely related species such as Neanderthals and Denisovans). Also known as **crossbreeding**

Homo denisova commonly called Denisovans, they are an extinct hominin species that lived alongside *Homo sapiens* with whom they are believed to have interbred. Their status as a distinct species or subspecies of *Homo sapiens* is still debated

Where do Denisovans belong? 4.1.12.3

OVERVIEW

How do we know that Denisovans are a distinct species that interbred with humans? Here we will look at the evidence supporting this hypothesis.

THEORY DETAILS

In 2010, scientists reported the discovery of bone fragments of a new hominin species in Denisova Cave in Siberia. These bones were dated to around 40 000 years ago and DNA was extracted and analysed. The nuclear DNA from the bone was found to be very closely related to Neanderthals, but different enough to be a new distinct species, termed ***Homo denisova***, or Denisovans.

To make things even more interesting, DNA taken from the genomes of Melanesian *Homo sapiens* revealed they share 4–6% DNA with Denisovans, but other human populations do not. This suggests an interbreeding event occurred between the elusive Denisovans and ancient Melanesians.

Figure 7 Denisovan molar tooth fossil found in Denisova Cave in Siberia in 2000. Some teeth and a few bone fragments are the only fossil evidence we have of Denisovans.

This likely occurred between 15 000 and 44 000 years ago as the ancestors of Melanesians migrated south through Southeast Asia. Some populations in Southeast Asia lack Denisovan DNA suggesting they may have arrived during a later wave of migration.

Theory summary

In this lesson you have learned about how biologists interpret the fossil record differently. You have looked closely at two species, Neanderthals and Denisovans, and analysed the evidence supporting crossbreeding events between them and humans, which is summarised in Figure 8.

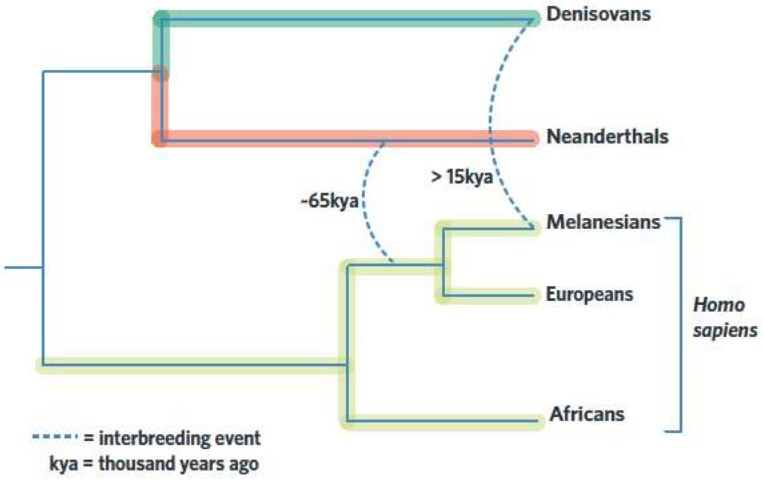


Figure 8 Phylogenetic tree depicting interbreeding events among modern humans, Denisovans, and Neanderthals

14C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a hominin species that interbred with non-African *Homo sapiens*, sharing 1–4% of their DNA

b _____ a hypothesis that suggests *Homo sapiens* originated in Africa and migrated to other continents in several waves

c _____ mating between modern humans and other closely related hominin species

d _____ a hominin species that interbred with *Homo sapiens*, sharing 4–6% of their DNA with some Melanesian humans

Question 2

Which of the following statements regarding hypotheses is false?

A New hypotheses are formed in light of new evidence.

B Evidence is not important for supporting a hypothesis, as long as you defend your position.

C Multiple hypotheses may be plausible until more evidence is found.

D A hypothesis becomes more likely as more evidence is found to support it.

Question 3

Which of the following does not support the Out of Africa hypothesis?

A Neanderthals interbred with non-African humans.

B Genetic diversity is lowest in African human populations.

C Fossils of human ancestors are predominantly found in Africa.

D Studies on mutation rates among humans point to Africa as the origin.

Question 4

Fill in the blanks in the following sentences.

The _____**I**_____ suggests that humans migrated from Africa to the rest of the world. As humans passed through the Middle East, it is believed they interbred with _____**II**_____ around _____**III**_____ years ago. Later, humans migrated through south-east Asia where they are likely to have interbred with _____**IV**_____ around _____**V**_____ years ago.

	I	II	III	IV	V
A	Out of Africa hypothesis	Neanderthals	65 000	Neanderthals again	15 000
B	multiregional hypothesis	Neanderthals	10 000	Denisovans	5 000
C	Out of Africa hypothesis	Neanderthals	65 000	Denisovans	15 000
D	Out of Africa hypothesis	Denisovans	10 000	Neanderthals	5 000

Question 5

Consider the following features of *Homo naledi*. Classify each according to which genus of hominin it suggests *Homo naledi* belongs to.

I Small skull

II Legs similar to modern humans

III Primitive rib cage shape

IV Dated to around 250 000 years old

V Fingers well adapted to climbing trees

	Australopithecus	***Homo***
A	III, IV, V	I, II
B	II	I, III, IV, V
C	I, III, IV	II, V
D	I, III, V	II, IV

Question 6

Which pieces of evidence support the hypothesis that *Homo neanderthalensis* interbred with *Homo sapiens*?

I Modern non-African humans have 1–4% Neanderthal DNA in their genome

II Neanderthals have a larger cranial capacity than modern humans

III Modern humans and Neanderthals both lived in Eurasia around the same time

IV mtDNA from humans was found to be different enough from mtDNA from Neanderthals to classify them as separate species

V Both modern humans and Neanderthals have evolved bipedalism

A I and III only

B II, III and IV only

C I, III and V only

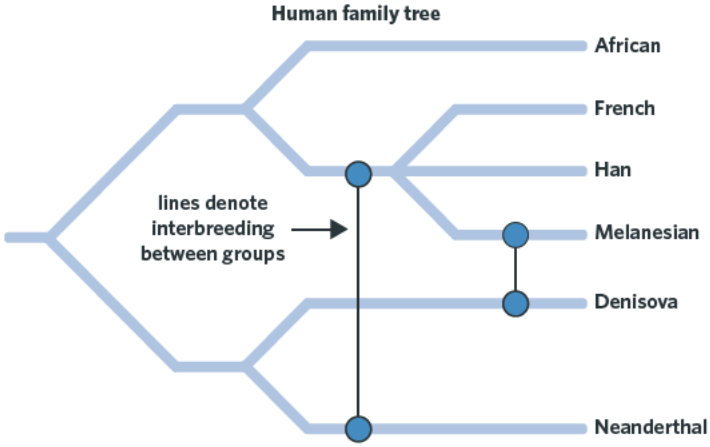
D I, II, III, IV and V

Exam-style questions

Within lesson

Use the following information to answer Questions 7 and 8.

This human family tree shows the relationships between different groups.



Source: Ghosh (2010), adapted by VCAA 2017 Sample Exam Section A Q35

Question 7 (1 MARK)

Which group would contain Denisovan DNA?

A Han group
B Neanderthal group
C Melanesian group
D African group

Adapted from VCAA 2017 Sample Exam Section A Q35

Question 8 (1 MARK)

The group most closely related to the Neanderthal group is the

A French group.
B Denisovan group.
C Melanesian group.
D Han group.

Adapted from VCAA 2017 Sample Exam Section A Q36

Use the following information to answer Questions 9–11.

Scientists have been studying the genomes of groups of present-day *Homo sapiens*. Most of the DNA in these present-day groups is the same as the DNA found in *Homo heidelbergensis*, suggesting that *H. heidelbergensis* is the direct ancestor of *Homo sapiens*. The scientists found that there were traces of DNA in these present-day groups from three *Homo* species, indicating earlier crossbreeding. The table provides information about eight species of *Homo*.

Species	When this species lived	Where this species lived
Homo rudolfensis	2.1 – 1.8 million years ago	eastern Africa
Homo habilis	1.9 – 1.4 million years ago	eastern and southern Africa
Homo erectus	1.9 million – 100 000 years ago	Africa and Asia
Homo antecessor	approximately 1.2 million years ago	Spain
Homo heidelbergensis	700 000 – 200 000 years ago	Africa, Europe and possibly Asia
Homo neanderthalensis	500 000 – 40 000 years ago	western Eurasia (as far east as Siberia)
Homo denisova	100 000 years ago	Siberia
Homo sapiens	approximately 180 000 years ago to present	worldwide

Source: Lewis (2016), adapted by VCAA 2018 Northern Hemisphere Exam Section A Q21

Question 9 (1 MARK)

Two of the species that crossbred were identified as *Homo erectus* and *Homo neanderthalensis*. Which species of *Homo* shown in the table could have been the third species to crossbreed?

A *H. rudolfensis*
B *H. antecessor*
C *H. denisova*
D *H. habilis*

Question 10 (1 MARK)

Based on the information in the table, which species would be least likely to interbreed with *Homo neanderthalensis*?

A *H. heidelbergensis*
B *H. sapiens*
C *H. erectus*
D *H. habilis*

Question 11 (1 MARK)

From the information in the table it can be concluded that

A technology within the *Homo* genus became more advanced as species spread across the world.
B species diversity within the *Homo* genus was much greater around 400 000 years ago.
C *Homo neanderthalensis* was much more widespread than *Homo sapiens*.
D the ancestor of the *Homo* genus likely lived in Siberia.

Question 12 (9 MARKS)

How much evidence is enough to declare a new species of human from a Philippines cave site?

By Darren Curnoe

Published in *The Conversation* April 11th 2019

The recent announcement of a new hominin species will cause a lot of head-shaking among anthropologists and archaeologists. Some will greet the publication with wild enthusiasm, others will howl angrily, believing the declaration goes way too far with too little evidence.

The new hominin is *Homo luzonensis*, named after the Philippines' main island of Luzon, where it was recovered during excavations of Callao Cave in 2007, 2011 and 2015. This new hominin is represented by a handful of heavily worn adult teeth from one or two individuals, one foot and two toe bones, two finger bones, and the fragment of the shaft of a juvenile thigh bone. These fossils have been dated to around 50 000 years ago.

The statistical comparisons made in the newly published research highlight a rather odd assortment of features in *Homo luzonensis*. Its anatomy is argued to be a peculiar mix of features normally found in living humans, *Homo erectus*, the Hobbit (*Homo floresiensis*), and *Australopithecus*. But the all-important type (or holotype) specimen comprises just a few teeth from the upper jaw, all of which are rather heavily worn down or broken. There's not a lot of anatomy preserved here, and this leaves many feeling the case for this new species is a little flimsy.

Its discovery could be ground-breaking because of its resemblance to *Australopithecus*, a genus that lived only in sub-Saharan Africa, between about 2 million and 5 million years ago. How astonishing would it be that something resembling *Australopithecus* would have survived a long, long, way from the African Rift Valley as recently as 50 000 years ago? Well, as it turns out, this is precisely the situation with the diminutive *Homo floresiensis* from Flores in eastern Indonesia, most recently dated between 60 000 and 100 000 years old. Again, while the Hobbit might have prepared us philosophically for yet more radical discoveries, the case for *Homo luzonensis* needs to be judged solely on its merits.

There's not much new evidence presented here about the dating of the site or the fossils themselves, and the work that has been done previously needs to be interpreted with a good deal of caution. The method used to date the actual fossils (called Uranium-series or U/Th Dating) can be notoriously unreliable when dating bones and teeth.

We need to keep a cool head, because the naming of any new species is still a scientific hypothesis, ripe for testing and far from set in stone.

a The anatomy of *Homo luzonensis* appears to be a mixture of several hominin species. Using your knowledge of fossils, provide a possible explanation for why this seems to be the case. (1 MARK)

b According to the article, what was so astonishing about the discovery of *Homo floresiensis*? (2 MARKS)

c Complete the following table by identifying two pieces of evidence in the text that suggest *Homo luzonensis* is a new hominin species.

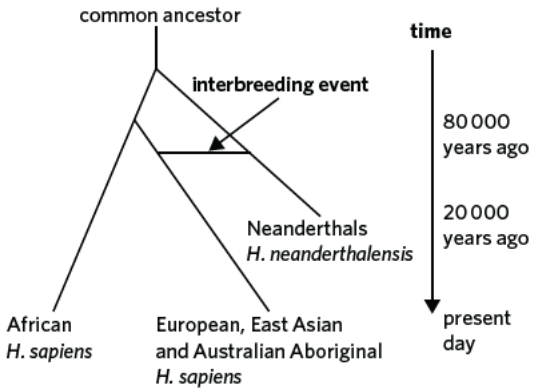
Evidence	Justification	Limitation
1.		
2.		

Justify how each piece of evidence supports this claim and identify a limitation of each piece of evidence for *H. luzonensis*. (6 MARKS)

Multiple lessons

Question 13 (7 MARKS)

Fossil evidence indicates that between 30 000 – 80 000 years ago, populations of two hominin species – modern humans (*Homo sapiens*) and the extinct Neanderthals (*Homo neanderthalensis*) – lived close to one another in parts of the Middle East, Europe, and Asia. Researchers have constructed a theory about the relationships between ancient populations. This is represented in the phylogenetic tree.



Recent DNA evidence has shown that:

- the genome of living humans of African descent does not contain Neanderthal DNA.
- the genomes of living humans of European, East Asian, and Australian Aboriginal descent all contain small amounts of Neanderthal DNA (1–4%).

a Explain how scientists could determine if DNA present in the *H. sapiens* genome comes from Neanderthals. (1 MARK)

b Suggest how DNA from *H. neanderthalensis* entered the genome of present-day European, East Asian and Australian Aboriginal *H. sapiens*, and continues to be found in modern populations. (2 MARKS)

c The majority of paleoanthropologists agree that *Homo sapiens* evolved in Africa, but exactly how they spread out across the globe is still debated. The most widely accepted hypothesis, termed the Out of Africa hypothesis, suggests that *H. sapiens* migrated across the globe from Africa in several waves between 50 000 and 130 000 years ago. These *H. sapiens* replaced other *Homo species* as they migrated throughout Europe, Asia, and the rest of Africa. This hypothesis also explains why Australian Aboriginal *H. sapiens* contain Neanderthal DNA despite no Neanderthal fossils ever being found in Australia.

An alternative hypothesis, termed the multiregional hypothesis, suggests that the ancestor of *H. sapiens* left Africa much sooner and formed several semi-isolated populations across the globe in Europe, Asia, Australia, and Africa. These distinct populations each speciated into *Homo sapiens* together, with continuous gene flow between the populations allowing them to remain the same species.

Most scientists consider that the absence of Neanderthal DNA in present-day African *H. sapiens* lends support to the Out of Africa hypothesis.

i Explain how the recent DNA evidence provided in the diagram is consistent with the Out of Africa hypothesis. (2 MARKS)

ii Explain how the recent DNA evidence provided in the diagram is inconsistent with the multiregional hypothesis. (2 MARKS)

Adapted from VCAA 2015 Section B Q11

Key science skills

Question 14 (7 MARKS)

Denisovans are a species of the genus *Homo* that existed around 40 000 years ago. They are known from fossils found in Siberia that contained DNA, allowing researchers to sequence the Denisovan genome.

Researchers have surveyed the genomes of the modern *Homo sapiens* population and have concluded that interbreeding must have occurred between Denisovans and *H. sapiens* between 15 000 and 50 000 years ago. Modern African *H. sapiens* do not contain Denisovan DNA whilst modern Asian and Australian *H. sapiens* contain a small percentage of Denisovan DNA.

a What implication does this DNA evidence have for the classification of the two hominin species, *H. sapiens* and Denisovans, according to the common definition of a species? (1 MARK)

b Explain why Denisovan DNA is not present in modern African *H. sapiens* but is present in other *H. sapiens* populations. (2 MARKS)

c Further research in the *H. sapiens* population has led to two new findings:

- The DNA from the Denisovan fossil in Siberia is more similar to Denisovan DNA in the East Asian genome than the Papua New Guinean genome.
- Modern individuals in Papua New Guinea contain 5% Denisovan DNA whilst East Asian populations contains far less Denisovan DNA.

Suggest a hypothesis that explains the origin of Denisovan DNA in both the East Asian and Papua New Guinean genomes. Justify your response by referring to both of the findings. (3 MARKS)

d Some groups of modern day humans have been found to contain sequences of hominin DNA that are not found in other humans, Neanderthals, or Denisovans.

Provide an explanation to account for these findings. (1 MARK)

ACTIVITIES

Hominin changes over time

Copy out the table below in your workbooks. Then fill it in by identifying how the feature has changed through hominin evolution and explain the functional and/or cognitive significance of this change. The first two rows have been filled in for you.

Feature	Trend	Functional and/or cognitive significance
Pelvis	Became more bowl-shaped and less flat	Promotes bipedalism and upright sitting
Teeth	Size decreased, particularly canines	Influenced by improved diet and advancements in cooking
Arm-to-leg ratio		
Jaw		
Skull		
Foramen magnum		
Brow ridge		
Femur angle		
Ribcage		
Hands		
Feet		

Piecing hominin evolution together

In the mindmap, the letters A-G indicate missing aspects of functional or cultural evolution. Which options in the list below should take the place of letters A-G to correctly show the connections between functional, cognitive, and cultural evolution?

I Improved diet

II Can see predators and prey

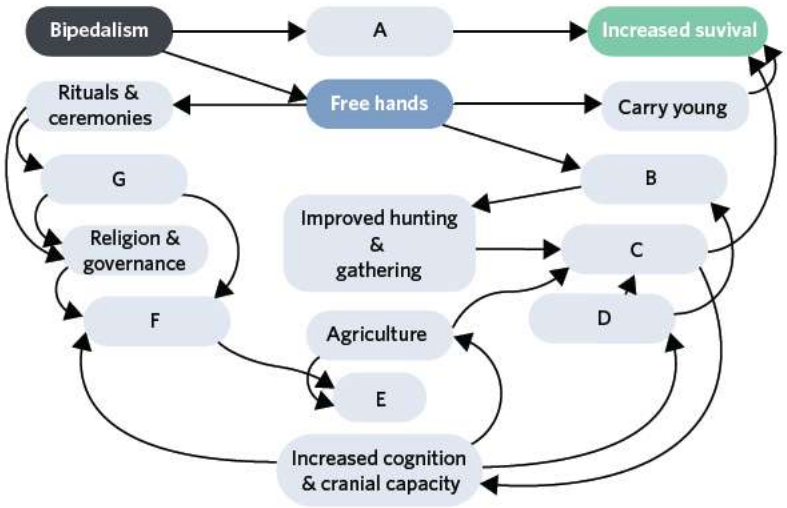
III Abstract thinking and art

IV Cooking and control of fire

V Larger human settlements

VI Improved communication and social cooperation

VII Improved tool making



Text analysis

Was agriculture the greatest blunder in human history?

By Darren Curnoe

Published in *The Conversation* May 23rd 2017

Twelve thousand years ago everybody lived as hunters and gatherers. But by 5 000 years ago most people lived as farmers. This brief period marked the biggest shift ever in human history with unparalleled changes in diet, culture, and technology, as well as social, economic, and political organisation, and even the patterns of disease people suffered. While there were upsides and downsides to the invention of agriculture, was it the greatest blunder in human history? Three decades ago Jared Diamond thought so, but was he right? Agriculture developed worldwide within a single and narrow window of time: between about 12 000 and 5 000 years ago. But as it happens it wasn't invented just once but actually originated at least seven times, and perhaps 11 times, and quite independently, as far as we know.

Farming was invented in places like the Fertile Crescent of the Middle East, the Yangzi and Yellow River Basins of China, the New Guinea highlands, in the Eastern USA, Central Mexico and South America, and in sub-Saharan Africa. And while its impacts were tremendous for people living in places like the Middle East or China, its impacts would have been very different for the early farmers of New Guinea.

The reasons why people took up farming in the first place remain elusive, but dramatic changes in the planet's climate during the last Ice Age — from around 20 000 years ago until 11 600 years ago — seem to have played a major role in its beginnings. The invention of agriculture thousands of years ago led to the domestication of today's major food crops like wheat, rice, barley, millet and maize, legumes like lentils and beans, sweet potato and taro, and animals like sheep, cattle, goats, pigs, alpacas, and chickens. It also dramatically increased the human carrying capacity of the planet. But in the process, the environment was dramatically transformed. What started as modest clearings gave way to fields, with forests felled and vast tracts of land turned over to growing crops and raising animals.

In most places, the health of early farmers was much poorer than their hunter-gatherer ancestors because of the narrower range of foods they consumed alongside widespread dietary deficiencies. At archaeological sites like Abu Hereyra in Syria, for example, the changes in diet accompanying the move away from hunting and gathering are clearly recorded. The diet of Abu Hereyra's occupants dropped from more than 150 wild plants consumed as hunter-gatherers to just a handful of crops as farmers.

In the Americas, where maize was domesticated and heavily relied upon as a staple crop, iron absorption was consequently low and dramatically increased the incidence of anaemia. While a rice-based diet, the main staple of early farmers in southern China, was deficient in protein and inhibited vitamin A absorption.

There was a sudden increase in the number of human settlements signalling a marked shift in population. While maternal and infant mortality increased, female fertility rose with farming, the fuel in the engine of population growth. The planet had supported roughly 8 million people when we were only hunter-gatherers. But the population exploded with the invention of agriculture climbing to 100 million people by 5 000 years ago, and reaching 7 billion people today.

People began to build settlements covering more than ten hectares - the size of ten rugby fields - which were permanently occupied. Early towns housed up to ten thousand people within rectangular stone houses with doors on their roofs at archaeological sites like Çatalhöyük in Turkey. By way of comparison, traditional hunting and gathering communities were small, perhaps up to 50 or 60 people. Crowded conditions in these new settlements, human waste, animal handling, and pest species attracted to them led to increased illness and the rapid spread of infectious disease. Today, around 75% of infectious diseases suffered by humans are zoonoses, ones obtained from or more often shared with domestic animals. Some common examples include influenza, the common cold, various parasites like tapeworms and highly infectious diseases that decimated millions of people in the past such as bubonic plague, tuberculosis, typhoid, and measles.

In response, natural selection dramatically sculpted the genome of these early farmers. The genes for immunity are over-represented in terms of the evidence for natural selection and most of the changes can be timed to the adoption of farming. And geneticists suggest that 85% of the disease-causing gene variants among contemporary populations arose alongside the rise and spread of agriculture.

cont'd

In the past, humans could only tolerate lactose during childhood, but with the domestication of dairy cows, natural selection provided northern European farmers and pastoralist populations in Africa and West Asia the lactase gene. It's almost completely absent elsewhere in the world and it allowed adults to tolerate lactose for the first time. Starch consumption is also a feature of agricultural societies and some hunter-gatherers living in arid environments. The amylase genes, which increase people's ability to digest starch in their diet, were also subject to strong natural selection and increased dramatically in number with the advent of farming.

Another surprising change seen in the skeletons of early farmers is a smaller skull especially the bones of the face. Palaeolithic hunter-gatherers had larger skulls due to their more mobile and active lifestyle including a diet which required much more chewing. Smaller faces affected oral health because human teeth didn't reduce proportionately to the smaller jaw, so dental crowding ensued. This led to increased dental disease along with extra cavities from a starchy diet.

Living in densely populated villages and towns created for the first time in human history private living spaces where people no longer shared their food or possessions with their community.

These changes dramatically shaped people's attitudes to material goods and wealth. Prestige items became highly sought after as hallmarks of power. And with larger populations came growing social and economic complexity and inequality and, naturally, increasing warfare.

Inequalities of wealth and status cemented the rise of hierarchical societies — first chiefdoms then hereditary lineages which ruled over the rapidly growing human settlements.

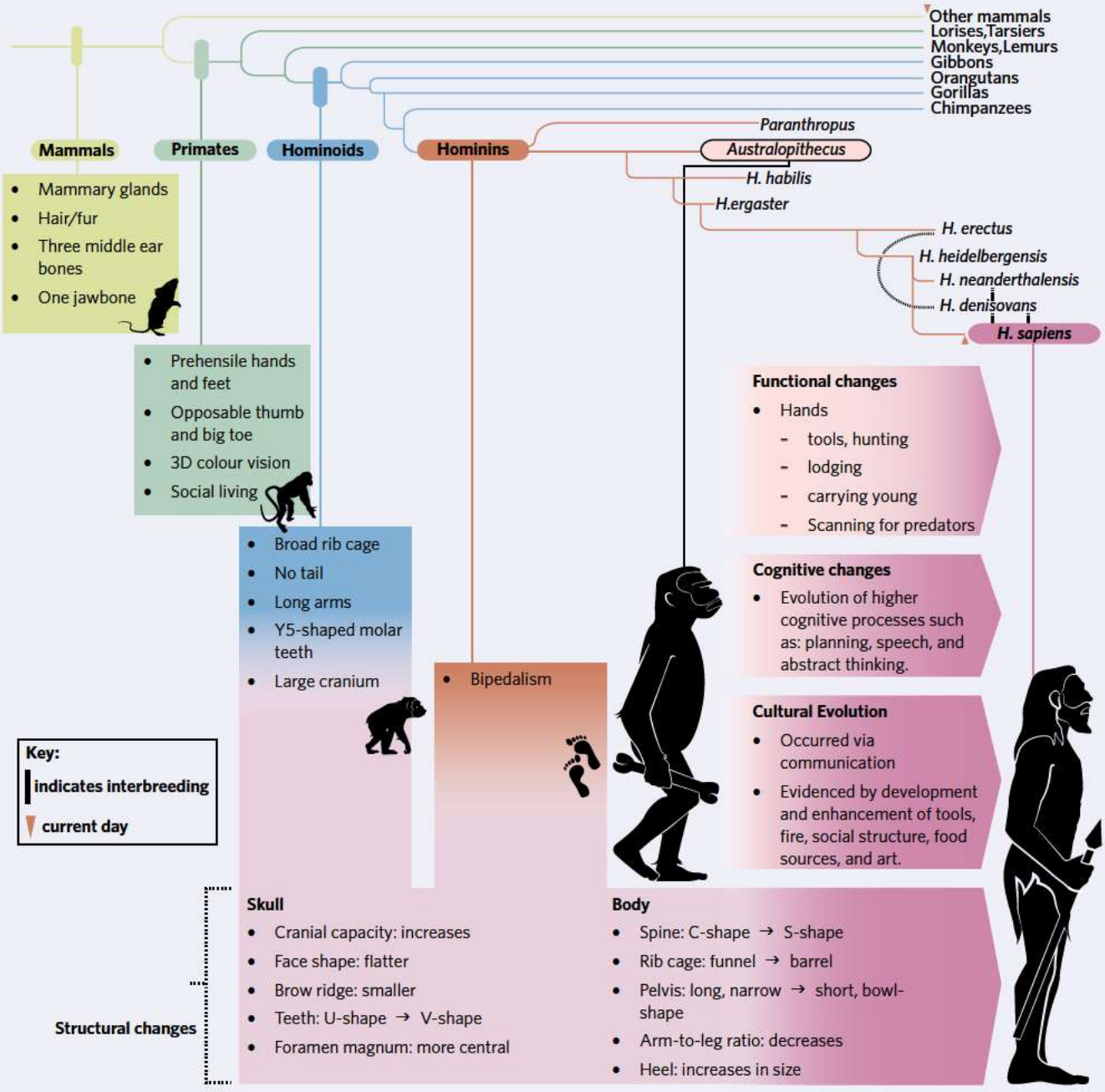
Eventually they expanded to form large cities, and then empires, with vast areas of land taken by force with armies under the control of emperors or kings and queens. This inherited power was the foundation of the 'great' civilisations that developed across the ancient world and into the modern era with its colonial legacies that are still very much with us today.

No doubt the bad well and truly outweighs all the good that came from the invention of farming all those millenia ago. Jared Diamond was right, the invention of agriculture was, without doubt, the biggest blunder in human history. But we're stuck with it, and with so many mouths to feed today we have to make it work better than ever. For the future of humankind and the planet.

Questions

1. Is the author in favour of the development of agriculture, or against it? Justify your response with evidence from the text.
2. For each paragraph, write a title that describes what is in that section of the article.
3. Describe two biological, social, and ethical implications of the invention of farming.
4. Explain why immune genes are over-represented in the human genome.
5. Suggest a reason for the rise of maternal and infant mortality, but also female fertility, as agriculture developed.
6. Explain what the author meant when he wrote '...it wasn't invented just once but actually originated at least seven times, and perhaps 11 times, and quite independently, as far as we know.'
7. Define the term 'carrying capacity'. Why did agriculture increase the planet's carrying capacity?
8. Imagine you are writing a rebuttal to this article entitled 'Was agriculture the greatest success in human history?' Describe two biological, social, and ethical advantages of the invention of farming.

CHAPTER SUMMARY



CHAPTER REVIEW QUESTIONS

SECTION A (9 MARKS)

Question 1 (1 MARK)

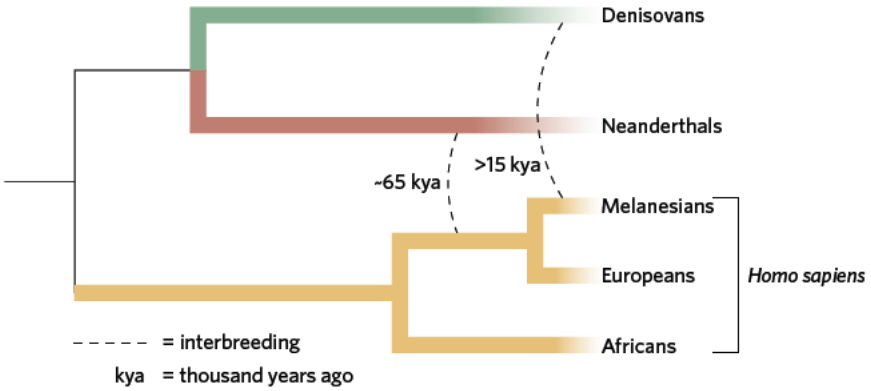
Which one of the following statements about hominin evolution is incorrect?

A *Homo habilis* was bipedal.
B *Homo sapiens* are the last remaining hominin species.
C *Homo sapiens* have the largest cranial capacity of all hominin species.
D It is thought that *Sahelanthropus tchadensis* was our last common ancestor with chimps.

Adapted from VCAA 2018 Section A Q38

Use the following information to answer Questions 2 and 3.

The phylogenetic tree illustrates recent interbreeding events between modern humans, Neanderthals, and Denisovans.



Question 2 (1 MARK)

Based on the information in the tree, which statement is most likely correct?

A Melanesians contain more Neanderthal DNA than Europeans.
B Africans contain Denisovan DNA.
C Neanderthals are more closely related to Europeans than Denisovans.
D Melanesians contain DNA from both Neanderthals and Denisovans.

Question 3 (1 MARK)

Some scientists believe Neanderthals and modern humans are the same species. One piece of evidence supporting this idea is that

A they have similar structural features including a prominent brow ridge and sloping forehead.
B modern humans and Neanderthals were able to mate to produce viable offspring.
C Neanderthal fossils have been found on every continent where modern humans live.
D genetic analysis shows that Neanderthal and modern human mtDNA sequences are indistinguishable.

Question 4 (1 MARK)

With respect to the classification of ancestors and relatives of modern humans, it is true to say that

A all hominoids are also hominins.
B hominins include tarsiers and *Homo sapiens*.
C all hominins are also hominoids.
D hominoids have a tail.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q20

Question 5 (1 MARK)

Which of the following characteristics are shared by all primates?

A Lack of tail, 3D vision, social living

B Opposable thumb, prehensile hands and feet, social living

C Large cranium, Y5-shaped molar teeth, social living

D Long arms, 3D vision, solitary living

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q38

Question 6 (1 MARK)

Scientists have recently discovered that Neanderthals used burial rituals for their dead and used complex tool making methods. These discoveries suggest that Neanderthals

A lived in large societies.

B had large brains.

C were bipedal.

D understood how to use fire.

Adapted from VCAA 2017 Section A Q36

Question 7 (1 MARK)

In regards to hominin evolution, evidence of cultural evolution could include

A a skull with a large cranial capacity.

B thumb bones that suggest an opposable hand.

C a bowl-shaped pelvis.

D cave paintings.

Adapted from VCAA 2018 Section A Q40

Use the following information to answer Questions 8 and 9.

A hominin species, *Homo floresiensis,* was identified from fossils found on an isolated Indonesian island. These fossils were dated to be 18 000 years old.

The adult skull of this upright bipedal hominin had a cranial volume less than one-third of the average cranial volume of a modern adult human. It had harder, thicker eyebrow ridges than *Homo sapiens*, a sharply sloping forehead and no chin.

H. floresiensis was just over one metre tall and their arm-to-leg ratio was slightly larger than modern humans. They weighed approximately 16 kg.

The fossils were found in sediment that also contained stone tools and fireplaces for cooking. The fireplaces contained the burnt bones of animals, each animal weighing more than 350 kg. The stone tools included blades, spearheads, and cutting and chopping tools.

Question 8 (1 MARK)

The evidence and current theories of hominin evolution indicate that

A *H. floresiensis* had complex art and burial rituals, suggesting a well-developed culture.

B the short stature and low body weight of *H. floresiensis* suggest they interbred with *H. sapiens*.

C the ability of *H. floresiensis* to hunt and cook animals up to 350 kg in size suggests social cooperation.

D the dating of *H. floresiensis* fossils to 18 000 years old suggests they are close relatives to *Homo denisova*.

Adapted from VCAA 2014 Section A Q39

Question 9 (1 MARK)

Which of the following structural features would suggest *H. floresiensis* is from the genus *Homo* and not the genus *Australopithecus*?

A A barrel-shaped ribcage

B A C-shaped spine

C Large canine and molar teeth

D A large arm-to-leg ratio

SECTION B (31 MARKS)

Question 10 (4 MARKS)

The following pictures show the skeletons of two primate species.

Image: Morphart Creation/Shutterstock.com

Species 1 **Species 2**

a Which of the two species is more related to *Homo sapiens*? (1 MARK)

b Identify one characteristic of this skeleton that supports your answer. (1 MARK)

c Would species 2 have sat upright? Explain your answer. (2 MARKS)

Question 11 (4 MARKS)

The development of bipedalism in hominins is believed to have had a very significant effect on human evolution.

a Describe two structural changes that have taken place in hominin evolution as a result of bipedalism. (2 MARKS)

b Describe two behavioural effects of bipedalism on hominin behaviour and explain how becoming bipedal led to these behaviours. (2 MARKS)

Adapted from VCAA 2014 Section B Q11d

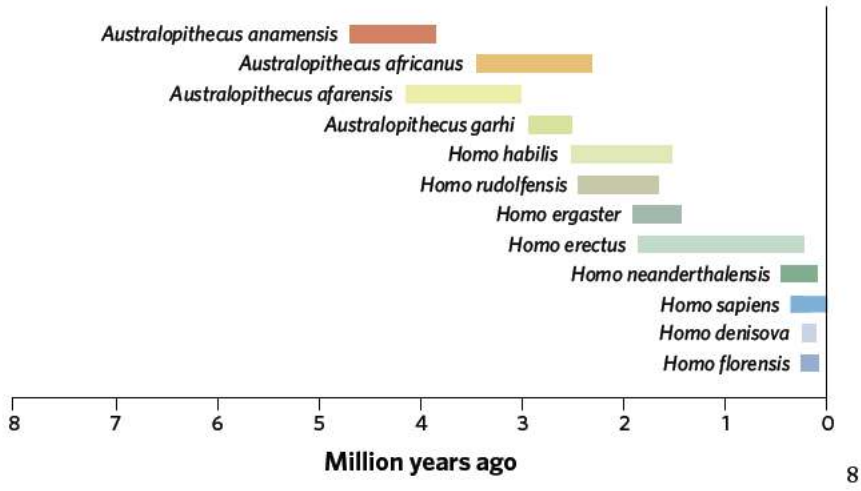
Question 12 (6 MARKS)

In 2013, about 1 500 fossil bones of a hominin species were found in a cave in South Africa. From these bones, scientists have managed to construct an almost-complete skeleton. The fossil bones have some features in common with those of the genus *Australopithecus*; however, there are enough similarities to the genus *Homo* that scientists classified the fossil skeleton as belonging to a new species, *Homo naledi*.

a What are two features that the fossil skull would need to have in order to be classified in the genus *Australopithecus* and not in the genus *Homo*? (2 MARKS)

b Calculating the age of these *H. naledi* fossils has been both difficult and controversial. A group of scientists claims that the fossil is more than 2 million years old, suggesting that *H. naledi* might be a 'link' between *Australopithecus* and *Homo*.

A second group of scientists has calculated the age of the *H. naledi* fossils to be only about 900 000 years and claims that *H. naledi* cannot be the 'link' between *Australopithecus* and *Homo*. The diagram indicates the time periods for different *Australopithecus* and *Homo* species.



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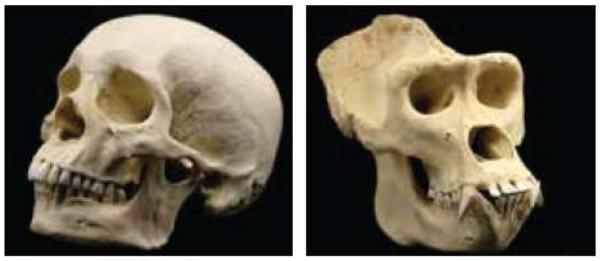
i If the first group of scientists correctly estimated the age of the *H. naledi* fossils to be over 2 million years old, what evidence from the graph would support this group's claim that *H. naledi* might be the 'link' between *Australopithecus* and *Homo*? (2 MARKS)

ii Scientists hypothesise that interbreeding was likely to have occurred between *Homo neanderthalensis* and Eurasian *Homo sapiens*. However, populations of *Homo sapiens* from Africa are believed not to have interbred with *Homo neanderthalensis*. Describe a method that would provide evidence to test the hypothesis that *Homo neanderthalensis* interbred with Eurasian *Homo sapiens* but not African *Homo sapiens*. (2 MARKS)

Adapted from VCAA 2017 Section B Q7

Question 13 (4 MARKS)

The following pictures show two primate skulls. One is a gorilla skull, the other is a *Homo sapiens* skull.



Images: uzuri/Shutterstock.com

Skull A **Skull B**

a Which of the two skulls is the gorilla skull? (1 MARK)

b Describe three features of the gorilla skull that distinguish it from that of *Homo sapiens*. (3 MARKS)

Question 14 (4 MARKS)

Between 2007 and 2015, fossil bones of a hominin species were found in a cave in the Philippines. The bones were a collection of worn adult teeth from one or two individuals, one foot and two toe bones, two finger bones, and the fragment of the shaft of a juvenile thigh bone. The fossil bones have some features in common with both the *Australopithecus* genus and the *Homo* genus.

a What are two skull features the hominin would need to have in order to be classified in the genus *Australopithecus* and not in the genus *Homo*? (2 MARKS)

b What are two non-skull features the hominin would need to have in order to be classified in the genus *Australopithecus* and not in the genus *Homo*? (2 MARKS)

Adapted from VCAA 2017 Section B Q7a

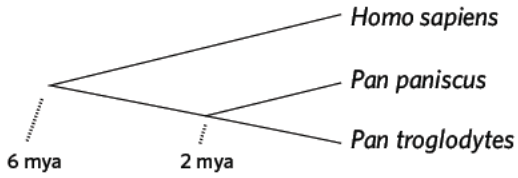
Question 15 (9 MARKS)

In 2008, two incomplete, fossilised skeletons were found in cave deposits in South Africa. The scientists compared the newly discovered bones with those of members of the genus *Australopithecus*, early *Homo*, modern humans, and apes.

a What two skeletal features would indicate the species lived primarily in trees? (2 MARKS)

b Additionally, scientists were attempting to indicate whether the species would have had a culture. What feature of the fossil could be used to determine this, and how could it suggest that the species was capable of cultural evolution? (2 MARKS)

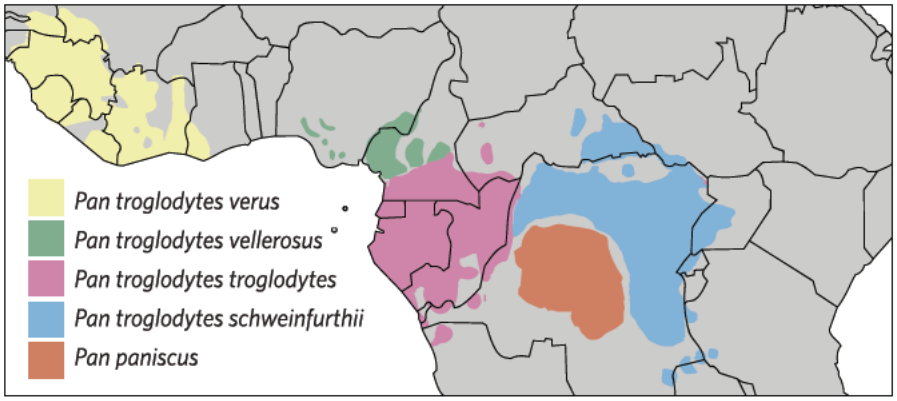
c It was found that these fossils came from a common chimpanzee, *Pan troglodytes*. Common chimpanzees are the closest living relatives to bonobos, *Pan paniscus*, and shared a common ancestor with them until diverging around 2 million years ago. The ancestor of these two chimp species diverged from our human ancestor around 6 million years ago.



Identify two methods that could be used to calculate the relatedness between humans, bonobos, and common chimpanzees. (2 MARKS)

d The genomes of various individuals from different bonobo and common chimpanzee populations were sequenced and compared to one another.

Astonishingly, scientists found that in some subspecies of chimpanzees (*P. t. troglodytes* and *P. t. schweinfurthii*) one percent of the chimpanzee genome is shared with bonobos. The map shows the distribution of common chimpanzee subspecies and bonobos.



Propose a hypothesis to account for the shared DNA in both bonobos (*Pan paniscus*) and some subspecies of common chimpanzees. Use geographic and genetic evidence to support your hypothesis. (3 MARKS)

BONUS – CARTOON QUESTIONS

A group of evolutionary biologists working out of Edrolo Headquarters recently discovered a new hominin species called *Homo douchensis*. The scientists were able to trace the evolution of *Homo douchensis* to an early ancestor and, using advanced computer modelling, were able to represent the evolution of modern *Homo douchensis* from this ancestor as a flip-cartoon. This cartoon has been included in pages 326 to 555 of this book.

A key behavioural feature of *Homo douchensis* is their tendency to teach and share their knowledge of biology with another recently discovered hominin species, *Homo edroller*, via a series of comprehensive online videos.

Multiple choice questions

Question 1 (1 MARK)

Which of the following structural features would you expect to see in *Homo douchensis* when compared to *Australopithecus afarensis*?

A. **a flatter foot**

B. **a C-shaped spine**

C. **an increased arm to leg ratio**

D. **a shorter, bowl-shaped pelvis**

Question 2 (1 MARK)

Homo douchensis' transferring of basic biology theory to the young *Homo edroller* is an example of cultural evolution. Which of the following is most important in the development of cultural evolution?

A. **the ability to use tools**

B. **barrel-shaped chests**

C. **language**

D. **cooking**

Short answer questions

Question 3 (2 MARKS)

Describe two effects of bipedalism on the behaviour of *Homo douchensis'* ancestors.

Question 4 (4 MARKS)

Compared to *Homo sapiens*, *Homo douchensis* has a much larger cranial capacity. Amongst hominins, larger cranial capacity is typically associated with an increased ability for abstract thinking. Using the theory of natural selection, describe how *Homo douchensis* evolved to have such a large cranial capacity compared to *Homo sapiens*.

UNIT 4

AOS2

How do humans impact on biological processes?

In this area of study students examine the impact of human culture and technological applications on biological processes. They apply their knowledge of the structure and function of the DNA molecule to examine how molecular tools and techniques can be used to manipulate the molecule for a particular purpose. Students describe gene technologies used to address human issues and consider their social and ethical implications. Scientific knowledge can both challenge and be challenged by society. Students examine biological challenges that illustrate how the reception of scientific knowledge is influenced by social, economic, and cultural factors.

Outcome 2

On completion of this unit the student should be able to describe how tools and techniques can be used to manipulate DNA, explain how biological knowledge is applied to biotechnical applications, and analyse the interrelationship between scientific knowledge and its applications in society.

Image: unoL/Shutterstock.com

UNIT 4 AOS 2, CHAPTER 15

DNA manipulation

15

15A Enzymes that cut, paste, and multiply DNA

15B Polymerase chain reaction

15C Gel electrophoresis

15D Bacterial transformation

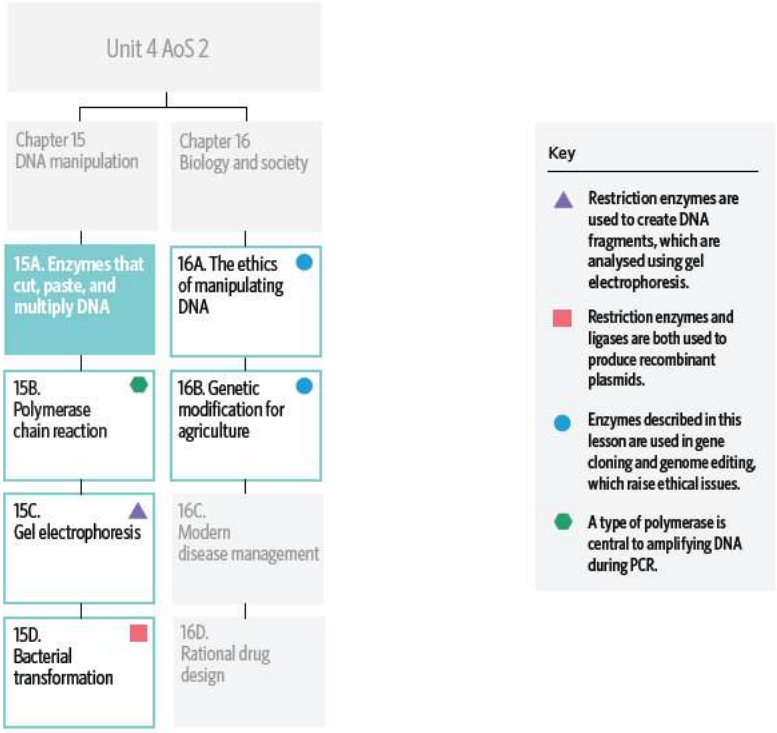
Key knowledge

- the use of enzymes including endonucleases (restriction enzymes), ligases, and polymerases
- amplification of DNA using the polymerase chain reaction
- the use of gel electrophoresis in sorting DNA fragments, including interpretation of gel runs
- the use of recombinant plasmids as vectors to transform bacterial cells

Image: Alexander Raths/Shutterstock.com

15A ENZYMES THAT CUT, PASTE, AND MULTIPLY DNA

Once upon a time, enzymes were free to live their natural lives catalysing reactions as they pleased. Then, one day, humans enslaved them and repurposed them for all sorts of roles, including cutting and pasting DNA for science experiments.



In this lesson you will learn how humans cut, paste, and multiply DNA using enzymes.

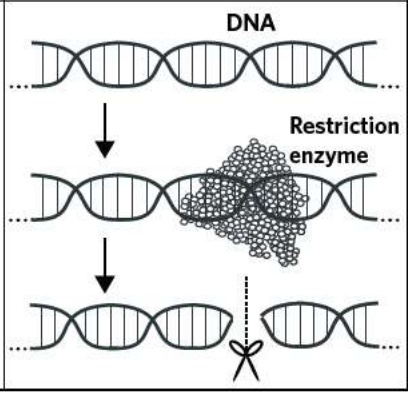
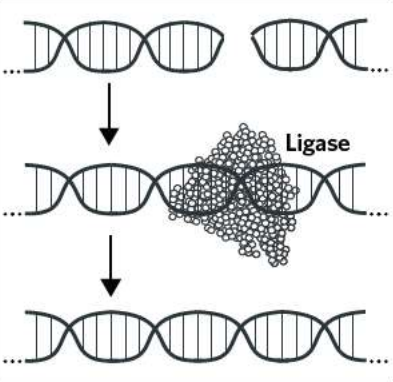
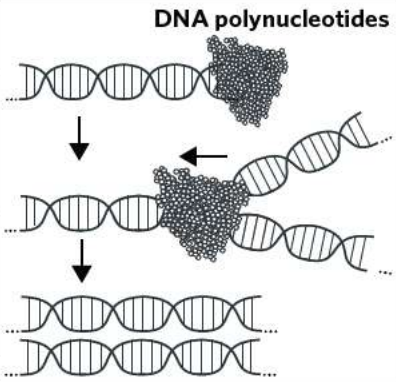
Study design dot point

- the use of enzymes including endonucleases (restriction enzymes), ligases, and polymerases

Key knowledge units

Restriction enzymes	4.2.1.1
Ligases	4.2.1.2
Polymerases	4.2.1.3

Table 1 Overview of enzymes that scientists use to manipulate DNA

Enzyme	Restriction enzyme	Ligase	Polymerase
Action	Cut DNA at a specific recognition site	Join (or *paste*) two fragments of DNA	Amplify (or *multiply*) sections of DNA or entire polynucleotides
Diagram			

Restriction enzymes 4.2.1.1

OVERVIEW

Scientists use a range of different 'molecular scissors' known as restriction enzymes to cut DNA at specific sites.

THEORY DETAILS

Restriction enzymes, a type of **endonuclease**, are enzymes that detect specific **recognition sites** and cut strands of DNA. To 'cut' the DNA, these enzymes cleave the phosphodiester bond of the sugar-phosphate backbone that holds DNA nucleotides together. Some scientists refer to this 'cutting' process as a 'restriction enzyme digestion'.

Restriction enzymes are sourced from bacteria, where they are produced as a defence mechanism to attack invading viral DNA that could harm the bacteria. The names of restriction enzymes are based on the bacteria in which they were discovered (e.g. EcoRI was discovered in *E. coli*).

The recognition site of a restriction enzyme, which is usually four to six nucleotides in length, is specific to each enzyme. Generally, recognition site sequences are palindromes, which means the 5' to 3' sequence of the template strand is the same as the 5' to 3' sequence of the non-template strand (Table 2).

Table 2 Recognition sites for some common restriction enzymes. You can see that EcoRI and HindIII create sticky ends, while AluI and HaeIII create blunt ends.

Restriction Enzyme	Recognition Sequence (read in 5' to 3' direction)
EcoRI	5' G* A A T T C 3' 3' C T T A A *G 5'
HindIII	5' A* A G C T T 3' 3' T T C G A *A 5'
AluI	5' A G* C T 3' 3' T C* G A 5'
HaeIII	5' G G* C C 3' 3' C C* G G 5'

Key

* = cut site

Restriction enzymes either create **sticky ends** or **blunt ends**. Blunt end restriction enzymes, such as AluI, cut DNA in the middle of the recognition site, which results in a straight cut and no overhanging nucleotides. Sticky end restriction enzymes, such as EcoRI, do not cut in the middle of the recognition site, resulting in a staggered cut with overhanging, unpaired nucleotides (Figure 1). They are called 'sticky' because the unpaired nucleotides will be attracted to, or want to stick to, a complementary set of unpaired nucleotides.

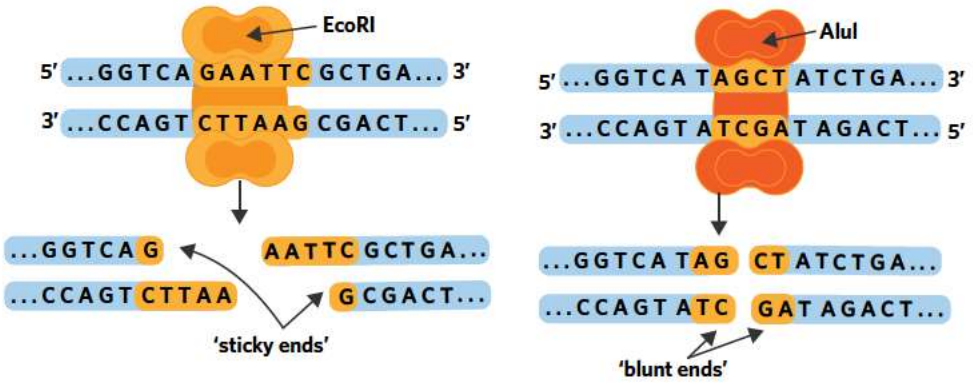


Figure 1 The action of restriction enzymes EcoRI and AluI at their recognition sites on a fragment of linear DNA. Note that EcoRI creates sticky ends, but AluI creates blunt ends.

restriction enzyme a bacterially-produced enzyme that acts like molecular scissors to cut nucleic acid strands at specific recognition sites. They are a type of endonuclease

endonuclease any enzyme that acts like molecular scissors to cut nucleic acid strands at specific recognition sites

recognition site a specific target sequence of DNA upon which a restriction enzyme acts

sticky end a staggered cut (rather than straight cut) by a restriction enzyme resulting in overhanging nucleotides

blunt end a straight cut by a restriction enzyme resulting in no overhanging nucleotides

plasmid a small, circular loop of DNA that is separate from a chromosome, typically found in bacteria

lesson link In ***15D***, you will learn about gene cloning. A key part of gene cloning is using a restriction enzyme to cut a **plasmid** and a gene, then inserting the gene into the plasmid. The advantage of using restriction enzymes that create sticky ends in this process is that the gene can only fit into the plasmid in one direction. If both the gene and the plasmid have blunt ends, the gene can be inserted back-to-front. This would affect how the inserted gene is transcribed and translated.

Tip Sometimes VCAA exams will ask you to determine how many fragments a piece of DNA will be cut into given a certain number of recognition sites. Be careful! For circular DNA like plasmids, the number of fragments will equal the number of recognition sites. For linear DNA, the number of fragments will equal the number of recognition sites plus one.

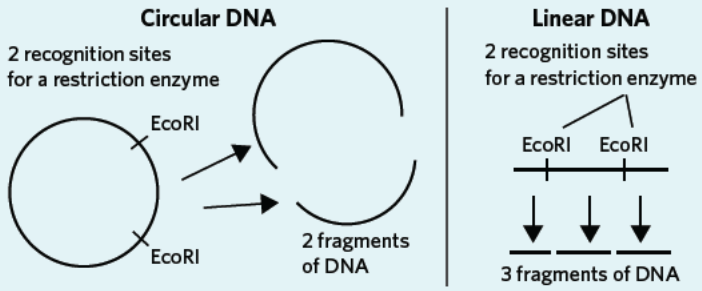


Figure 2 For circular DNA, two recognition sites leads to two fragments. For linear DNA, the same number of recognition sites leads to three fragments of DNA.

ligase an enzyme that joins two DNA or two RNA fragments together by catalysing the formation of phosphodiester bonds

polymerase an enzyme that synthesises a polymer from monomers, such as forming a DNA strand from nucleic acids

primer a short, single strand of nucleic acids that act as a starting point for polymerase enzymes to attach

Ligases 4.2.1.2

OVERVIEW

Ligases are enzymes that can join two fragments of DNA or RNA together.

THEORY DETAILS

Ligases are enzymes that join two fragments of DNA or RNA. To do this, the enzyme will catalyse the formation of phosphodiester bonds between the two fragments to merge them together. Essentially, ligase enzymes do the reverse of restriction enzymes. However, ligases lack the specificity of restriction enzymes - they can join together any blunt or sticky-ended nucleotides. There are two types of ligase enzymes: DNA ligase, which joins two DNA fragments, and RNA ligase, which joins two RNA fragments.

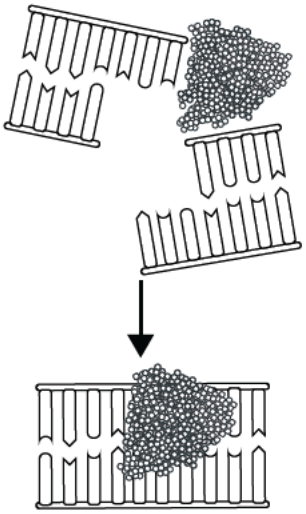


Figure 3 DNA ligase joining two sticky end DNA fragments together

Polymerases 4.2.1.3

OVERVIEW

Polymerases add nucleotides to DNA or RNA, which can lead to copying entire genes, chromosomes, or genomes.

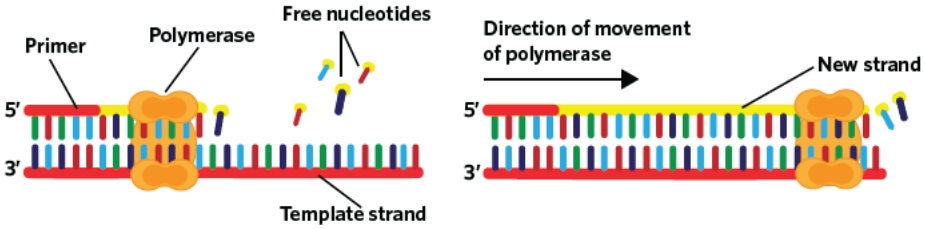


Figure 4 DNA polymerase synthesising a new strand from a template strand

THEORY DETAILS

Polymerases synthesise polymer chains from monomer building blocks. There are two particular polymerases used for gene manipulation: DNA polymerase, which builds up DNA strands, and RNA polymerase, which creates RNA strands.

Polymerases require a **primer** to attach to the start of a template strand of DNA. Primers are single-stranded short chains of nucleotides, usually RNA, that are complementary to the template strand. Once attached to the primer, the polymerase enzyme can read and synthesise a complementary strand to the template strand in a 5' to 3' direction.

lesson link In ***lesson 4C,*** you learnt that RNA polymerase is used to transcribe DNA.

Theory summary

DNA manipulation involves the use of different enzymes to alter DNA. Restriction enzymes can be used to cut DNA at specific recognition sites, ligases join fragments of DNA together, and polymerases synthesise new complementary strands of DNA. During the rest of this chapter, you will learn about scientific techniques that use these enzymes to manipulate DNA.

15A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a type of enzyme that synthesises polymers from monomers
b _____ the result of a staggered cut in a DNA strand by an enzyme
c _____ a protein that joins DNA fragments together
d _____ a type of endonuclease
e _____ a restriction enzyme's specific target sequence
f _____ the result of a linear cut through DNA

Question 2

Complete the following table.

Action	Enzyme
X	Restriction enzymes
Connect	Y
Z	Polymerase enzymes

	X	Y	Z
A	Join	Endonucleases	Multiply
B	Cut	Endonucleases	Amplify
C	Join	Ligase	Sort
D	Cut	Ligase	Multiply

Question 3

Classify the following restriction enzymes as either sticky-end or blunt-end restriction enzymes.

	Restriction Enzyme	Recognition Sequence (read in 5′ to 3′ direction)
I	EcoRI	G* A A T T C C T T A A *G
II	HaeIII	G G* C C C C* G G
III	BamHI	G * G A T C C C C T A G * G
IV	AluI	A G* C T T C* G A
V	HindIII	A* A G C T T T T C G A *A

	Sticky end restriction enzymes	Blunt end restriction enzyes
A	I, II, III, IV	V
B	II, IV	I, III, V
C	I, III, V	II, IV
D	I, III	II, IV, V

Question 4

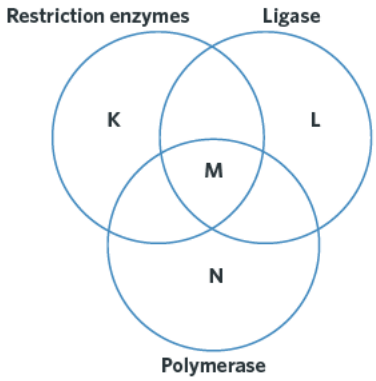
Which of the following statements is false?

A Endonucleases act as molecular scissors.
B Ligases have specific recognition sites.
C Polymerases catalyse the synthesis of polynucleotides.
D Sticky-end endonucleases generate DNA fragments with overhanging nucleotides.

Question 5

Fill in the Venn diagram.

	K	L	M	N
A	Joins fragments together	Requires primer to begin operating	Involves creating a duplicate piece of DNA	Amplifies DNA
B	Specific to a certain base sequence	Joins fragments together	Protein molecule	Requires primer to begin operating
C	Molecular scissors	Only one type	Only acts on DNA	Used in transcription
D	Creates a duplicate piece of DNA	Only acts on DNA	Requires primer to begin operating	Only acts on RNA



Exam-style questions

Within lesson

Question 6 (1 MARK)

The role of DNA ligase is to

A act as molecular scissors and cut DNA at a specific sequence.
B synthesise a strand of DNA complementary to its template.
C join fragments of DNA together by catalysing the formation of phosphodiester bonds.
D unravel double-stranded DNA to allow polymerase to read the template strand.

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q9d

Question 7 (1 MARK)

Enzymes can be used to cut, insert, and amplify genes into circular pieces of DNA known as plasmids. Which of the following options shows the correct function of each enzyme?

	Cuts plasmid	Inserts gene into plasmid	Amplifies plasmid DNA
A	endonuclease	DNA polymerase	DNA ligase
B	endonuclease	DNA ligase	DNA polymerase
C	DNA ligase	endonuclease	DNA polymerase
D	DNA polymerase	DNA ligase	endonuclease

Use the following information to answer Questions 8 and 9.

Genetic engineers use restriction enzymes to cut DNA into smaller fragments. The recognition sites of several restriction enzymes are shown in the table. The symbol * denotes the recognition site (position of the cut).

Restriction Enzyme	Recognition Sequence (read in 5′ to 3′ direction)
EcoRI	G* A A T T C C T T A A *G
HindIII	A* A G C T T T T C G A *A

AluI	A G* ¦ C T T C* ¦ G A
HaeIII	G G* ¦ C C C C* ¦ G G

Question 8 (1 MARK)

Consider a fragment of linear double-stranded DNA with the sequence

5′ **G G C C T A T G A A G C T T G A A** 3′

3′ **C C G G A T A C T T C G A A C T T** 5′

Adding HindIII to a solution containing one copy of this double-stranded DNA produces

A two fragments of double-stranded DNA, each with blunt ends.

B four fragments of single-stranded DNA, each with blunt ends.

C two fragments of double-stranded DNA, each with a sticky end.

D four fragments of single-stranded DNA, each with a sticky end.

Adapted from VCAA 2013 Section A Q29

Question 9 (1 MARK)

Now consider a different length of linear double-stranded DNA with the sequence

5′ **G A A T T C G A A G G T T T A A T G G C T** 3′

3′ **C T T A A G C T T C C A A A T T A C C G A** 5′

Which enzyme(s) will cut this piece of DNA?

A EcoRI only

B HindIII only

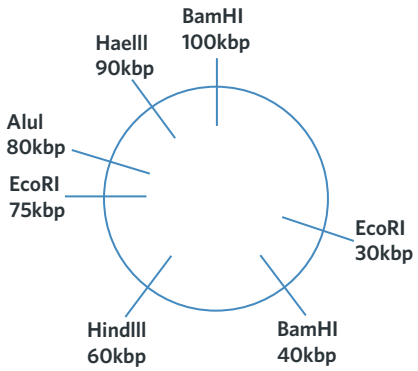
C AluI and HindIII only

D AluI, HindIII, and HaeIII only

Adapted from VCAA 2013 Section A Q30

Question 10 (3 MARKS)

Consider the following circular plasmid that has a total length of 100kbp.
The recognition sites of five different enzymes are shown.



The plasmid was treated with restriction enzymes BamHI, HaeIII, and HindIII.

a What is the role of a restriction enzyme? (1 MARK)

b How many fragments of DNA will be produced? (1 MARK)

c What will be the respective lengths (in kbp) of these fragments? (1 MARK)

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q28

Multiple lessons

Question 11 (6 MARKS)

GloFish are fish that have undergone modifications to their genome by adding a gene encoding green fluorescent protein (GFP) from a fluorescent jellyfish which produces the protein in order to glow. Once this gene is part of the fish's genome, cellular functions occur to produce the protein.

a Identify the process by which a complementary mRNA strand is synthesised from the DNA template strand. (1 MARK)

b Outline the steps of translation in the synthesis of GFP. (3 MARKS)

c In order to insert the gene encoding GFP into fish, it first needs to be isolated from the jellyfish genome. Identify the enzyme that acts as molecular scissors and is required to isolate the gene encoding GFP from the jellyfish genome. (1 MARK)

d Scientists also use DNA ligase enzymes. Outline the role of DNA ligase. (1 MARK)

Adapted from VCAA 2018 Section B Q1a

Key science skills

Question 12 (13 MARKS)

Ahmed and Sunitha are investigating the recognition sites of an unknown restriction enzyme. They have a singular piece of DNA, four different known restriction enzymes, and an unknown enzyme. The sequence of the DNA is:

5' **ATCGATCTTAAGCTTCGAAGGATCCATTCCCGGG** 3'

3' **TAGCTAGAATTCGAAGCTTCCTAGGTAAGGGCCC** 5'

a Given a template strand of DNA, which type of enzyme would aid the process of amplification of a complementary strand? (1 MARK)

b Ahmed sourced the following table from a research article that shows the recognition sites of their four known restriction enzymes.

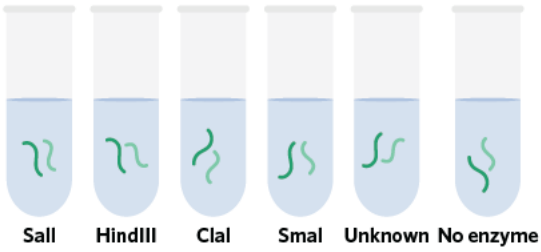
Restriction Enzyme	Recognition Sequence (read in 5′ to 3′ direction)
SalI	G*¦T C G A C C A G C T¦*G
HindIII	A*¦A G C T T T T C G A¦*A
ClaI	A T*¦C G A T T A G C¦*T A
SmaI	C C C*¦G G G G G G*¦C C C

Restriction enzymes can produce either a sticky end or a blunt end.

i Explain what sticky end restriction enzymes are and how they can be useful. (2 MARKS)

ii From the four known restriction enzymes, identify which ones create sticky ends (1 MARK)

c Ahmed and Sunitha successfully multiplied the number of DNA strands and have enough to complete the experiment. They set up six test tubes with identical amounts of DNA buffer solution. The experimental set up is shown.



They added each of the four restriction enzymes into the first four test tubes and the unknown enzyme into the fifth. For the final test tube, no enzyme was added. All of the test tubes were then incubated for one hour to allow the restriction enzymes to digest the DNA samples.

When running the experiment, neither Ahmed or Sunitha made any mistakes.

i Outline the purpose of the test tube without an enzyme and explain how it improves the reliability of the results. (2 MARKS)

ii Apart from amount of DNA buffer solution and incubation time, identify two factors that must be kept constant across the test tubes for the digestion stage of the experiment. (2 MARKS)

iii Ahmed hypothesised that the HindIII sample will see no change to the DNA as the HindIII recognition site is not present in the sample. Sunitha disagrees and believes there will be two fragments of DNA produced from the HindIII sample. Identify who is correct. Justify your response. (2 MARKS)

d Two DNA fragments were produced in the unknown sample. The sequences of these fragments are shown.

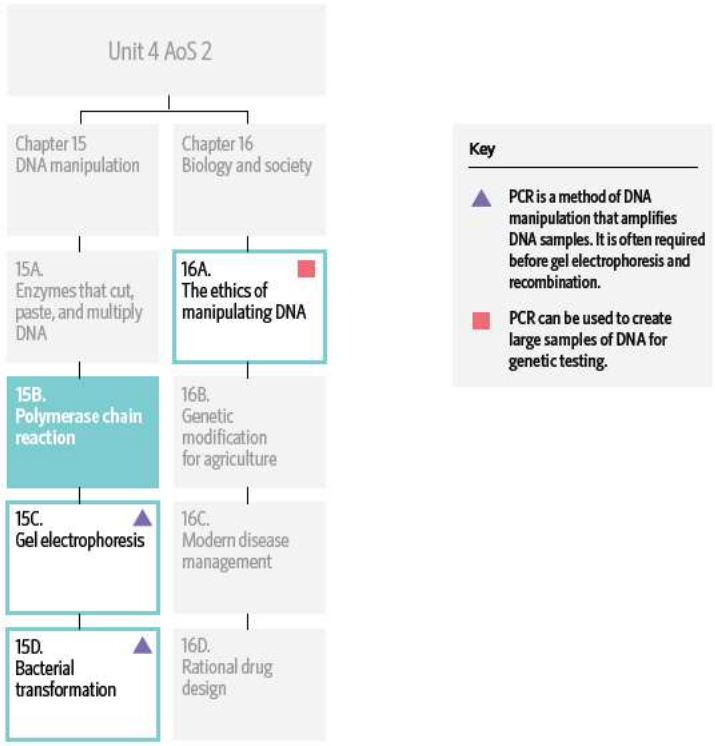
Fragment 1
5′ **ATCGATCTTAAGCTTCGAAG** 3′
3′ **TAGCTAGAATTCGAAGCTTCCTAG** 5′
Fragment 2
5′ **GATCCATTCCCGGG** 3′
3′ **GTAAGGGCCC** 5′

i Explain whether or not Ahmed and Sunitha are able to identify the unknown restriction enzyme. (1 MARK)

ii From the fragments, explain what information Ahmed and Sunitha can extract about the type of restriction enzyme and its recognition site. (2 MARKS)

15B POLYMERASE CHAIN REACTION

Ever wonder how forensic scientists can identify a criminal from just a drop of blood? They use the polymerase chain reaction (PCR).



In this lesson you will learn the purpose and process of the polymerase chain reaction (PCR).

Study design dot point

- amplification of DNA using the polymerase chain reaction

Key knowledge unit

How the polymerase chain reaction works	4.2.2.1

How the polymerase chain reaction works 4.2.2.1

OVERVIEW

PCR is a multistep process that amplifies a sequence of DNA through the use of primers and a polymerase enzyme.

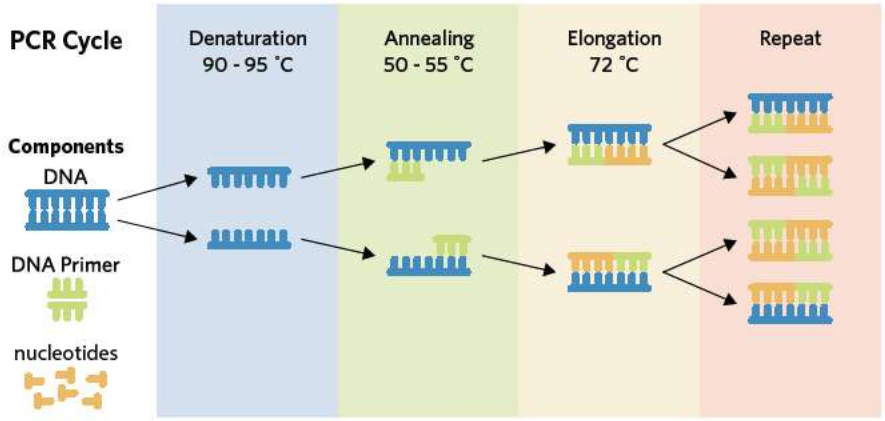


Figure 1 Overview of the polymerase chain reaction

THEORY DETAILS

Purpose of the polymerase chain reaction

PCR is a DNA manipulation technique that **amplifies** DNA by making multiple identical copies. After each cycle of PCR, the amount of DNA present is doubled (Table 1).

When undertaking a PCR cycle, scientists do not usually copy the entire genome. Instead, they focus on certain genes marked by the primers or restriction enzymes to make the process more efficient.

PCR is used whenever there is an insufficient DNA sample for testing. For example, PCR can be applied to:

- forensic testing samples of bodily fluids
- paternity testing
- analysing gene fragments for genetic diseases.

Process of the polymerase chain reaction

PCR is a four-step process that requires the following materials to take place:

- A DNA sample that subsequently gets denatured and amplified through PCR.
- ***Taq* polymerase** (Figure 2) is required in the elongation stage to bind complementary nucleotides to the single-stranded DNA.
- Nucleotide bases must be constantly available for *Taq* polymerase to create a new strand that is complementary to the single-stranded DNA.
- **DNA primers** join to the single-stranded DNA by complementary base pairing to form the first segment of double-stranded DNA, allowing *Taq* polymerase to attach and begin extending the DNA strand.

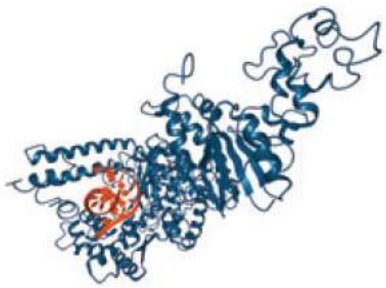


Image: molekuul_be/Shutterstock.com

Figure 2 The 3D-structure of *Taq* polymerase (blue) wrapped around DNA (red)

Image: Vit Kovalcik/Shutterstock.com

Figure 3 Photograph of a PCR cycler machine

To begin PCR, a mixture of the above materials is placed into a thermal cycler (Figure 3), where it undergoes the following processes:

1. **Denaturation stage** – DNA is heated to approximately 94 °C to break the hydrogen bonds and separate the strands, forming single-stranded DNA.
2. **Annealing stage** – The single-stranded DNA is cooled to approximately 55 °C to allow the primers to bind to complementary sequences on the single-stranded DNA.
3. **Elongation stage** – The DNA is heated again to 72 °C which allows *Taq* polymerase to work optimally. It binds to the primer, which acts as a starting region, and begins synthesising a new complementary strand of DNA.
4. Repeat – The cycle (steps 1-3) is repeated multiple times to create more copies of DNA.

Tip **A common mistake on VCAA exams is mixing up the processes of PCR and DNA hybridisation, which you learnt about in 13B. Remember, DNA hybridisation is used to measure relatedness and follows the process of denaturation, hybridisation, and melting. PCR is used to amplify DNA and follows the process of denaturing, annealing, elongation, and repeating.**

Theory summary

The polymerase chain reaction cycle involves 1) denaturation of a small DNA sample, 2) annealing of primers, and 3) the extension of these primers to form double-stranded DNA. This cycle is repeated multiple times to amplify the amount of DNA from a sample.

Table 1 The number of double-stranded DNA molecules per PCR cycle. You can determine the number of double-stranded DNA molecules formed through the formula $x = 2^n$.

Number of cycles (n)	Number of double-stranded DNA (x)
0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	256
9	512
10	1024

polymerase chain reaction (PCR) a laboratory technique that results in the production of many identical copies of DNA over a short period of time through repeated thermal cycling

amplify to make many copies of a molecule

***Taq* polymerase** a heat-resistant DNA polymerase enzyme that amplifies a single-stranded DNA molecule by attaching complementary nucleotides

primer a short, single strand of nucleic acids that act as a starting point for polymerase enzymes to attach

denaturation stage first step in PCR when hydrogen bonds are broken and individual strands of DNA are separated

annealing stage second step in PCR when the primer bonds to a DNA strand by complementary base pairing

elongation stage third step in PCR where nucleotides are added to synthesise a complementary strand of DNA

lesson link In ***15A***, you learnt about polymerase enzymes and their function of synthesising new strands of DNA. *Taq* polymerase is a heat resistant polymerase enzyme that is used in PCR.

15B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a DNA polymerase enzyme that is primarily used in PCR

b _____ a short piece of DNA to which *Taq* polymerase binds

c _____ the stage of PCR that occurs at the hottest temperature

d _____ the joining together of a primer to the single-stranded DNA

Question 2

Which of the following is not required in the mixture for PCR to occur?

A RNA

B *Taq* polymerase

C Nucleotide bases

D Primers

Question 3

Complete the following table displaying the number of double-stranded DNA molecules per PCR cycle.

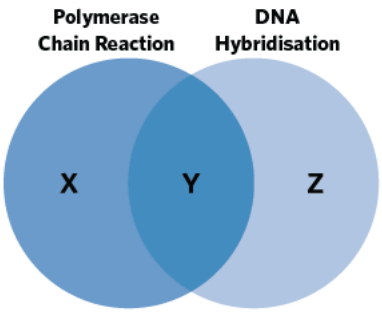
Number of cycles (n)	Number of double-stranded DNA (x)
K	1
2	**L**
M	8
1	**N**

	K	L	M	N
A	0	3	2	1
B	1	4	3	2
C	0	4	3	2
D	1	4	3	1

Question 4

Complete the following Venn diagram outlining the differences and similarities between PCR and DNA hybridisation.

	X	Y	Z
A	Primers are part of the mixture	Both processes involve manipulating the temperature of the DNA samples	*Taq* polymerase synthesises a new strand of DNA
B	*Taq* polymerase synthesises a new strand of DNA	The melting temperature is calculated and analysed	The purpose is to measure the relatedness between samples of DNA
C	The first step is to denature the DNA at high temperatures	The purpose is to amplify the amount of DNA in a sample	Primers are part of the mixture
D	The purpose is to amplify the amount of DNA in a sample	The first step is to denature the DNA at high temperatures	The melting temperature is calculated and analysed



Question 5

Order the following steps in PCR.

1 DNA is cooled to ~ 55 °C which allows the primers to anneal to the DNA strands.

2 The cycle is repeated to produce more copies of the DNA.

3 A strand of DNA from a second species is added to the solution and they hybridise together.

4 DNA is heated to ~ 94 °C to break the hydrogen bonds between strands.

5 *Taq* polymerase begins synthesising when the temperature reaches 72 °C.

A 1, 2, 3, 4, 5
B 4, 1, 5
C 4, 1, 5, 2
D 4, 1, 3, 5, 2

Exam-style questions

Within lesson

Question 6 (1 MARK)

The process known as the polymerase chain reaction (PCR) involves repeated cycles made up of several steps.

During PCR the

A first step of each cycle involves heating the sample to 72 °C.
B second step of each cycle involves cooling the sample to 37 °C.
C third step of each cycle involves *Taq* polymerase synthesising a complementary strand.
D third step of each cycle involves measuring the melting temperature of each sample.

Adapted from VCAA 2017 Section A Q34

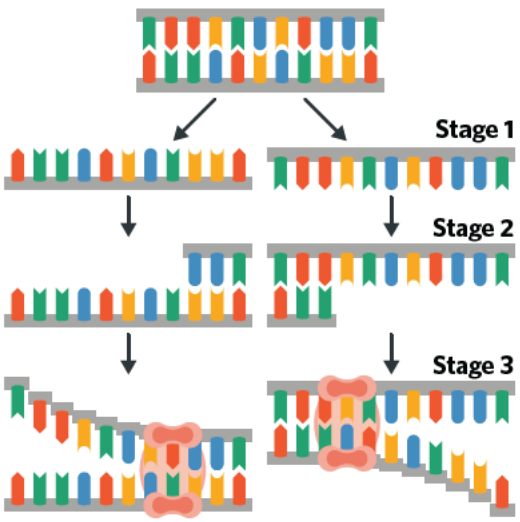
Question 7 (1 MARK)

In the polymerase chain reaction, primers are required to allow *Taq* polymerase to begin copying. Which of the following outlines why two different types of primers are necessary?

A The nucleotide sequence is different at the 5′ ends of the two DNA strands that are copied.
B *Taq* polymerase requires both a start and stop primer.
C Two primers help to show the relatedness between strands of DNA.
D Only one primer is needed, not two, as the DNA is complementary and copied in Okazaki fragments.

Question 8 (6 MARKS)

The following diagram represents a method of DNA manipulation.



a Identify the method shown in the diagram. (1 MARK)

b Outline the process of stage 1. (1 MARK)

c Name and explain why the smaller DNA strands are added to the mixture and used in stage 2 of this process. (2 MARKS)

d Stage 3 of this process must occur at a specific temperature. State this temperature and explain why it is required. (2 MARKS)

Multiple lessons

Question 9 (1 MARK)

The following diagram represents a DNA molecule and the positions of the recognition sites for the restriction enzymes BamHI, EcoRI, HaeIII, and SalI.

Restriction enzymes

A cut DNA fragments at specific recognition sites.

B join DNA fragments at specific recognition sites.

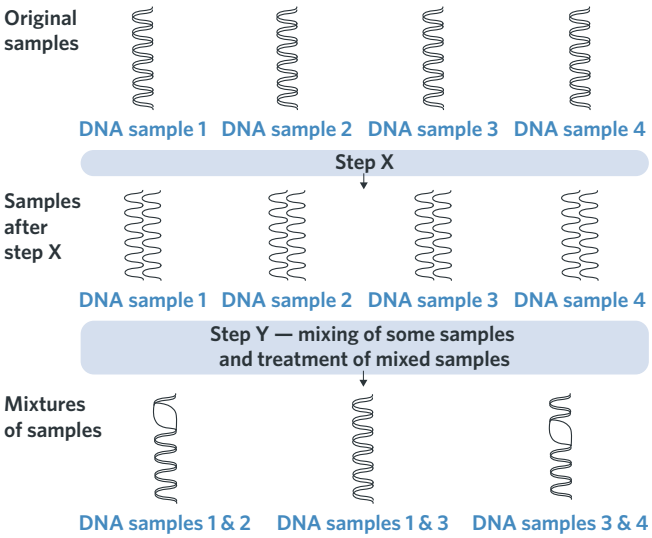
C amplify DNA fragments at specific recognition sites.

D duplicate DNA fragments at specific recognition sites.

Adapted from VCAA 2017 Section A Q38

Question 10 (1 MARK)

Samples of DNA were taken from four individuals. The sample went through a series of steps and the resulting DNA is shown.



The method represented is

A restriction enzymes.

B the polymerase chain reaction.

C DNA hybridisation.

D transcription.

Adapted from VCAA 2013 Section A Q33

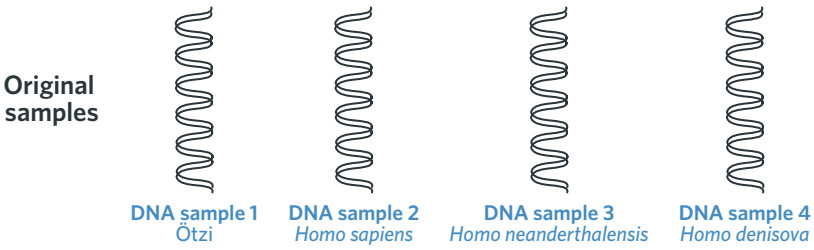
Question 11 (8 MARKS)

In 1991, the body of a man was found frozen beneath a glacier in Italy. Researchers named him Ötzi. Ötzi is one of the oldest mummified hominin bodies ever found. Scientists have successfully extracted DNA from the nuclei of his frozen cells, however, they could only extract a small amount.

a Identify the process used to amplify DNA. (1 MARK)

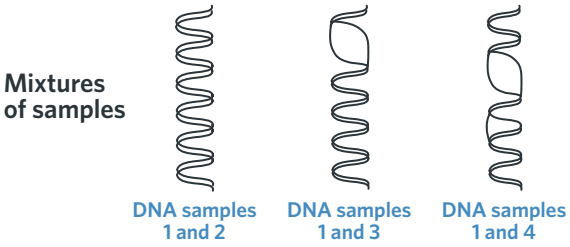
b Identify and explain the purpose of one of the substances that must be added to the mixture for the amplification of DNA to occur. (2 MARKS)

c Scientists had to determine which species Ötzi belonged to. To do this, they extracted three samples of DNA from the following species: *Homo sapiens*, *Homo neanderthalensis*, and *Homo denisova*.



i Identify and outline the process used to compare the relatedness of these samples of DNA. (4 MARKS)

ii The results of the process outlined in part ci can be seen in the diagram.



From this information, identify which species Ötzi belongs to. (1 MARK)

Adapted from VCAA 2014 Section B Q11a

Key science skills

Question 12 (9 MARKS)

Mohammad and Rashida are forensic scientists investigating a crime scene. They have found a small amount of DNA and amplified it. The DNA amplification mixture was made up of the specific DNA segment they found, a plentiful supply of four nucleotide bases, *Taq* polymerase, and DNA primers.

a The process to amplify DNA is a three-step process.

i Name the process to amplify DNA. (1 MARK)

ii Briefly describe the steps of this technique. (3 MARKS)

b Mohammad and Rashida completed the process separately. The table outlines the temperatures they used in each step.

Step	Mohammad	Rashida
1	37 °C	94 °C
2	55 °C	55 °C
3	72 °C	72 °C

Mohammad and Rashida compared their results of their DNA amplification and only one of them was successful.

i Identify whose method was unsuccessful. Justify your response. (2 MARKS)

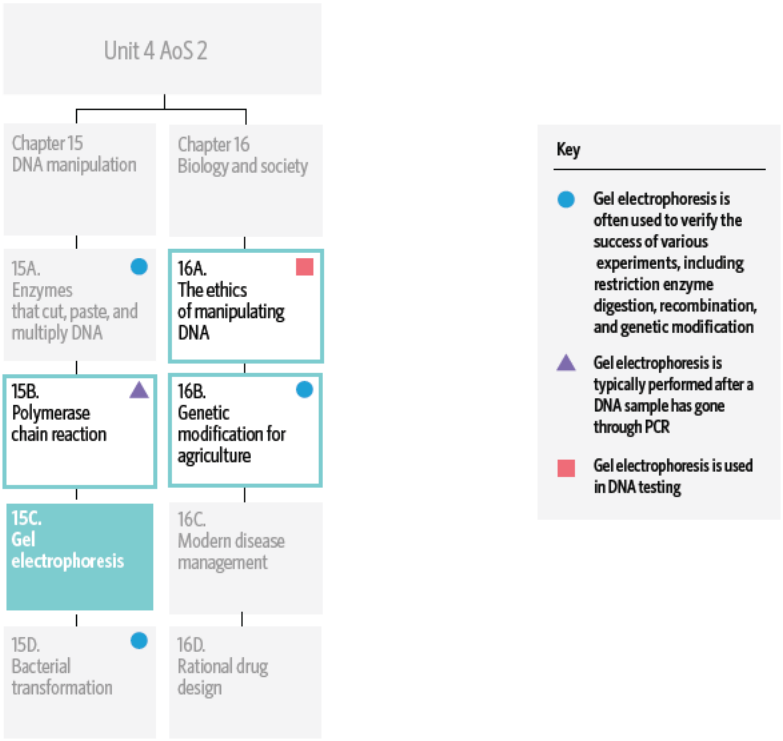
ii The temperature difference occurred because of faulty calibration of the thermal cycler. Given this information, identify the type of measurement error that occurred. (1 MARK)

c Identify one potential factor that Mohammed and Rashida must consider when amplifying the DNA sample. (1 MARK)

d Rashida was teaching the process of PCR to Diego, an eager Year 12 student. Diego did not understand why the DNA primer was necessary. Explain the function of DNA primers in the mixture. (1 MARK)

15C GEL ELECTROPHORESIS

Gel electrophoresis is basically witchcraft. You place your DNA fragments into a piece of jelly and electrocute it. This separates different DNA fragments and, by reading the lines that appear in the jelly, you can determine their size.



In this lesson you will learn how to separate pieces of DNA using gel electrophoresis and how to interpret the data from this experiment.

Study design dot point

- the use of gel electrophoresis in sorting DNA fragments, including interpretation of gel runs

Key knowledge units

How to separate fragments of DNA	4.2.3.1
How to read gels	4.2.3.2

How to separate fragments of DNA 4.2.3.1

OVERVIEW

Gel electrophoresis allows you to separate fragments of DNA that you've prepared using either restriction enzymes or PCR.

THEORY DETAILS

Gel electrophoresis is a laboratory technique used by scientists to measure the size of DNA fragments. It is typically used after a sample of DNA has been cut up using restriction enzymes or after a short sequence of DNA has been amplified using PCR.

gel electrophoresis a technique that separates DNA fragments based on their molecular size

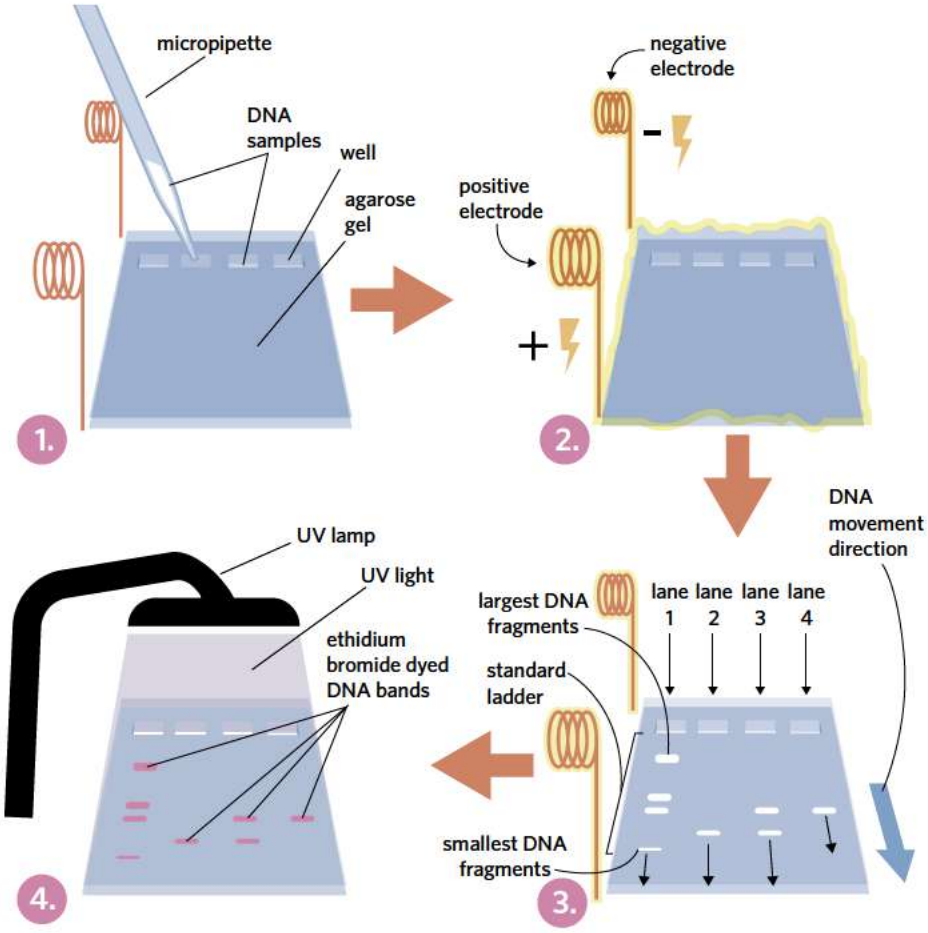


Figure 1 The process of gel electrophoresis

well an indent in the gel into which a DNA sample is loaded

standard ladder a mixture of DNA fragments of known length that are used in order to infer the size of fragments in a sample

agarose gel a sponge-like gel used in gel electrophoresis that contains pores for DNA fragments to move through

buffer an ion-filled solution that carries current through the agarose gel

electrode conductors of electricity that are attached to both ends of a gel allowing a current to pass through it

band a line seen in the gel after running gel electrophoresis that corresponds to a collection of DNA fragments of a specific size

ethidium bromide a fluorescent dye that binds to DNA fragments in a gel and allows them to be visualised

The process of gel electrophoresis is described in the following steps:

1 The DNA samples are placed in the **wells** at one end of the gel using a micropipette. A **standard ladder** is typically loaded into one well which helps with estimating the size of the unknown DNA fragments by comparing them to the known fragments in the standard ladder. The gel is made of **agarose**, a sponge-like jelly that is filled with tiny pores. This agarose gel is immersed in a **buffer** solution which helps carry an electric current.

2 An electric current is passed through the gel using two **electrodes** – one positive, one negative. The negative electrode is near the wells and the positive electrode is at the opposite end of the gel. Since DNA is negatively charged, it is attracted to the positive electrode. DNA fragments will move from the wells, through the tiny pores in the agarose gel, towards the positive electrode.

3 Smaller DNA fragments move faster through the gel and so travel further than larger fragments, which don't move as easily through the pores in the agarose. After a few hours, the current is switched off and the DNA fragments stop moving in the gel and settle into **bands**. The DNA fragments are now separated based on size.

4 The DNA is difficult to see with the naked eye and so the gel must be stained with a fluorescent dye such as **ethidium bromide**, allowing the bands of DNA to be visualised under an ultraviolet (UV) lamp. This dye can be included in the gel before the experiment or applied after.

When gel electrophoresis separates DNA fragments based on size, long fragments of DNA collect in bands of DNA near the well, while shorter fragments form bands further from the well. So, if person A's allele for eye colour is 10 kb long, and person B's allele for eye colour is 15 kb long, person A's band will move further from the well (Figure 2). If they shared the same allele (e.g. person A and C), the bands would end up in the same place.

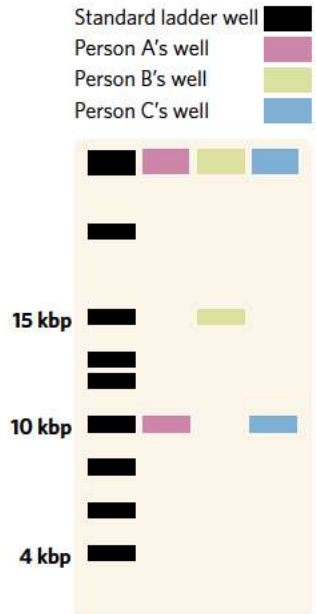


Figure 2 An example of a gel comparing persons A, B, and C against a standard ladder

It's important to note that each band in the gel actually contains thousands of fragments of DNA, all of the same molecular size. The DNA sample loaded into the well is usually a mixture of different DNA fragments. This allows bands corresponding to a particular size to be cut out of the gel for use in other experiments (Figure 3).

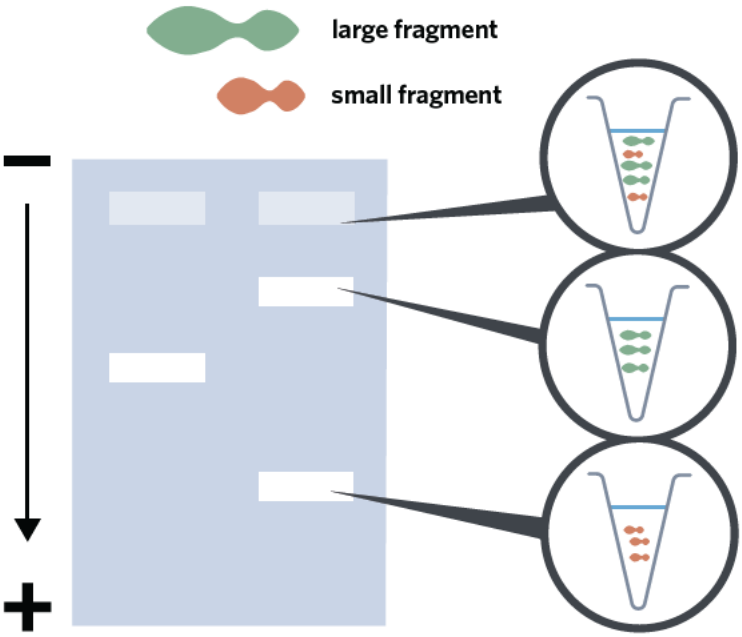


Figure 3 A closer look at a gel electrophoresis experiment

Analogy

What would run through a dense forest faster: an elephant or a fox? While an elephant could plow through, it would be hindered by thick brush and densely packed trees. A fox, however, could squeeze between narrow gaps and dodge obstacles.
The situation is the same for small and large DNA fragments in gel electrophoresis. The small fragments can slip through the pores in the agar gel with ease, while the large fragments get tangled up so travel less distance in the same amount of time.

How to read gels 4.2.3.2

OVERVIEW

Gel electrophoresis is a fundamental laboratory technique and being able to interpret the gels is key to passing exams. Here you will learn how to interpret the results of a gel electrophoresis experiment to determine the size of DNA fragments. You will also look at genotyping as a practical application of gel electrophoresis to help solidify your understanding.

THEORY DETAILS

A standard ladder contains a number of DNA fragments with a known molecular size. Molecular size indicates the length of a nucleic acid sequence. The units used are **base pairs (bp)**, representing a single nucleotide, and **kilobases (kb)**, representing 1 000 nucleotides.

In Figure 4, the standard ladder contains five fragments that are known to be 100, 200, 300, 400, and 500 bp. By comparing the other bands in the gel to the standard ladder we can estimate their molecular size. The single band in **lane** 3 lines up with the 500 bp band in the standard ladder, indicating that the DNA fragments in this band are 500 nucleotides long.

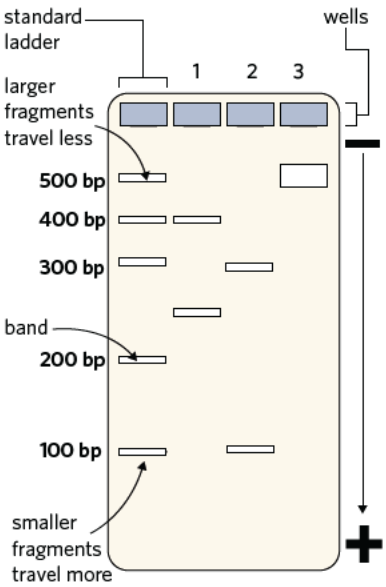


Figure 4 A typical gel electrophoresis result

Lanes 1 and 2 both contain two bands of DNA. Each band represents fragments of a particular size that were present in that DNA sample. The molecular sizes of the DNA in the two bands in lane 1 are roughly 250 and 400 bp and the two bands in lane 2 are roughly 100 and 300 bp. You may notice the band in lane 3 is also thicker than the bands in the other lanes. This means that particular band contains more DNA than the other bands.

Standard ladders are vital because DNA fragments of the same size don't always travel the same distance. Every gel type is different. For example, in one gel a 100 bp fragment may travel 7.8 cm whilst in another gel it may travel 8.6 cm, so length can't be used to measure molecular size. These variations are due to factors such as voltage, time in gel, buffer concentration, and gel composition, which are controlled if you load a standard ladder alongside your samples.

base pair (bp) a unit of measurement that corresponds to one nucleotide

kilobase (kb) a unit of measurement that corresponds to one thousand nucleotides. May also be written as **kbp**

lane the column of gel corresponding to each sample of DNA

Case study

Genotyping is a technique that uses gel electrophoresis to determine the genotype of an organism at a particular allele. Such a technique may be used to determine which alleles fruit flies, a popular lab animal, have at the *Cyp6g1* locus. This gene encodes a protein called cytochrome P450, which plays an important role in metabolism. A large insertion mutation in this gene gives fruit flies resistance to the harmful agricultural insecticide called DDT. The allele conferring DDT resistance, termed *DDT-R* (R), is 243 bp while the wild-type DDT-sensitive allele, termed *DDT-S* (S), is 126 bp. Scientists will design primers that are specific to the *Cyp6g1* gene and use PCR to amplify this region. The PCR products are run using gel electrophoresis to distinguish between these two alleles by separating DNA based on size (Figure 5).

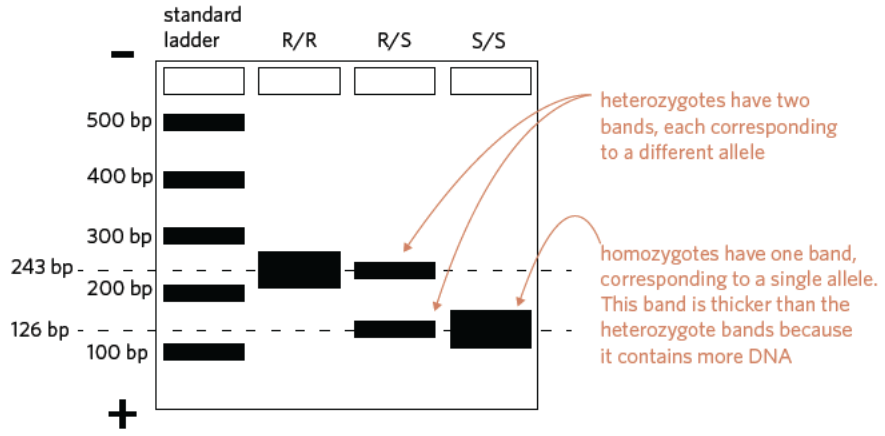


Figure 5 Using gel electrophoresis to identify the genotypes of flies at the *Cyp6g1* locus

It's important to note that identifying alleles using gel electrophoresis only works if they differ in base pair length. Point mutations, for example, are harder to distinguish using gel electrophoresis and require extra steps.

lesson link Gel electrophoresis has many applications, including genotyping, restriction enzyme analysis, bacterial transformation, and DNA profiling, many of which will be explored in the exam-style questions for this lesson as well as in ***lesson 16A.***

Theory summary

Gel electrophoresis uses electricity to separate pieces of DNA based on size. Separating DNA fragments is useful as it allows you to determine:

- how many different sizes or DNA fragments are in your sample
- the size of each fragment in your sample.

These two simple things can be used in a number of ways by scientists to gather information.

15C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ these are attached to both ends of the gel and allow an electric current to run through it

b _____ a collection of fragments of known base pair length in a gel that are used as a reference point for sample DNA fragments

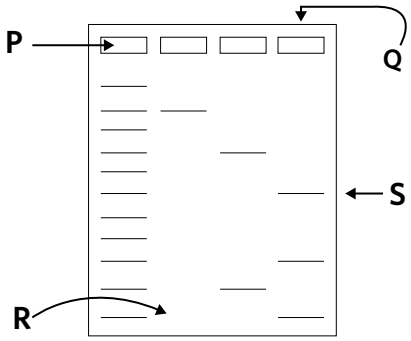
c _____ a lab technique used by scientists to separate fragments of DNA and determine their length

d _____ a measure of the number of nucleotides in a nucleic acid

e _____ a fluorescent dye that is commonly used to visualise DNA in gels

Question 2

The diagram shows the results of a gel electrophoresis experiment. Which group of statements correctly identifies the features labelled P – S in the diagram?



	P	Q	R	S
A	well	lane	agarose gel	band
B	loader	lane	buffer	band
C	well	column	agarose gel	band
D	well	lane	agarose gel	piece

Question 3

The following are the steps involved in setting up a gel electrophoresis experiment. Which option indicates the correct order of these steps?

1 DNA samples are loaded into wells in each lane of the agarose gel.

2 Bands can be cut from the gel and purified for use in further experiments.

3 Gel is submerged in buffer and an electric current is passed through the samples.

4 DNA is prepared using restriction enzymes or PCR.

5 DNA samples are loaded into bands of the agarose gel.

6 Bands are visualised under ultraviolet light.

7 DNA fragments migrate towards the positive electrode.

8 DNA fragments migrate towards the negative electrode.

A 4,1,3,8,6

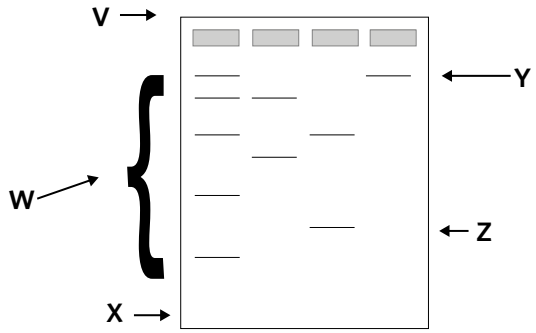
B 4,1,3,7,6,2

C 5,3,7,4,6,2

D 1,3,8,4,6

Question 4

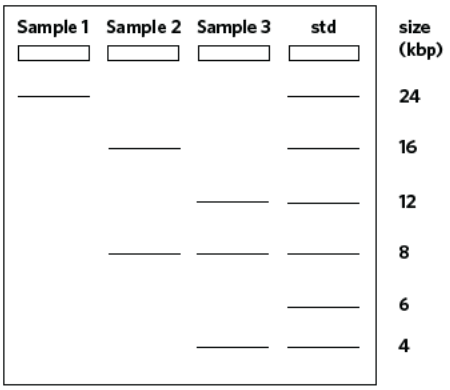
The following diagram shows the results of a gel electrophoresis experiment. Which group of statements correctly identifies the features labelled V – Z in the diagram?



	V	W	X	Y	Z
A	positive electrode	standard ladder	negative electrode	larger fragment	smaller fragment
B	negative electrode	molecular size marker	positive electrode	smaller fragment	larger fragment
C	positive electrode	molecular size marker	negative electrode	smaller fragment	larger fragment
D	negative electrode	standard ladder	positive electrode	larger fragment	smaller fragment

Question 5

The following diagram shows the results of a gel electrophoresis experiment. The fourth lane (labelled std) contains a standard DNA ladder.



Which of the following statements is correct?

A One of the bands in Sample 2 contains DNA fragments that are 16 nucleotides long.

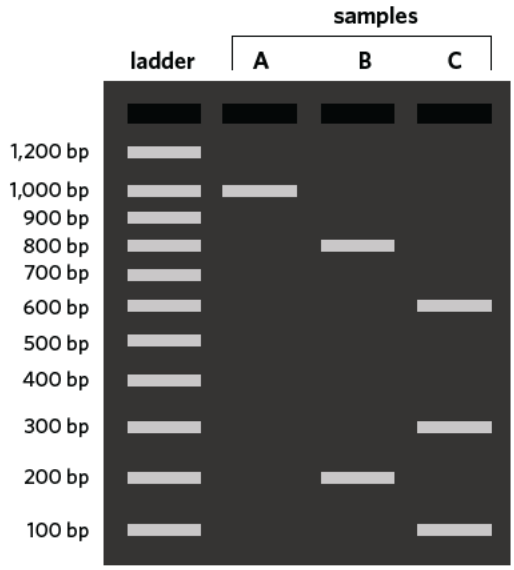
B Sample 2 contains fragments of DNA that are 12 000 nucleotides long.

C Sample 1 contains the smallest DNA fragments of the 3 samples.

D One of the bands in Sample 3 contains DNA fragments of 4 000 bp in size.

Question 6

The following diagram shows the results of a gel electrophoresis experiment.



Which of the following statements is correct?

A Sample C contains 3 fragments of 500, 200, and 100 bp in size.

B Sample B contains 2 fragments of 500 and 200 bp in size.

C Sample C contains 3 fragments of 600, 300, and 100 bp in size.

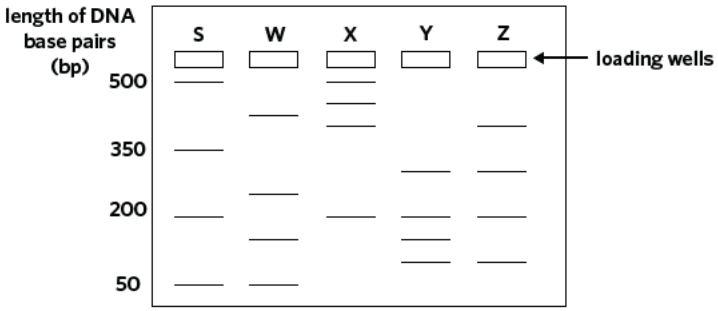
D The lane labelled 'Marker' contains no DNA fragments in it.

Exam-style questions

Within lesson

Use the following information to answer Questions 7 and 8.

Four samples of DNA were loaded into four different wells in lanes W, X, Y, and Z. A standard ladder was loaded into the well in lane S. The following gel electrophoresis shows the results



Question 7 (1 MARK)

Which lane represents a sample that was loaded with DNA fragments of four different lengths: 100, 200, 300, and 400 bp?

A W

B X

C Y

D Z

Adapted from VCAA 2018 Section A Q30

Question 8 (1 MARK)

Which of the following lanes contains the band that is closest to the positive electrode?

A W

B X

C Y

D Z

Adapted from VCAA 2018 Section A Q31

Question 9 (1 MARK)

During a fight between a number of people, one person (victim) was seriously injured. Blood samples were taken from the victim, the crime scene, and four suspects. DNA was extracted from white blood cells in each of the blood samples and gel electrophoresis of the samples was carried out. The results are shown in the following diagram.

The person most likely to have been at the crime scene is

A Suspect 1.

B Suspect 2.

C Suspect 3.

D Suspect 4.

Adapted from VCAA 2013 Section A Q28

Question 10 (7 MARKS)

There were three suspects in an assault case. A forensic scientist found blood, other than the victim's, at the site. DNA was extracted from five blood samples:

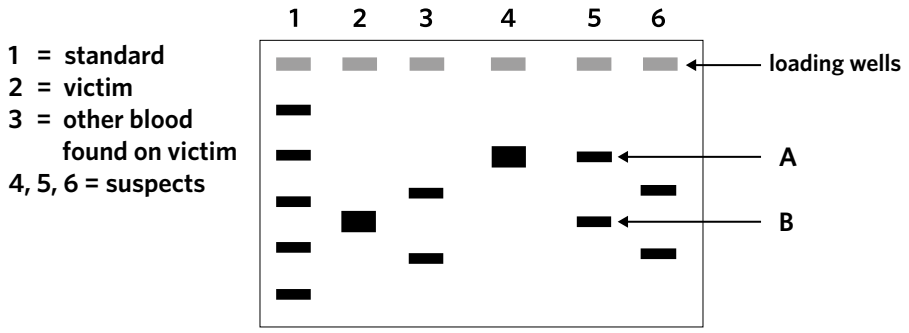
- the victim
- blood found on the victim (not the victim's)
- the three suspects.

Short tandem repeat (STR) sequences were used in forensic analysis. A STR of 4 bases, called D18S51, is located on chromosome 18. This STR has many alleles which differ from each other by the number of times the sequence AGAA is repeated.

DNA from each sample was amplified using PCR and loaded into a gel and electrophoresis was performed to separate the fragments of DNA.

a Name two properties of DNA fragments which allow them to be separated from each other during gel electrophoresis. (2 MARKS)

b The following diagram shows the gel.



i Why is there only one band in lanes 2 and 4 but two bands in lanes 3, 5, and 6? (1 MARK)

ii How many different alleles at the D18S51 locus are represented on the gel in individuals 2 – 6? (1 MARK)

iii Which fragment of DNA, A or B, has the greater number of the 4 base repeat sequence? (1 MARK)

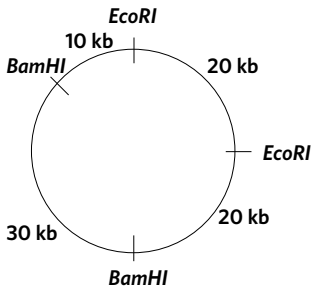
iv Based on the data, which of the suspects committed the assault? Justify your response. (2 MARKS)

Adapted from VCAA 2002 Exam 2 Section B Q5

Multiple lessons

Question 11 (1 MARK)

The following diagram represents a plasmid and the position of recognition sites for the restriction enzymes BamHI and EcoRI.



A plasmid cut with BamHI was run using gel electrophoresis. How many bands would appear on the gel?

A 1

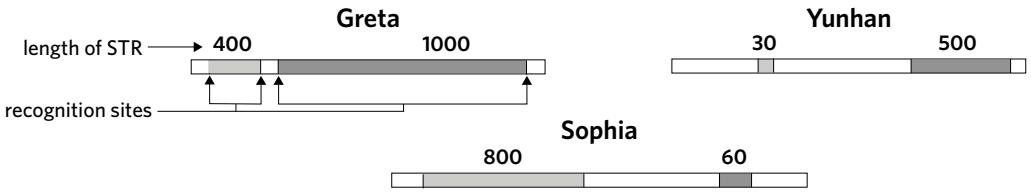
B 2

C 3

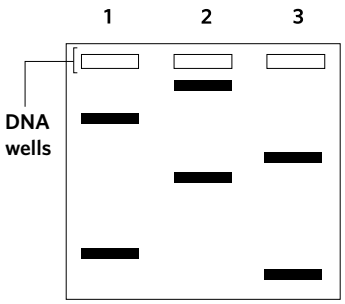
D 4

Question 12 (1 MARK)

Scientists analysed the DNA samples of three students: Greta, Yunhan, and Sophia. Two short tandem repeats (STRs) that are unique to each individual were investigated. Each student's DNA was digested using a restriction enzyme. The length of each STR for each student is shown in the following diagram.



The DNA of each student was separated using gel electrophoresis and the positions of the STRs were observed. STRs were marked with a fluorescent probe and were the only visible bands in the gel. The results are shown in the following diagram of the electrophoresis gel.



From the results and the information provided for each student, it can be concluded that the DNA in wells 1, 2, and 3 respectively belong to

A Yunhan, Greta, and Sophia.

B Yunhan, Sophia, and Greta.

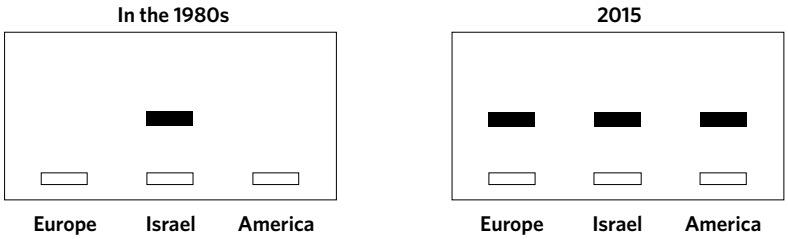
C Sophia, Yunhan, and Greta.

D Sophia, Greta, and Yunhan.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q26

Question 13 (1 MARK)

The wheat leaf blotch pathogen, *Mycosphaerella graminicola*, is present in many parts of the world. The spores of the pathogen can be carried in the wind and on exported wheat. The following diagrams show gels of the shared allele at a particular locus, termed the restriction fragment length polymorphism (RFLP), in *M. graminicola* populations from three locations.



With respect to *M. graminicola*, which conclusion is supported by the data?

A Genetic drift in isolated populations has allowed present-day wheat crops to become infected by *M. graminicola.*

B Random mutations have arisen within Europe and America that have made wheat more susceptible to *M. graminicola.*

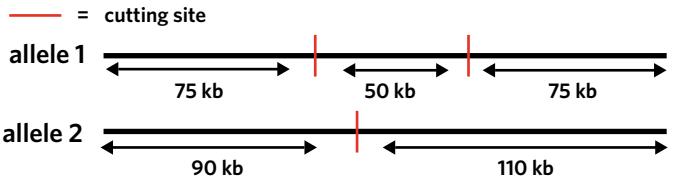
C *M. graminicola* genetic diversity has decreased since the 1980s.

D Gene flow between populations has allowed *M. graminicola* to spread to other wheat populations.

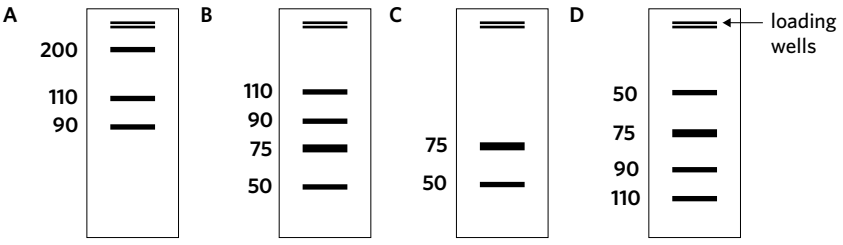
Adapted from VCAA 2015 Section A Q34

Question 14 (1 MARK)

Cutting sites for a particular restriction enzyme vary in a 200 kb region of human chromosome 2. The cutting sites for allele 1 and 2 are shown in the following diagram.



The DNA of a person heterozygous for these alleles would have which of the following gel patterns after digestion with this restriction enzyme?

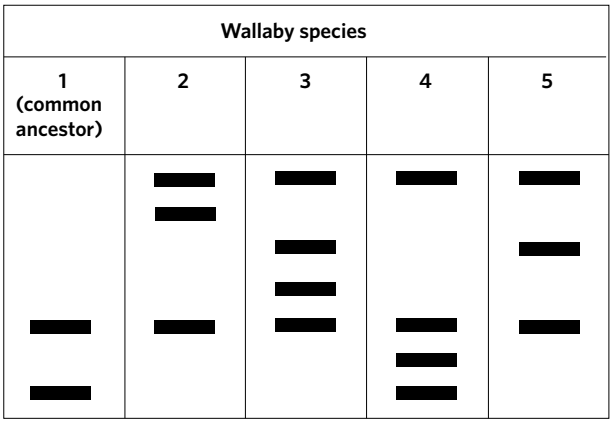


Adapted from VCAA 2005 Exam 2 Section A Q18

Use the following information to answer Questions 15 and 16.

Scientists analysed DNA markers from four wallaby species. Using gel electrophoresis, they compared these DNA markers to DNA extracted from the remains of a common ancestor.

Electrophoresis gel of wallaby species



Question 15 (1 MARK)

Which wallaby species is most closely related to the common ancestor (Wallaby species 1)?

A Wallaby species 2

B Wallaby species 3

C Wallaby species 4

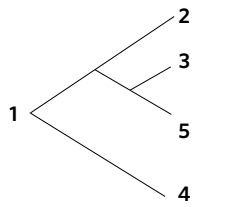
D Wallaby species 5

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q25

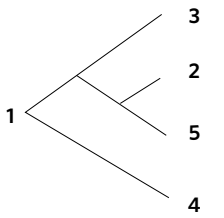
Question 16 (1 MARK)

Which phylogenetic tree most accurately represents the relationship between the five wallaby species?

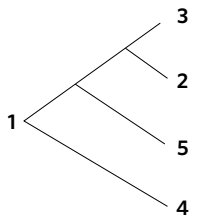
A



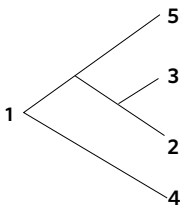
B



C



D

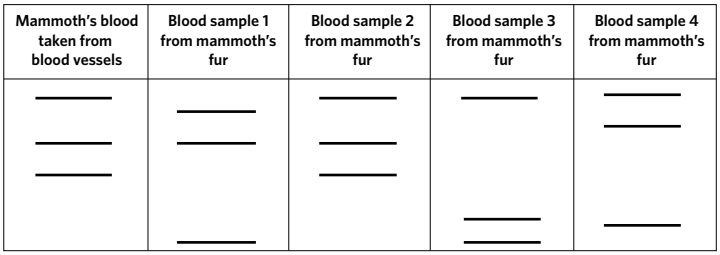


Key science skills

Question 17 (2 MARKS)

Scientists discovered the remains of a 15 000 year old mammoth frozen beneath the ice in Siberia. Scientists extracted DNA from the nucleus of its frozen white blood cells.

Using gel electrophoresis, scientists discovered that there were four different blood samples on the mammoth's fur. Their results were as follows:



a Which blood sample on the mammoth's fur belongs to the mammoth? (1 MARK)

b Provide a possible explanation for the presence of the other blood samples on the mammoth's fur. (1 MARK)

Adapted from VCAA 2014 Section B Q11b

Question 18 (9 MARKS)

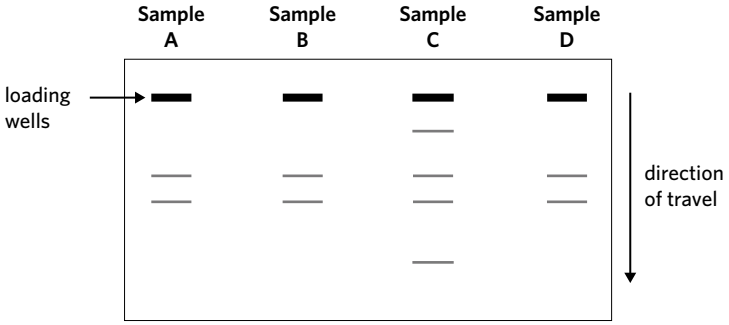
Riku wanted to set up an experiment to test the relatedness between him and his family members by using restriction fragment length polymorphism (RFLP) analysis. He first used gel electrophoresis to test four samples of his own DNA taken from mouth swabs. Before running his DNA samples on the gel, Riku needed to amplify the amount of DNA in each of the four samples.

a Riku wants to obtain larger quantities of identical DNA to use in gel electrophoresis.

i Name the process Riku could use to amplify DNA. (1 MARK)

ii Describe the process Riku could use to amplify DNA. (3 MARKS)

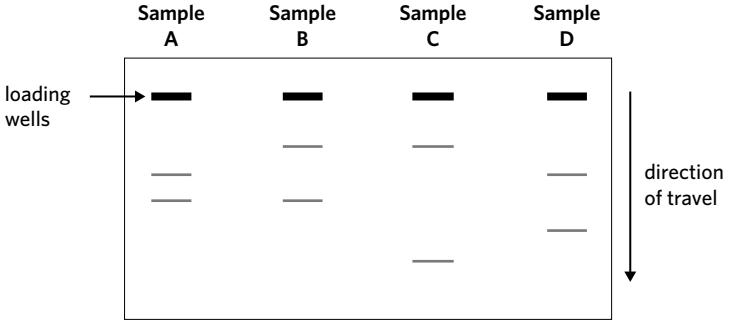
b After amplifying the amount of DNA in each of the four samples. Riku separated out the RFLP alleles using gel electrophoresis. The results are shown in the following diagram.



Suggest a possible reason why the results for Sample 3 are different from the results for the other three samples. (1 MARK)

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q7e

c Riku obtained DNA samples from three different family members (his mother, his father, and his maternal grandfather) and separated out the alleles at the RFLP locus using gel electrophoresis. Riku's own DNA is shown in Sample A. The results are shown.



Based on this data, identify which family member each of the three other DNA samples belong to. (2 MARKS)

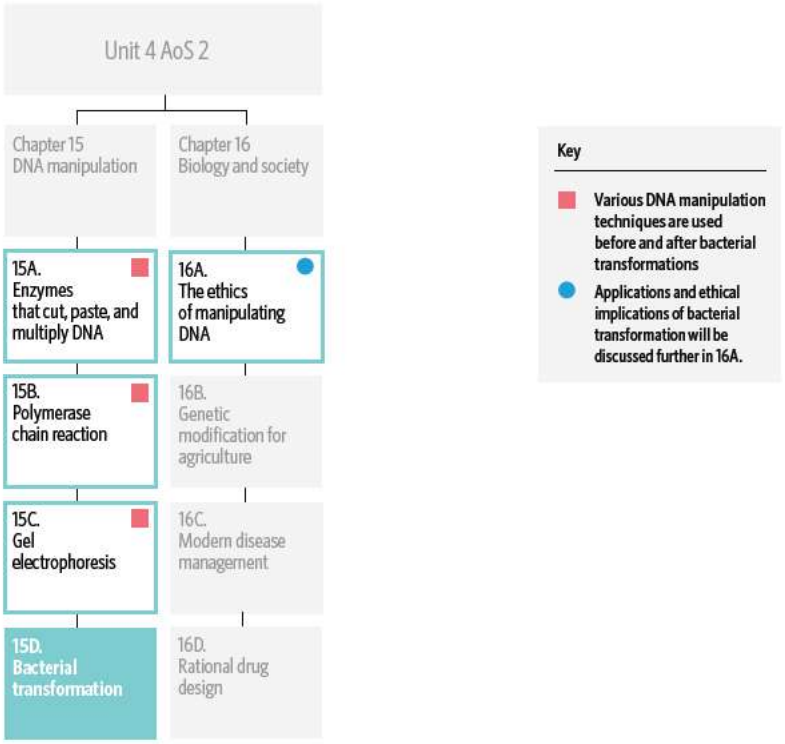
d Riku is considering running the experiment again but with a standard ladder.

i What is the purpose of a standard ladder in gel electrophoresis experiments? (1 MARK)

ii Would including a standard ladder improve the results of Riku's experiment? Justify your response. (1 MARK)

15D BACTERIAL TRANSFORMATION

Using bacterial transformation, scientists are able to insert novel genes into bacteria to repurpose them into tiny protein-producing factories.



In this lesson you will learn how DNA manipulation techniques can be used to produce recombinant plasmids which can then be used to transform bacteria. Through this process, we can produce large amounts of desirable proteins, such as insulin which is used as a treatment for people with diabetes.

Study design dot point

- the use of recombinant plasmids as vectors to transform bacterial cells

Key knowledge units

Making a recombinant plasmid	4.2.4.1
Transforming bacteria	4.2.4.2

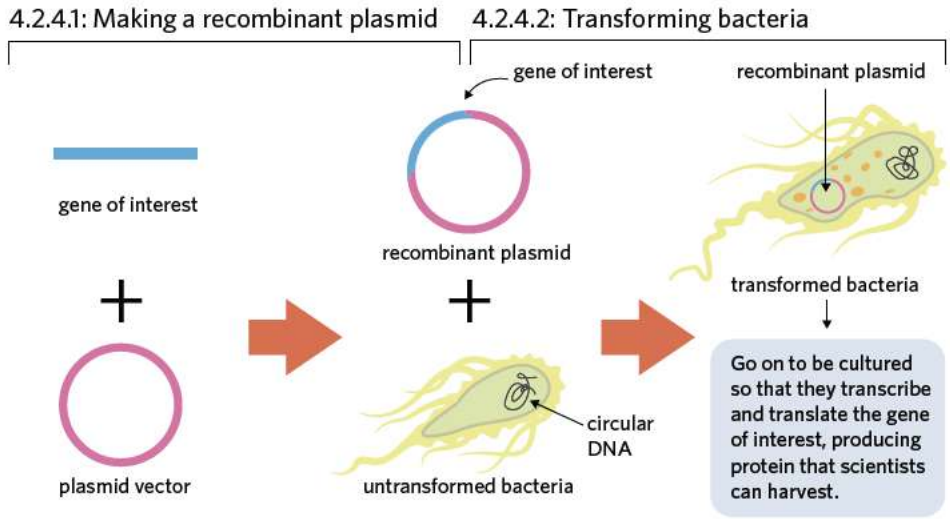


Figure 1 Simplified process of transforming bacteria to express a gene of interest

Making a recombinant plasmid 4.2.4.1

OVERVIEW

Genetic engineers are often interested in introducing DNA into an organism where it doesn't naturally occur. A simple way of doing this is to insert **foreign DNA** into a plasmid that can be taken up by bacteria. The bacteria can then express the protein encoded by that foreign DNA.

foreign DNA DNA that is not found naturally within an organism

gene of interest the gene we wish to express in recombinant bacteria. This gene often encodes a protein we wish to produce in commercial quantities. Also known as the **desired gene** or **insert DNA**

plasmid vector a plasmid that is modified to be an ideal vector for transformation experiments

vector a means of introducing foreign DNA into an organism; plasmids are a popular vector in bacterial transformation

reporter gene a gene located on the plasmid vector that expresses an easily identifiable characteristic, allowing scientists to identify transformed bacteria. For example, green fluorescent protein (GFP)

origin of replication (ORI) a sequence found in prokaryotes that signals the start site of DNA replication

THEORY DETAILS

Whilst eukaryotes contain linear DNA, bacteria have genetic material in the form of circular DNA. Additionally, bacteria also contain circular plasmids in their cytoplasm which replicate and express genes independently of the circular chromosome. Scientists have hijacked this system by creating their own plasmids and inserting them into bacteria, which then produce the desired proteins. The steps to do this are outlined below and in Figure 2.

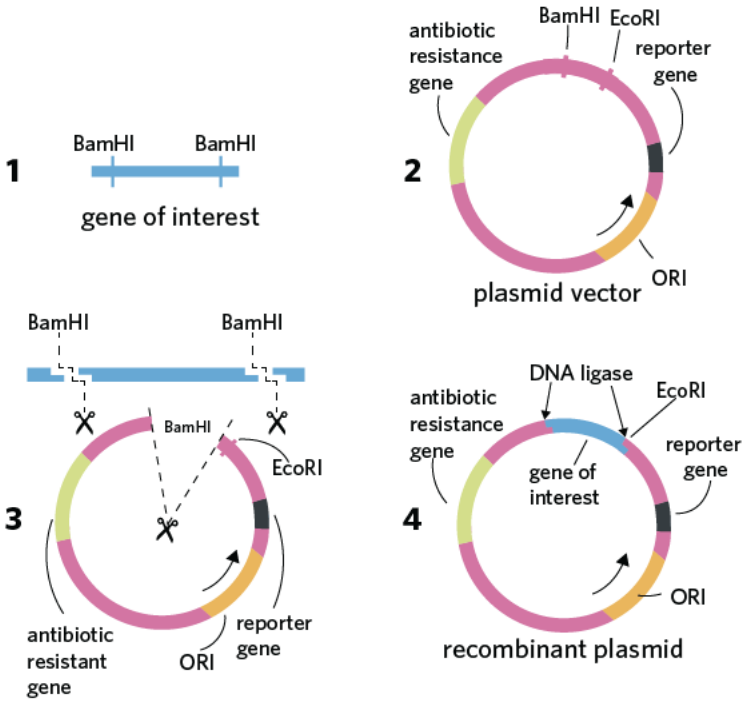


Figure 2 The steps involved in making a recombinant plasmid

1 **Gene of interest** – a sequence of DNA encoding the protein we wish to produce is generated, this is referred to as our gene of interest. There are several ways of generating a piece of DNA for insertion but these are not assessed by VCAA and so will not be covered in depth here. In short, the DNA sequence of a human protein is isolated and used for insertion. Despite the gene of interest coming from another organism, bacteria are able to use the gene of interest to synthesise a protein because the genetic code is universal – a CUU codon encodes leucine no matter where the codon is expressed.

2 **Plasmid vector** – a plasmid vector is selected into which our gene of interest will be inserted. Many different plasmid vectors have been designed by scientists, but most contain four important things:

- I Restriction enzyme sites – a site on the plasmid that can be recognised and cut by restriction enzymes, allowing the gene of interest to be inserted.
- II An antibiotic resistance gene – e.g. amp^R which confers ampicillin resistance or *tetA* which confers tetracycline resistance.
- III A **reporter gene** – a gene that creates an easily identifiable phenotype. For example, the gene *gfp* is a common reporter gene which encodes green fluorescent protein (GFP). This protein fluoresces under UV light allowing transformed bacteria to be easily identified.
- IV **Origin of replication (ORI)** – a sequence that signals the start site for DNA replication in bacteria.

3 Restriction enzymes – our gene of interest and our plasmid are both cut with the same restriction enzyme to generate identical sticky ends on either end of the sequence. The overhanging nucleotides of our gene of interest will be complementary to the overhanging nucleotides on the plasmid vector, allowing them to form hydrogen bonds with each other easily. Blunt end restriction enzymes may also be used but are less efficient than using sticky end restriction enzymes, as a blunt end can bond with any other blunt end.

4 DNA ligase – DNA ligase is added to join the gene of interest to the plasmid vector by forming phosphodiester bonds in the sugar-phosphate backbone to form a circular piece of DNA, termed a **recombinant plasmid**. Not every plasmid will take up the gene of interest; in fact, most plasmids will simply ligate back with themselves and are termed **non-recombinant plasmids**. The result of this procedure gives you a mixture of both recombinant and non-recombinant plasmids. To separate the recombinant plasmids from the non-recombinant plasmids, the plasmids must be taken up by bacteria (see 'Transforming bacteria 4.2.4.2').

Transforming bacteria 4.2.4.2

OVERVIEW

Many bacteria will naturally take up free-floating DNA from their environment into their cytosol through a process known as transformation. Biologists are able to take advantage of this process to make bacteria take up recombinant plasmids (which we learned how to make in 'Making a recombinant plasmid 4.2.4.1'). This second process is typically what we refer to as bacterial transformation.

THEORY DETAILS

The steps of bacterial **transformation** and selection are outlined below and in Figure 3.

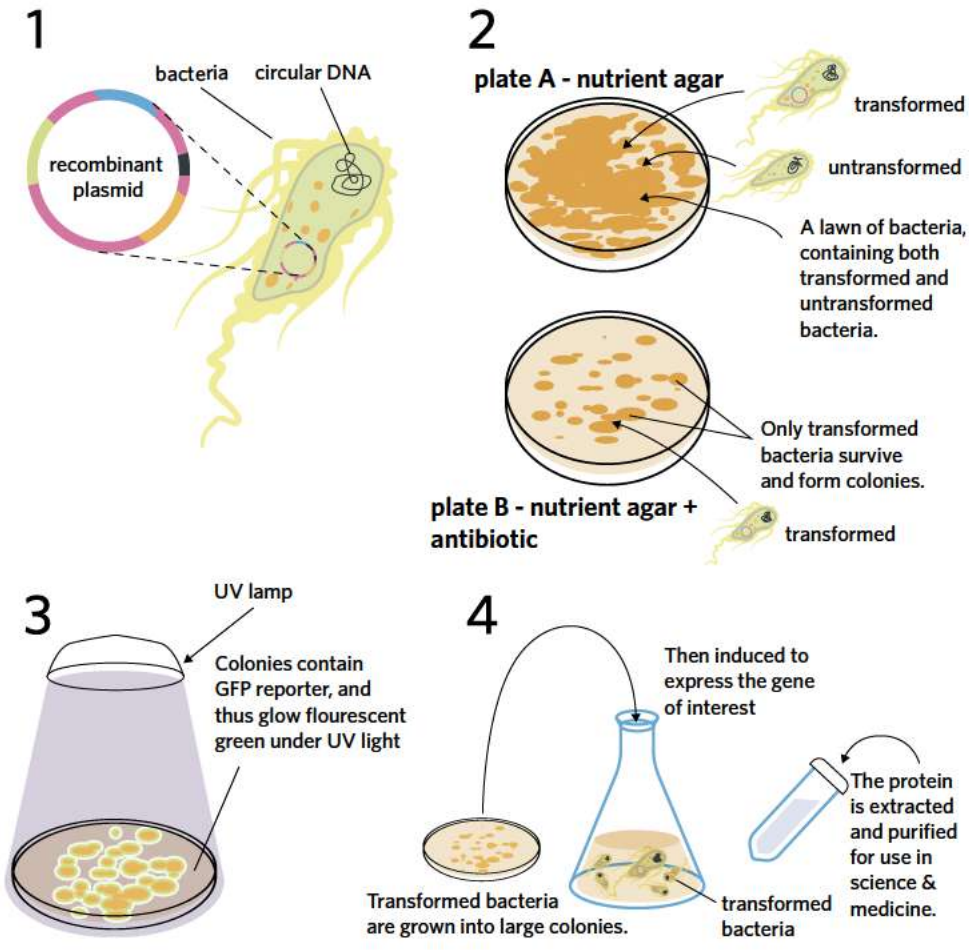


Figure 3 The steps involved in bacterial transformation and selection

recombinant plasmid a plasmid vector that has ligated to the gene of interest to form a new single piece of circular DNA

non-recombinant plasmid a plasmid that has either ligated with itself rather than with the gene of interest or was never cut in the first place. These plasmids are selected against using antibiotic selection or reporter genes

transformation the process by which bacteria take up foreign DNA from their environment. Scientists use this process to introduce recombinant plasmids into bacteria

antibiotic selection the process of culturing bacteria on antibiotic-containing medium, which only allows transformed bacteria to grow

culture a lab technique in which cells/organisms are grown in a sterile environment with a nutrient supply

nutrient agar a jelly-like substance containing nutrients needed for bacterial survival in culture

inducer a molecule that enables the expression of the reporter by binding to the promoter sequence of the reporter gene

1 Uptake of recombinant plasmid – the recombinant plasmid is inserted into the cytoplasm of bacteria. Some common methods to do this include:

   I Heat shock – bacteria and plasmids are placed in a calcium ion solution on ice. The calcium ions help make the plasma membrane of the bacteria more permeable. The solution is then heated to around 37-42°C for 25-45 seconds. This sudden change in temperature makes the plasma membrane even more permeable and allows plasmid vectors to enter the bacteria's cytoplasm.

   II Electroporation – a similar process to heat shock but instead, an electric current is passed through a solution containing bacteria and plasmids. The current causes the plasma membrane to become more permeable allowing plasmid vectors to enter.

2 **Antibiotic selection** – not many bacteria will take up a plasmid and undergo transformation. In order to distinguish between transformed and untransformed bacteria, the mixture is **cultured** onto two plates:

- plate A contains **nutrient agar**
- plate B contains nutrient agar + antibiotic

Both untransformed and transformed bacteria are able to grow on plate A since there is no antibiotic. As a result, a lawn of bacterial growth is formed, meaning that the entire surface of the plate is covered by bacteria. Transformed bacteria contain the recombinant plasmid vector which gives them antibiotic resistance whilst untransformed bacteria do not. Therefore, only transformed cells will survive and form colonies on the antibiotic-containing agar on plate B. Each colony on plate B represents a transformation event where a single bacterium took up the recombinant plasmid, allowing it to survive, multiply, and form a colony of identical daughter cells.

3 Bacterial identification – Transformed bacteria can further be identified by their reporter gene. If our plasmid contains the *gfp* gene then transformed bacterial cultures can be identified by their fluorescence under UV light (Figure 4). Some plasmids contain a promoter sequence next to the reporter gene that only allows reporter gene expression when an **inducer** molecule such as arabinose is present in the nutrient agar.
Scientists can also check for transformed bacteria by sampling colonies and performing restriction digests, PCR, or DNA sequencing. This is important because bacteria might have taken up a plasmid, but the plasmid might not be recombinant (i.e. the cut plasmid joined back together before the gene of interest was inserted) or the gene of interest may be inserted in the wrong direction (Figure 5). Once scientists have identified colonies with successfully transformed bacteria, they can be grown in bulk for protein production.

4 Protein production – the transformed bacteria are cultured and induced to transcribe and translate the gene of interest. Then, because bacteria make lots of different proteins, the protein of interest is extracted and purified. Commonly used proteins that are made from transformed bacteria include:

- Insulin – manages diabetes
- Erythropoietin – for treatment of anaemia
- Growth hormone – manages growth disorders
- Interferon – for treatment of some cancers
- Hepatitis B surface antigen – for use in hepatitis B vaccine
- Chymosin – for cheese production
- Alpha-amylase – for ethanol and high fructose corn syrup production.

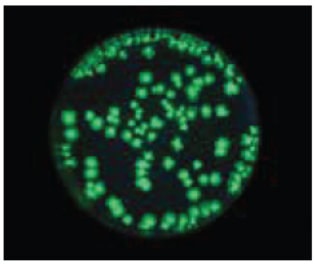


Image: 77Ivan/Shutterstock.com

Figure 4 Transformed *E. coli* bacteria containing the *gfp* gene fluoresce green under UV light.

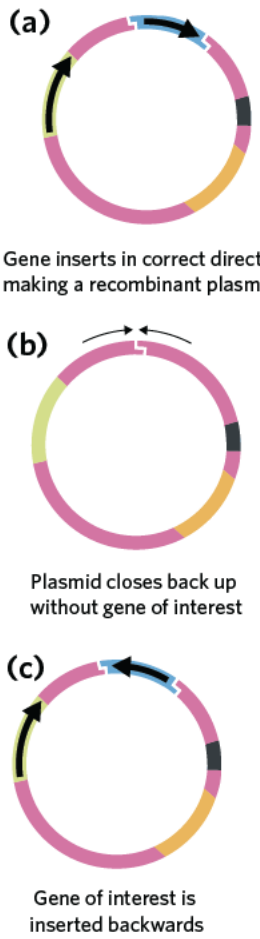


Figure 5 Why scientists must check that bacteria have taken up the right bacteria: **(a)** successfully recombinant plasmid; **(b)** the plasmid never took up the gene of interest; **(c)** the gene of interest was inserted back-to-front (more likely with blunt restriction cuts).

Theory summary

Bacterial transformation occurs through the extraction of genes, formation of recombinant plasmids, and uptake by bacteria. To distinguish transformed bacteria from non-transformed bacteria, an antibiotic resistance gene is included in the plasmid vector which will be expressed by transformed bacteria. In addition, a reporter gene may also be included in the plasmid vector that will express an obvious phenotype, making transformed bacteria easily identifiable.

lesson link Further applications of bacterial transformation such as gene cloning (***16A***) and genetic modification (***16B***) will be explored in future lessons. In this lesson, the focus is on the process of transformation itself.

15D QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ a gene that we wish to express in bacteria. The protein product may be harvested from bacterial cells for further use

b _____ a piece of circular DNA into which the desired gene is inserted. They contain genes useful for the process of bacterial transformation

c _____ the process of introducing foreign DNA into bacteria

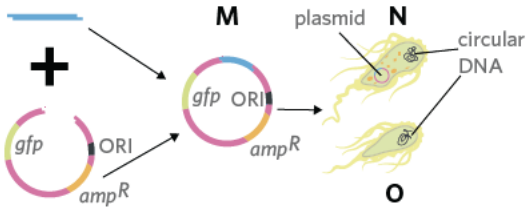
d _____ a gene that expresses an easily identifiable trait, making it easy for transformed bacteria to be identified

e _____ the process of using antibiotics to select for bacteria containing the plasmid vector

f _____ a plasmid vector that has successfully ligated with the gene of interest

Question 2

Identify the structures labelled M – O in the following diagram.



	M	N	O
A	transformed bacteria	recombinant plasmid	untransformed bacteria
B	recombinant plasmid	untransformed bacteria	transformed bacteria
C	untransformed bacteria	plasmid vector	transformed bacteria
D	recombinant plasmid	transformed bacteria	untransformed bacteria

Question 3

What is the correct order of the following steps in bacterial transformation?

1 Recombinant plasmids and bacteria are mixed together in solution. Electroporation or heat shock increases the bacteria's membrane permeability, allowing plasmids to pass into the cytoplasm

2 The gene of interest is generated and an appropriate plasmid vector is chosen

3 Bacteria are cultured on an antibiotic-containing medium. Only transformed bacteria are able to grow and form colonies

4 Restriction enzymes are used to create complementary sticky ends on both the gene of interest and the plasmid vector

5 DNA ligase is added to join the gene of interest and plasmid vector by sealing the sugar-phosphate backbone

A 2, 4, 5, 1, 3

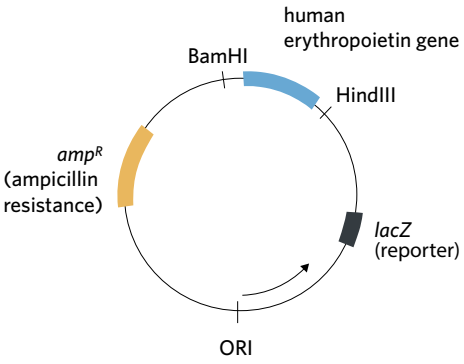
B 3, 2, 4, 5, 1

C 2, 5, 4, 3, 1

D 2, 1, 4, 5, 3

Question 4

The diagram shows a typical recombinant plasmid. Which of the following statements is true?



A The desired gene and plasmid vector were cut using the BamHI restriction enzyme.

B Bacteria containing this plasmid are able to generate human erythropoietin protein despite the gene coming from a different species.

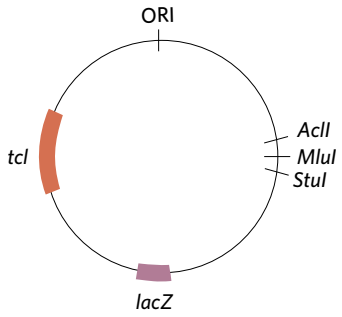
C This plasmid is considered transformed because it contains the human erythropoietin gene.

D The *lacZ* gene is a reporter, which means that it gives a bacteria containing this plasmid resistance to antibiotics.

Question 5

Tommy is attempting to generate recombinant plasmids using the gene of interest, gene X, and the following plasmid vector. The restriction sites are labelled on the plasmid. The sequences of DNA flanking (next to) gene X are shown.

5′ flanking sequence	5′ – AGCAACGCGT – 3′
3′ flanking sequence	5′ – CACGCGTTAG – 3′



The recognition sites for three restriction enzymes: AclI, MluI, and StuI are shown in the table. Which of the three restriction enzymes would Tommy use to generate a recombinant plasmid containing gene X?

Restriction enzyme	Recognition site
AclI	5′...A A▼C G T T...3′ 3′...T T G C▲A A...5′
MluI	5′...A▼C G C G T...3′ 3′...T G C G C▲A...5′
StuI	5′...A G G▼C C T...3′ 3′...T C C▲G G A...5′

A AclI

B MluI

C StuI

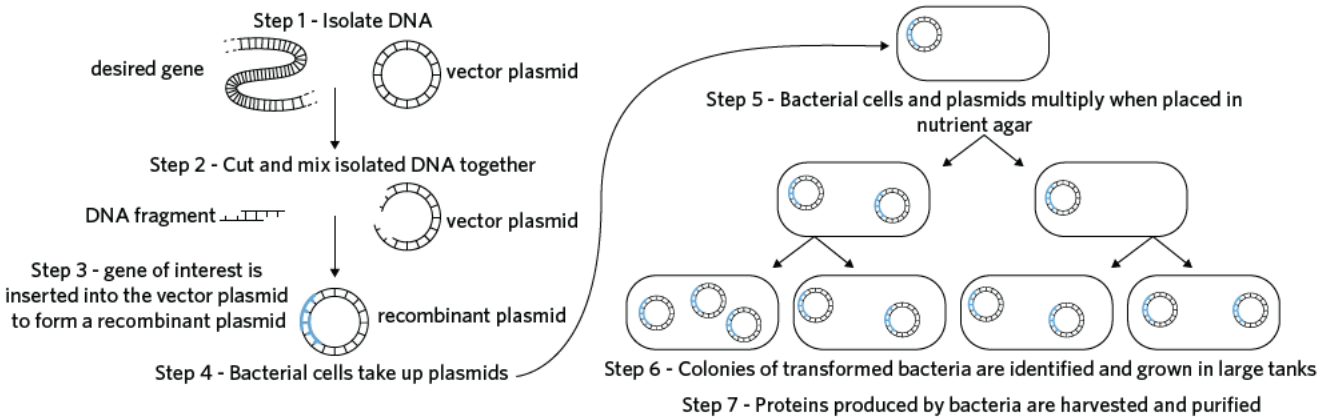
D None of the above

Exam-style questions

Within lesson

Use the following information to answer Questions 6–8.

A molecular biologist performed the procedure outlined in the flow chart.



Question 6 (1 MARK)

Which one of the following shows the enzymes required in Steps 2 and 3?

	Cuts plasmid and gene of interest	Joins gene of interest with plasmid
A	DNA ligase	DNA polymerase
B	DNA ligase	restriction enzyme
C	restriction enzyme	DNA polymerase
D	restriction enzyme	DNA ligase

Adapted from VCAA 2014 Section A Q25

Question 7 (1 MARK)

Which one of the following is a correct statement about the procedure outlined?

A In Step 1, the gene of interest and the vector plasmid are always isolated from the same organism.

B After Step 2, the overhanging nucleotides of the gene of interest and vector plasmid are complementary to each other.

C In Step 3, the recombinant plasmid is able to replicate to generate more copies of the gene of interest.

D Multiplication of DNA in Step 5 is due to the polymerase chain reaction.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q37

Question 8 (1 MARK)

One application of the process outlined is to

A use plants containing recombinant plasmids to produce large quantities of human proteins, such as erythropoietin.

B produce human organs inside pigs that can be transplanted into humans who require an organ transplant.

C produce commercial quantities of proteins such as human insulin.

D grow tissues in culture from human stem cells for laboratory models.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q38

Use the following information to answer Questions 9 and 10.

Bacteria can be transformed with an artificial erythropoietin gene and cultured to make the erythropoietin protein in commercial quantities.

The steps taken to produce genetically engineered erythropoietin are summarised. The order of the steps has been mixed up.

I Harvest and purify erythropoietin protein from transformed bacteria

II Add recombinant plasmids to bacteria and heat to enhance uptake of plasmids

III Identify successfully transformed bacteria

IV Add DNA ligase to join the erythropoietin gene and plasmid vector

V Culture transformed and untransformed bacteria on antibiotic-containing nutrient agar

VI Use enzymes to generate cuts in the erythropoietin gene and plasmid vector

Question 9 (1 MARK)

The correct sequence of steps involved in producing erythropoietin using bacterial transformation is

A IV, VI, II, III, V, I.

B V, VI, IV, II, III, I.

C VI, IV, II, V, III, I.

D VI, IV, V, II, I, III.

Adapted from VCAA 2013 Section A Q34

Question 10 (1 MARK)

The enzyme used to cut the erythropoietin gene and plasmid DNA at step VI is also known as

A DNA ligase.

B DNA polymerase.

C a restriction enzyme.

D a protease.

Adapted from VCAA 2013 Section A Q35

Multiple lessons

Question 11 (8 MARKS)

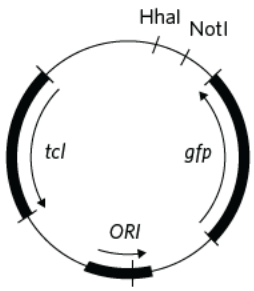
Scientists use recombinant bacterial plasmids as vectors to transform bacteria for a range of purposes in research and biotechnology.

a What is meant by the term 'transform' when creating transformed bacteria? (1 MARK)

Adapted from VCAA 2017 Section B Q9a

b A particular bacterial plasmid contains recognition sites for the restriction enzymes HhaI and NotI, along with the gene encoding tetracycline resistance (*tcI*), the gene encoding green fluorescent protein (*gfp*) and an origin of replication (*ORI*). Cells expressing *gfp* fluoresce green under UV light.

The diagram shows the positions of these recognition sites, *tcI,* and *gfp* as well as the position of the origin of replication within this plasmid.



Recombinant bacterial plasmids are often used to produce bacteria capable of synthesising human proteins. This may be achieved by inserting the gene encoding the human protein into the bacterial plasmid.

The gene can be inserted into the bacterial plasmid by using restriction enzymes.

i Describe how restriction enzymes, such as HhaI and NotI, are used to help insert a gene coding for a human protein into this plasmid. (2 MARKS)

Adapted from VCAA 2017 Section B Q9bi

ii Describe how DNA ligase is used to help insert a gene coding for a human protein into this plasmid. (1 MARK)

c After the scientists had carried out the steps required to make plasmids with the inserted human gene, these plasmids were mixed with a culture of bacteria. This mixture was treated so that these plasmids would move into the bacterial cells. Not all bacteria took up these plasmids.

Describe what results scientists would expect to see if they cultured the treated bacterial cells on nutrient agar containing tetracycline. Explain the meaning of these results. (3 MARKS)

Adapted from VCAA 2017 Section B Q9c

d What characteristic of the genetic code enables a human protein to be made by bacterial cells? (1 MARK)

Adapted from VCAA 2015 Section B Q7d

Key science skills

Use the following information to answer Questions 12–14.

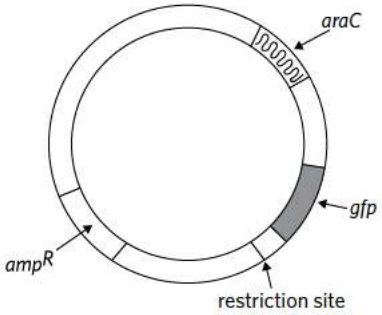
To clone a gene of interest, the following four steps are performed:

1 A plasmid is cut with an enzyme

2 The gene of interest is ligated into the plasmid

3 Plasmids are transferred to bacteria

4 Bacteria are grown on four nutrient agar plates (labelled W, X, Y and Z) that are coated with or without ampicillin and arabinose.

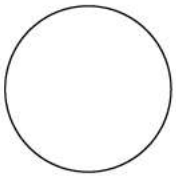
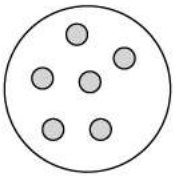
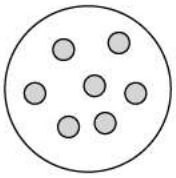


An example of a plasmid used in cloning is shown in the diagram.

This plasmid contains a restriction site and the following three genes:

- *amp*^{R} – confers resistance to the antibacterial agent ampicillin
- *gfp* – encodes the green fluorescent protein (GFP), which fluoresces under UV light
- *araC* – when arabinose is present, this gene expresses a protein that is necessary to promote *gfp* expression

The results from a bacterial transformation experiment are shown in the table.

Plate	W untransformed bacteria only	X untransformed bacteria only	Y transformed bacteria	Z transformed bacteria
Diagram of plate				
Added to plate	nutrient agar only	nutrient agar and ampicillin	nutrient agar, ampicillin, and arabinose	nutrient agar and ampicillin
Description of result	lawn of bacteria	no growth	bacterial colonies present	bacterial colonies present

Question 12 (1 MARK)

The purpose of the enzyme in the first step of this experiment is to

A give both the plasmid and gene of interest complementary sticky ends, allowing them to ligate.

B give both the plasmid and gene of interest blunt ends, allowing segments of DNA to ligate together in various conformations.

C randomly cut DNA into fragments so that they can ligate and create a new recombinant plasmid that may potentially be beneficial.

D reduce the effects of confounding variables due to different restriction enzymes.

Adapted from VCAA 2015 Section A Q25

Question 13 (1 MARK)

The results of plate W and X suggest that

A the efficiency of transformation of bacteria is quite low.

B untransformed bacteria are unable to grow in the presence of ampicillin.

C untransformed bacteria are only able to grow in the presence of arabinose.

D untransformed bacteria are unable to form colonies.

Adapted from VCAA 2015 Section A Q25

Question 14 (1 MARK)

Which of the following statements is correct in regards to plate Z?

A The presence of the *gfp* gene allows colonies to fluoresce under UV light when arabinose is present.

B Untransformed bacteria would be able to grow if arabinose was present.

C Bacterial colonies have evolved antibiotic resistance, allowing them to grow in the presence of ampicillin.

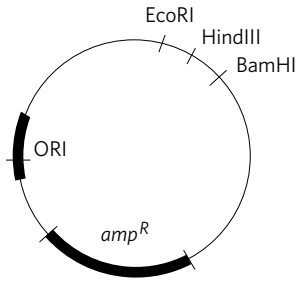
D mRNA for *gfp* would be absent in the bacterial colonies.

Adapted from VCAA 2015 Section A Q25

Question 15 (13 MARKS)

Chymosin is an enzyme used to manufacture cheese. Found in rennet, chymosin is traditionally extracted from the fourth stomach of newborn calves. Because of the difficulties in sourcing chymosin, scientists engineered a non-pathogenic strain of recombinant *E. coli* that can generate large quantities of chymosin in a laboratory. Currently, about 60–90 % of hard cheese in the USA and UK is made with genetically engineered chymosin.

The *E. coli* plasmid contains recognition sites for the restriction enzymes EcoRI, HindIII, and BamHI, along with the gene for ampicillin resistance (amp^R) and an origin of replication (ORI). The diagram shows the positions of these recognition sites and ampicillin-resistance gene as well as the position of the origin of replication within this plasmid.



a Explain what is meant by 'non-pathogenic strain of recombinant *E. coli*'. (1 MARK)

b Before inserting the gene for chymosin into *E. coli,* scientists must amplify the section of calf DNA that codes for chymosin. Name the process that scientists use to amplify DNA. (1 MARK)

c Once the scientists have isolated and amplified the gene of interest, they can insert it into the plasmids. To do this, they use the restriction enzyme HindIII.
Draw and label a diagram to show the position of the chymosin gene in this plasmid when HindIII is used. Include the position of the recognition sites for the restriction enzymes EcoRI, HindIII, and BamHI on the plasmid. (1 MARK)

d Next, scientists must introduce the recombinant plasmids into the non-pathogenic *E. coli.* To do this, they use the heat-shock method which involves causing a sudden temperature change that makes the cell membrane of the bacteria more permeable to the recombinant plasmids.
Identify the 'vector' in this experiment. Justify your response. (2 MARKS)

e Not all the *E. coli* will take up the recombinant plasmids. To test which bacteria are transformed, the scientists set up four Petri dishes:

Plate A.	Nutrient agar + *E. coli* not exposed to plasmids
Plate B.	Nutrient agar + ampicillin + *E. coli* not exposed to plasmids
Plate C.	Nutrient agar + *E. coli* exposed to plasmids + heat shocked
Plate D.	Nutrient agar + ampicillin + *E. coli* exposed to plasmids + heat shocked

The Petri dishes were incubated overnight at 37°C. The scientists found bacterial growth on plates A, C, and D but no growth on plate B.

i Explain the scientists' results for each Petri dish, including whether any results were unexpected. (4 MARKS)

ii After incubation, which Petri dish(es) will contain only transformed bacteria? Justify your response. (2 MARKS)

iii What is the purpose of Petri dishes A and B? (2 MARKS)

Adapted from VCAA 2017 Section B Q9

ACTIVITY

Virtual DNA manipulation

Aim

To explore the processes of DNA extraction, PCR, and gel electrophoresis through the use of virtual labs.

Procedure

Part A – DNA extraction

1 Access the Learn Genetics virtual lab (learn.genetics.utah.edu/content/labs/extraction/) and work through the simulated DNA extraction.

Part B – Polymerase chain reaction (PCR)

2 Access the Learn Genetics virtual lab (learn.genetics.utah.edu/content/labs/pcr/) and work through the simulated PCR. Note: You may need to click and hold when transferring items from one place to another.

Part C – Gel electrophoresis

3 Access the Learn Genetics virtual lab (learn.genetics.utah.edu/content/labs/gel/) and work through the simulated gel electrophoresis.

4 Answer the questions about the virtual lab procedures.

5 Read through the *Alu* insertion polymorphism scenario and answer the questions that follow.

Questions

Making a DNA profile is a three-part process, which was demonstrated in the virtual labs. In Part A you collected some cells and extracted DNA from them. In Part B you copied the extracted DNA using PCR. In Part C you separated the fragments of DNA by gel electrophoresis.

1 During the DNA extraction in Part A, the microcentrifuge tube containing the cells was placed into a warm water bath. What was the purpose of this step?

2 When the DNA for PCR was prepared, two primers, free nucleotides, and DNA polymerase were added to the PCR tube. One of the purposes of PCR was to make multiple copies of introns at a particular locus within the chromosome.

   a What is an intron?

   b How many copies of an intron does each person have?

   c Which of the ingredients was there to ensure that only the 'target intron' (that is, the bases that need to be isolated) would be amplified during PCR?

3 The PCR machine (also called a DNA thermal cycler or thermocycler) was set so it successively cycled between 95 °C, 50 °C, and 72 °C during PCR.

   a What occurs during step 1 of each PCR cycle? Why did the temperature need to reach 95 °C for this step?

   b What occurs during step 2 of each PCR cycle? Why did the temperature need to be decreased to 50 °C for this step?

   c What occurs during step 3 of each PCR cycle? Why did the temperature need to be increased to 72 °C for this step?

4 *Taq* polymerase, the DNA polymerase used in PCR, has been isolated from thermophilic bacteria found in hot springs. Explain why *Taq* polymerase is used for PCR rather than human DNA polymerase.

5 In Part C, DNA was loaded into the lanes of an electrophoresis gel. When the electric current was turned on, the fragments of DNA started moving out of the wells and toward the other end of the gel. What caused the DNA fragments to move in this direction?

6 After running the gel electrophoresis, the gel was removed from the chamber and stained. Why are dyes such as ethidium bromide needed to locate the bands of DNA in the gel after electrophoresis?
When preparing a PCR tube, it is possible that the DNA sample and/or the solutions that are added may accidentally become contaminated with DNA from the individual who prepared it.

   a What evidence would be seen in the gel to indicate contamination?

   b If contamination of an individual's DNA sample occurs after PCR has been completed, explain why it is unlikely to have any significant effect on the result.

Scenario

An *Alu* insertion polymorphism is a length of DNA that is found in some people but not in others. These lengths of DNA can be transcribed and then reinserted back into the chromosome at a different location. While many scientists consider *Alu* insertion polymorphisms as evolutionarily functionless, others have suggested they play an important role in the creation of new genes. Regardless, these DNA sequences can be isolated and tested for in the same way as other genes.

The *TPA* gene is located on the short arm of chromosome 8 and encodes the tissue plasminogen activator (TPA), which is a protein important in the breakdown of blood clots. One intron in the *TPA* gene is 100 base pairs long (bp). In some people there is a 300 bp *Alu* insertion polymorphism (called TPA-25) within that 100 bp intron, making the intron 400 bp long in total

In the past, *Alu* insertions were useful because they were used in forensics when profiling was undertaken using restriction fragment length polymorphism (RFLP) analysis. An *Alu* insertion contains a recognition site for the restriction enzyme Alu1. This enzyme cuts at the four-base palindrome AGCT, leaving blunt ends.

Scenario Questions

1 During PCR, the *TPA* gene intron that is amplified has two forms (alleles): a 100 bp allele without TPA-25, and a 400 bp long allele with TPA-25 (the *Alu* insertion element). Would you expect the DNA fragments from both of these alleles to move down the gel at the same speed? Explain your answer.

2 The allele with the TPA-25 *Alu* insertion has arisen by mutation. What is a mutation?

3 The mutant allele with the TPA-25 *Alu* insertion is 300 bp longer than the normal allele because it contains a 300 bp *Alu* insert. This *Alu* insert is so named because there is a recognition sequence (AGCT) in the middle of it for the restriction enzyme Alu1. What is a recognition sequence?

4 If the DNA sample was digested with the restriction enzyme Alu1 after PCR and then the fragments were separated using gel electrophoresis, how many bands would appear in the lane?

CHAPTER SUMMARY

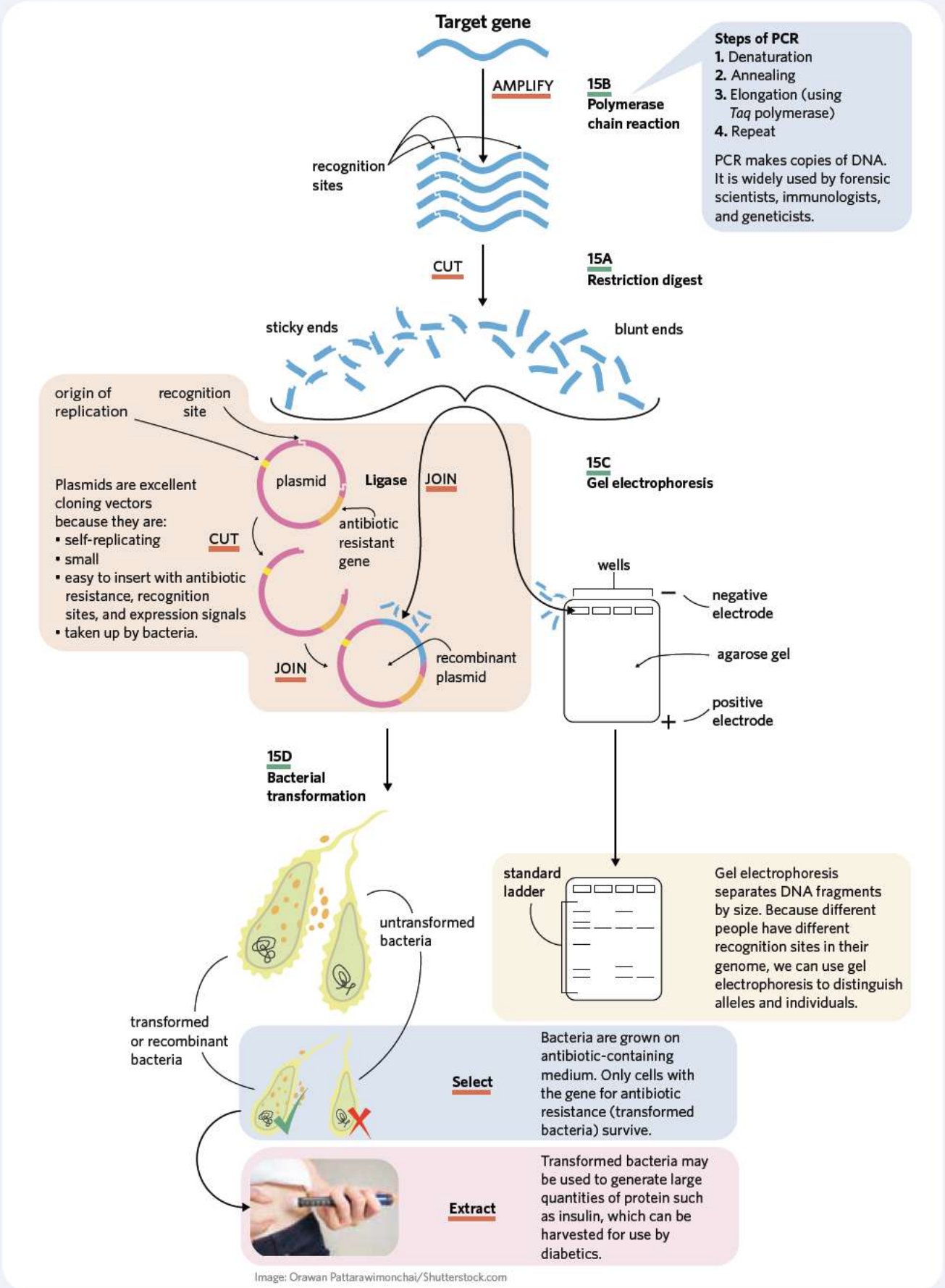


Image: Orawan Pattarawimonchai/Shutterstock.com

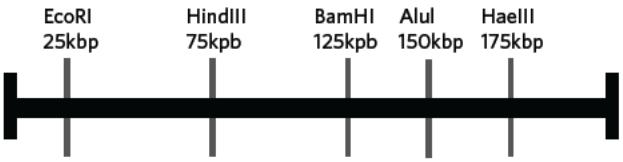
CHAPTER REVIEW QUESTIONS

SECTION A (15 MARKS)

Question 1 (1 MARK)

Consider the following linear section of DNA that has a total length of 200kbp. The recognition site of five different enzymes is shown.

The linear section of DNA shown was treated with the three restriction enzymes BamHI, HaeIII, and HindIII.



How many fragments of DNA would be produced and what would be the lengths of these fragments?

	Number of fragments	Lengths (kbp)
A	3	50, 50, 75
B	4	25, 25, 75, 75
C	4	25, 50, 50, 75
D	6	25, 25, 25, 25, 50, 50

Question 2 (1 MARK)

The CRISPR technique is a gene editing method. It involves a protein called Cas9 and a short piece of guide RNA (gRNA). The gRNA leads Cas9 to a gene in the DNA that scientists wish to edit. Cas9 is an endonuclease that acts in a similar way to a restriction enzyme.

What action is Cas9 expected to perform?

A cut DNA fragments

B join DNA fragments

C amplify DNA fragments

D sort DNA fragments

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q9c

Question 3 (1 MARK)

Which of the following is a correct statement about recombinant plasmids?

A The plasmid and desired gene must be extracted from the same organism.

B The same restriction enzyme must be used on both the gene and plasmid.

C DNA ligase, which is used to splice the gene into the plasmid, must have the same specific recognition sequence as the restriction enzyme used.

D Recombinant plasmids can be inserted directly into the human genome.

Question 4 (1 MARK)

Recombinant bacterial plasmids are vectors used to transform bacteria. In this context, 'vectors' are

A used as unedited genetic material that acts as a control in experiments.

B not used at all.

C used as a means of transporting foreign DNA into a cell/organism.

D proteins that are produced by the transformed bacteria.

Adapted from VCAA 2017 Section B Q9a

Question 5 (1 MARK)

In DNA manipulation, researchers often use polymerase enzymes.

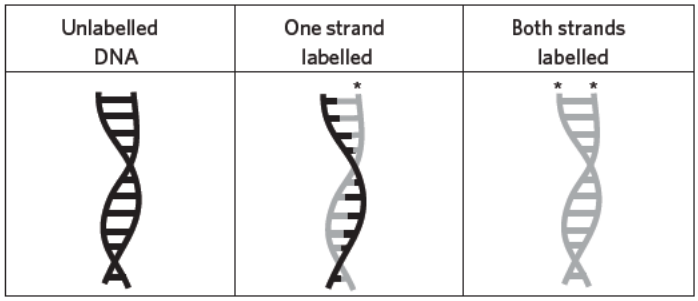
The function of polymerase enzymes is to

A create nucleotides from organic and inorganic materials.
B join a gene to the plasmid DNA at complementary sticky ends.
C clone a plasmid in order to produce enough plasmids to ensure effective treatment.
D cut the DNA of the plasmid and a gene in the same manner in order to produce matching sticky ends.

Adapted from VCAA 2016 Section A Q36

Question 6 (1 MARK)

Radioactively labelled nucleotides were incubated with an unlabelled molecule of DNA. Appropriate enzymes were added and the DNA was allowed to replicate for three cycles. Examine the following key.



Given that three cycles of DNA replication occurred, the end result would be

A


B

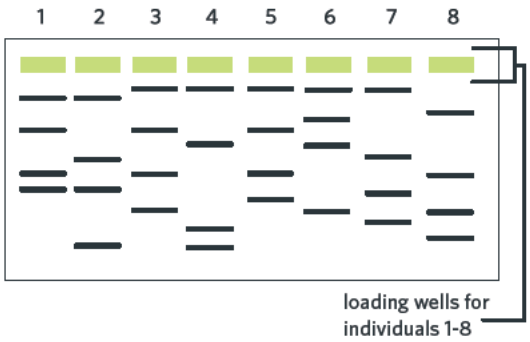

C


D


Adapted from VCAA 2011 Exam 2 Section A Q11

Question 7 (1 MARK)

Genetic testing can be used to test for the allele for haemophilia, a genetic disorder that causes blood to not clot properly, making it difficult to control bleeding. Eight individual family members were tested for the haemophilia allele. The diagram shows the electrophoresis gel results of a test for the presence of the allele. Individuals 1 and 3 have been diagnosed with the disease.



Which other individual is likely to suffer from haemophilia?

A 2
B 5
C 6
D 8

Adapted from VCAA 2018 Section A Q34

Question 8 (1 MARK)

A ribosome contains two distinct subunits: a large subunit and a small subunit. Ribosomes from plant cells were isolated and subjected to gel electrophoresis for proteins. The results are shown.

Which one of the following can be correctly concluded from the gel electrophoresis results?

A Cytosolic ribosomal subunits travel at the greatest speeds.

B Cytosolic and mitochondrial ribosomes translate the same types of protein.

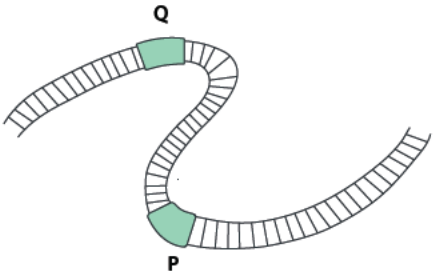
C Mitochondria contain the ribosomal subunits of the smallest size.

D Chloroplast ribosomal subunits have opposing charges to each other.

Adapted from VCAA 2015 Section A Q28

Question 9 (1 MARK)

The DNA of a small virus is depicted in the diagram, showing the positions of cutting sites (P and Q) for two restriction enzymes.



The length of DNA fragments obtained when using these restriction enzymes is shown in the table.

Cutting Site	Restriction enzyme used	Length of DNA fragments obtained (kbp)
Q	AluI	2, 8
P	HaeIII	6, 4

If both AluI and HaeIII are used together on this viral DNA, the length of the fragments obtained would be

A 2, 8, 6, 4.

B 2, 14, 4.

C 6, 4.

D 2, 4, 4.

Adapted from VCAA 2008 Exam 2 Section A Q20

Question 10 (1 MARK)

Plasmids of bacteria are used to transfer selected genes from one species to another. The process can be represented as shown.

bacterial plasmid cut → foreign gene and plasmid mixed → plasmid with inserted foreign gene

Enzymes are used to facilitate several of these steps.

Which enzyme(s) is/are required in this three-step process?

A restriction enzymes

B DNA ligase

C DNA ligase and DNA polymerase

D restriction enzymes and DNA ligase

Adapted from VCAA 2014 Section A Q25

Use the following information to answer Questions 11 and 12.

The diagram represents a DNA molecule and the position of the recognition sites for the restriction enzymes BamHI, EcoRI, and HindIII.

Also shown is a diagram of an electrophoresis gel in which the lanes R – W show the separation of DNA segments resulting from digestion of the molecule with one or more of the restriction enzymes.

Question 11 (1 MARK)

Which of the following shows the correct match between the lane and the restriction enzyme(s) used to digest the DNA molecule?

	R	S	T	U
A	HindIII	EcoRI	BamHI	EcoRI, HindIII
B	BamHI	HindIII	BamHI	BamHI, HindIII
C	HindIII	BamHI	EcoRI	EcoRI
D	EcoRI	BamHI	HindIII	BamHI, EcoRI

Adapted from VCAA 2017 Section A Q38

Question 12 (1 MARK)

Which combination of restriction enzymes were used to digest the DNA found in lane V?

A EcoRI, HindIII

B BamHI, HindIII

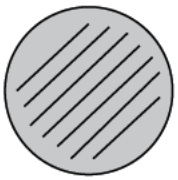
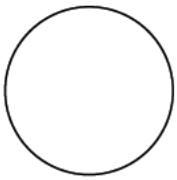
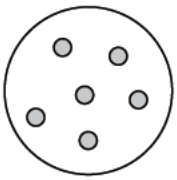
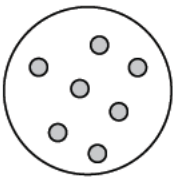
C BamHI, EcoRI

D BamHI, EcoRI, HindIII

Use the following information to answer Questions 13–15.

A plasmid has been designed to include the gene for the green fluorescent protein (*gfp*). This will cause bacteria to fluoresce green under UV light. In addition to this, scientists have added an ampicillin resistance gene and a gene encoding a protein required to promote the expression of *gfp* when arabinose is present.

Scientists culture bacteria on four different plates. The results from their bacterial transformations are shown in the table.

Plate	W untransformed bacteria only	X untransformed bacteria only	Y transformed bacteria	Z transformed bacteria
Diagram of plate				
Added to plate	nutrient agar only	nutrient agar and ampicillin	nutrient agar, ampicillin and arabinose	nutrient agar and ampicillin
Description of result	lawn of bacteria	no growth	bacterial colonies present	bacterial colonies present

Question 13 (1 MARK)

Which plate(s) acts as a control in the experiment?

A Plate W

B Plate X

C Plate W and X

D Plate W and Z

Adapted from VCAA 2015 Section A Q25

Question 14 (1 MARK)

Which of the following statements is the most accurate?

A Only plate Y will fluoresce under UV light.

B Plate X has no growth because there was no arabinose present.

C Plate Z has less growth than Plate Y because there was no arabinose present.

D Plate W will fluoresce the most under UV light.

Question 15 (1 MARK)

A fifth plate was set up with untransformed bacteria added to a plate that contained nutrient agar, ampicillin, and arabinose. The plate would produce the same results as

A plate W.

B plate X.

C plate Y.

D plate Z.

SECTION B (25 MARKS)

Question 16 (4 MARKS)

The CRISPR technique is a gene editing method. It involves a protein called Cas9 and a short piece of guide RNA (gRNA). The gRNA leads Cas9 to a gene in the DNA that scientists wish to edit. Cas9 acts like molecular scissors to cut DNA.

a What type of enzyme does Cas9 act like? (1 MARK)

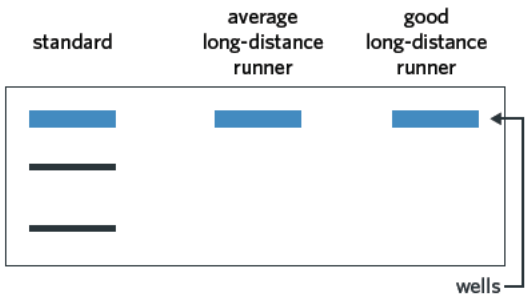
b To utilise the CRISPR technique, many copies of gRNA is required. The polymerase chain reaction (PCR) is undertaken to do this. Outline the process of the PCR. (3 MARKS)

Question 17 (6 MARKS)

Scientists investigating the performance of athletes found that one gene contributing to the performance of sprinters is the *ACTN3* gene. There are two alleles of the gene, the *577R* allele and the *577X* allele. The *577X* allele codes for a very short protein fragment in muscle fibres due to a stop codon mutation. The table summarises the athletic potential for the three possible genotypes for the *ACTN3* gene.

***ACTN3* genotype**	**Athletic potential**
577R / 577R	good sprinter
577R / 577X	average sprinter or long-distance runner
577X / 577X	good long-distance runner

A scientist tested sprinters to see if they possessed the *577R* allele. Samples were obtained from athletes' muscle fibres. A standard containing proteins of the same lengths as the proteins coded for by both alleles *577X* and *577R* was used as a comparison.
The standard and the samples were exposed to gel electrophoresis. In gel electrophoresis, protein molecules separate according to size and charge in the same way as DNA molecules.
The result for the standard is shown in the diagram.



a On a separate piece of paper, draw the above diagram and draw the bands expected for an average long-distance runner and for a good long-distance runner. (2 MARKS)

b Explain why these bands should be in these positions. (2 MARKS)

c Explain the purpose of the standard ladder. (2 MARKS)

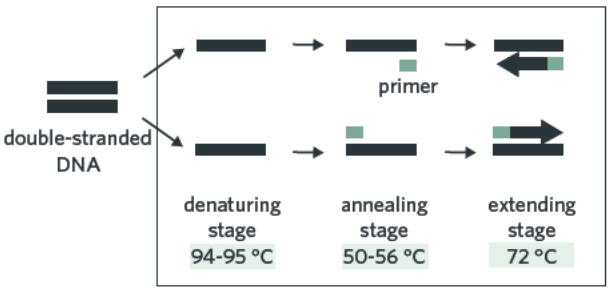
Adapted from VCAA 2012 Exam 2 Section B Q2b

Question 18 (5 MARKS)

The diagram represents the polymerase chain reaction.

a Describe what happens to the DNA when the mixture is heated during the denaturing stage. (2 MARKS)

b Explain why the temperature was reduced in the annealing stage and then increased in the extending stage. (3 MARKS)



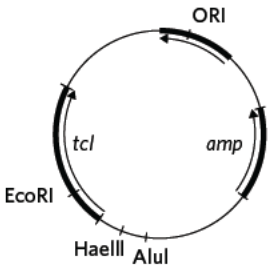
Adapted from VCAA 2018 Section A Q28

Question 19 (10 MARKS)

A particular bacterial plasmid contains recognition sites for the restriction enzymes EcoRI, *Alu*I, and HaeIII, along with two antibiotic-resistant genes, ampicillin resistance (*amp*) and tetracycline resistance (*tcl*), and an origin of replication (ORI). Scientists are attempting to insert the human gene for insulin into the plasmid for bacterial transformation.

a Explain how plasmids can be used to make bacteria produce human insulin. (3 MARKS)

b The diagram shows the positions of these recognition sites and antibiotic-resistant genes as well as the position of the origin of replication within this plasmid.



The restriction enzyme EcoRI was used to insert a gene coding for human insulin into this plasmid.

i Draw and label a diagram to show the position of the human insulin gene in this plasmid when EcoRI is used. Include the position of the recognition sites for the restriction enzymes AluI and HaeIII on the plasmid. (1 MARK)

ii After the scientists had carried out the steps required to make plasmids with the inserted human gene, these plasmids were mixed with a culture of bacteria. This mixture was treated so that these plasmids would move into the bacterial cells. Not all bacteria took up these plasmids. Explain how scientists can extract transformed bacteria from the sample. (2 MARKS)

c The table outlines the recognition sites of each of the restriction enzymes used.

Restriction enzyme	Recognition sequence (read in 5′ to 3′ direction)
EcoRI	G* A A T T C C T T A A *G
AluI	A G* C T T C* G A
HaeIII	G G* C C C C* G G

Source: Genome Research Limited, in Your Genome, <www.yourgenome.org>

i With reference to the recognition site, describe the difference between EcoRI and the other restriction enzymes. (2 MARKS)

ii Explain the benefit of using EcoRI instead of AluI or HaeIII to cut the plasmid. (2 MARKS)

Adapted from VCAA 2017 Section B Q9a

UNIT 4 AOS 2, CHAPTER 16

Biology and society

16

16A The ethics of manipulating DNA

16B Genetic modification for agriculture

16C Modern disease management

16D Rational drug design

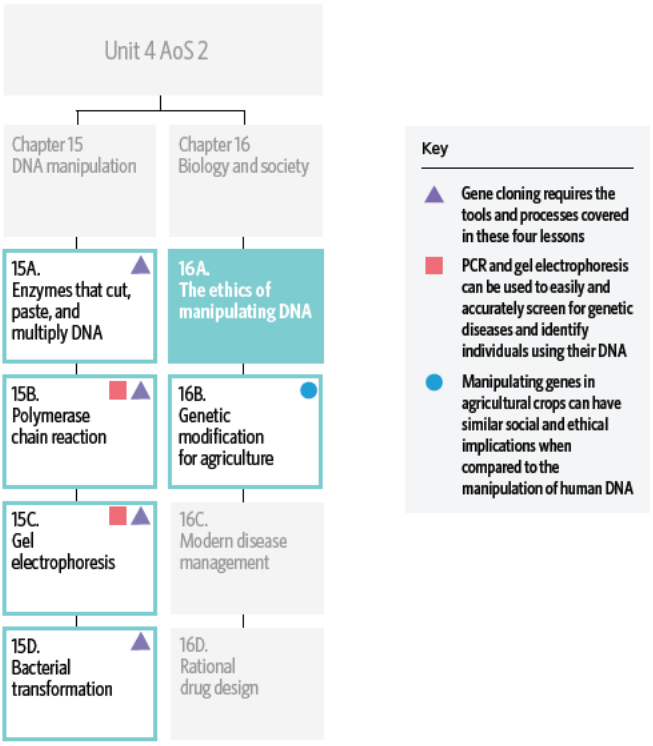
Key knowledge

- techniques that apply DNA knowledge (specifically gene cloning, genetic screening, and DNA profiling) including social and ethical implications and issues
- the distinction between genetically modified and transgenic organisms, their use in agriculture to increase crop productivity and to provide resistance to insect predation and/or disease, and the biological, social, and ethical implications that are raised by their use
- strategies that deal with the emergence of new diseases in a globally connected world, including the distinction between epidemics and pandemics, the use of scientific knowledge to identify the pathogen, and the types of treatments
- the use of chemical agents against pathogens including the distinction between antibiotics and antiviral drugs with reference to their mode of action and biological effectiveness.
- the concept of rational drug design in terms of the complementary nature (shape and charge) of small molecules that are designed to bind tightly to target biomolecules (limited to enzymes) resulting in the enzyme's inhibition and giving rise to a consequential therapeutic benefit, illustrated by the Australian development of the antiviral drug Relenza as a neuraminidase inhibitor

Image: Calin Tatu/Shutterstock.com

16A THE ETHICS OF MANIPULATING DNA

Science fiction no more! By manipulating DNA we have the potential to radically change the fundamental structure of the world we live in. But will we create a universal paradise, or will our control of genetics lead to a worldwide dystopia?



In this lesson you will learn how recent advances in DNA manipulation technologies, including the use of gene cloning, genetic screening, and DNA profiling, are rapidly changing the world in which we live. However, many of these advances must be considered in terms of their potential social and ethical consequences.

Study design dot point

- techniques that apply DNA knowledge (specifically gene cloning, genetic screening, and DNA profiling) including social and ethical implications and issues

Key knowledge units

Gene cloning	4.2.5.1
Genetic screening	4.2.5.2
DNA profiling	4.2.5.3
Social and ethical implications of DNA manipulation	4.2.5.4

Gene cloning 4.2.5.1

OVERVIEW

Many diseases can be linked to malfunctioning proteins caused by mutations in the genetic code. Recently, scientists have found ways to **clone** particular genes for therapeutic benefit. These cloned genes can be used to treat disease by mass producing specific proteins and giving them to a patient who has a malfunctioning version of that protein, or by directly inserting the healthy cloned gene into the patient's genome.

clone to make a genetically identical organism or section of DNA

THEORY DETAILS

Bacterial gene cloning

In 15D, you learned that we can insert target genes into bacterial plasmids (which can then be inserted into bacteria) using gene editing techniques. This is one of the most widely-used types of gene cloning. We use this technique to produce and harvest specific proteins for use in medicine and industry.

Many consider bacterial sources of medicinal protein to be more ethical than non-bacterial sources. For instance, the two widespread proteins insulin and human growth hormone were historically harvested from the bodies of cattle, pigs, and humans. Now, with the use of transformed bacteria, they can be mass produced quickly, ethically, and safely.

Image: Orawan Pattarawimonchai/ Shutterstock.com

Figure 1 Diabetes can be treated by injecting insulin proteins made from transformed bacteria which can synthesise the human insulin protein.

In vivo and *ex vivo* gene therapy

Scientists hope that they will soon be able to treat many genetic disorders with **gene therapy**. Gene therapy involves replacing malfunctioning alleles with normally functioning alleles. This insertion of an allele can be done by directly integrating an allele into the DNA of a host organism, or by introducing transformed bacteria into a cell.

In vivo is latin for 'in the body', and refers to a procedure where a gene is inserted into a patient's cells without those cells being removed first. An ***ex vivo*** procedure involves removing cells or tissues, inserting a gene into these cells in a lab, and then returning these modified cells. *Ex vivo* procedures are considered safer as you can tell if the cells are responding as expected before returning them to the body.

gene therapy the use of genetic technologies to treat genetic disorders

ex vivo scientific processes being performed on cells, tissues, or organs outside of the body

in vivo processes or experiments performed in the body

Gene therapy is usually more effective if performed on a zygote because all the cells that develop from the zygote will have the normal gene. In contrast, gene therapy on somatic or differentiated cells only affects those particular cells. Gene therapy can be achieved using viral vectors and CRISPR-Cas9.

Viral vectors

Cloned pieces of DNA can be directly inserted into the genome of an organism with viral vectors. By doing this, the target cells can express the normal form of a protein.

Viruses have an inherent ability to insert their genetic material into a host's nuclear DNA, so we can use them to insert target genes into particular sections of DNA. Viruses are modified using the same gene editing techniques used to make recombinant plasmids (15D).

Theoretically, these technologies could be used to treat genetic diseases or facilitate genetic modification by replacing faulty genes with properly functioning ones. For instance, the use of viral vectors to integrate healthy alleles as a treatment for cystic fibrosis is currently being explored. However, once inserted, these alterations are permanent and the widespread use of these technologies concerns many academics due to the potential unforeseen consequences in later life. Additionally, any modifications to germline cells have the potential to be inherited by subsequent generations. This will alter allele frequencies in the population, impacting the process of evolution. For now, these concerns mean viral vectors are used sparingly in humans and are subject to extensive clinical trials before use.

CRISPR-Cas9

In 15A, you learned about the specificity of restriction enzymes that can be used in genetic modification. While this increases the accuracy of a procedure, the scope of **genetic engineering** is restricted to the total amount of restriction enzymes available. Restriction enzymes are also costly, as you often have to purchase individual enzymes from companies.

genetic engineering the use of genetic technologies to alter DNA and RNA

The new CRISPR-Cas9 technique provides an exciting alternative to the traditional restriction enzyme method. Similar to restriction enzymes, the Cas9 protein was originally used by bacteria to fend off viral attacks. The Cas9 protein uses a guide RNA to recognise and cleave invading DNA. By specifically constructing this guide RNA, we can teach the Cas9 protein to recognise a specific sequence of DNA and cut it. The Cas9 protein is a DNA tool that can recognise and cut any section of DNA more quickly and effectively than even the best restriction enzymes.

Theoretically, the Cas9 protein can be used to insert, alter, or remove genes in almost any location in an organism's genome.

lesson link In **15A** you learned about restriction enzymes. The recently discovered Cas9 protein is not a restriction enzyme but acts similarly to restriction enzymes. Both Cas9 and restriction enzymes are types of endonuclease.

Due to ethical considerations, genetic modification using the Cas9 protein is used sparingly when modifying plant and animal genomes, and its use is almost nonexistent in humans. However, in the future, the Cas9 protein may prove to be a safe and precise tool for use in both *in vivo* and *ex vivo* gene therapies, and in the creation of genetically modified organisms.

Case study

We can also clone whole organisms by nuclear transfer. Dolly the sheep (born 1996) was the first example of a cloned mammal using nuclear transfer from a somatic cell. The process involved transferring the nucleus from a somatic sheep cell into an enucleated egg cell (egg cell with the nucleus removed) of another sheep. The modified egg cell then developed similarly to a regular zygote. Using the nuclear DNA of specialised cells (such as a skin cell) is much less successful than using the DNA from a zygote or stem cell.

Genetic screening 4.2.5.2

OVERVIEW

Our genes determine who we are and many of the diseases that we are likely to develop throughout our lifetimes. Genetic screening can allow us to predict and plan for these genetic diseases.

THEORY DETAILS

We can test an individual's DNA to determine their susceptibility to particular genetic diseases. This can be really helpful for patients and families to understand the disease, and for doctors to prescribe treatments. However, before we can check someone's DNA, we must first obtain a sample, which can be taken either before or after birth.

Prenatal screening has the potential to identify abnormalities early in a pregnancy. This early identification can allow planning for or the treatment of genetic diseases, which can significantly improve outcomes for patients. Without treatment many of these genetic diseases can reduce the quality of life, or even threaten the life of both the foetus and the mother. Doctors have two main ways of DNA sampling in prenatal screening:

- **Amniocentesis** – a doctor samples foetal cells suspended in amniotic fluid (Figure 2a).
- **Chorionic villus sampling** (CVS) – a doctor samples foetal cells within the chorionic villi which are adhered to the placental wall (Figure 2b).

amniocentesis sampling amniotic fluid from within the womb for use in genetic screening

chorionic villus sampling sampling cells adhered to the placental wall for use in genetic screening

genetic screening testing an individual's DNA to characterise their susceptibility to particular genetic diseases

Prenatal **genetic screening** is by no means compulsory. However, genetic screening is likely to be recommended by a doctor if:

- the mother is over 35
- the mother has a history of abnormal pregnancies
- there is a family history of genetic diseases
- the mother has undergone previous testing which indicate an increase in risk.

It is important to note that what may seem like insignificant external influences can have massive impacts on the growth, development, and overall health of foetuses. There can be risks associated with these screening processes, but most doctors agree that the benefits of prenatal screening outweigh the risks.

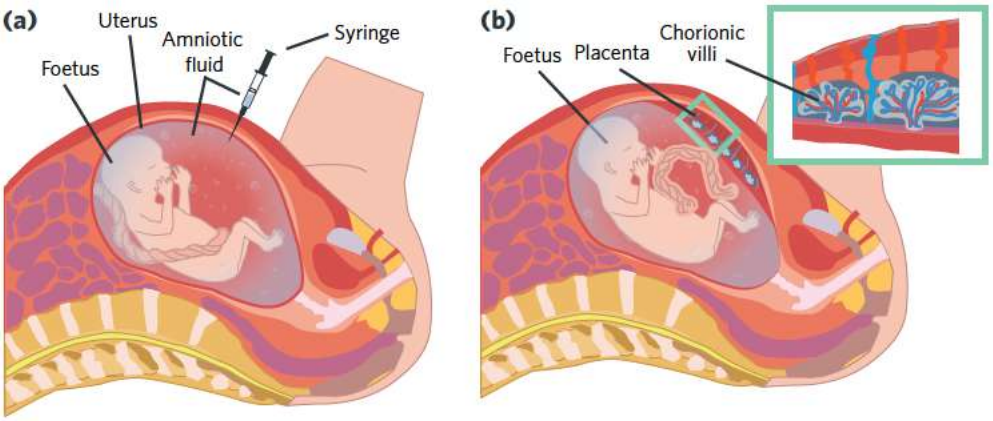


Figure 2 The procedures of **(a)** amniocentesis and **(b)** chorionic villus sampling

After an individual is born, genetic screening is much easier. DNA is usually extracted from blood cells. The risks associated with DNA sampling after birth are less than those associated with DNA sampling in the womb, although the prenatal identification of defects may prove much more useful.

Once the genetic information of the individual has been obtained, there are a few options to determine their susceptibility to a genetic disease. Gel electrophoresis can be used to determine if the disease-causing alleles are present. Otherwise, alleles can be tagged with a fluorescent mRNA strand, or the entire genome can be sequenced and searched for disease-causing alleles. Unfortunately, we do not know the exact causes of many genetic diseases. Instead, we have identified alleles which seem to increase an individual's risk of developing a disease. Therefore, experts generally only indicate the likelihood of an individual's chance of developing a disease.

Only certain genetic diseases are screened for within Australia, including cystic fibrosis, Huntington's disease, and chromosomal abnormalities. Other countries screen for a different set of genetic diseases. Some factors considered when choosing to screen for disease include:

- the cost of screening for the disease
- the severity of the genetic disease
- the rate of incidence of the disease
- the accuracy of the screening test.

lesson link In ***15C***, you learnt about gel electrophoresis. This process is often used in genetic screening and DNA profiling.

DNA profiling 4.2.5.3

OVERVIEW

With only a single swab of the cheek or a drop of blood, we can determine the identity and relatedness of individuals with high accuracy.

THEORY DETAILS

Imagine that you are an officer of the law who is investigating a murder. The crime scene is covered with blood and fingerprints, which you believe belong to the perpetrator. Before the recent advances in DNA technologies, you would be forced to utilise neanderthalic investigational techniques such as: following leads, talking to witnesses, or matching fingerprints. Nowadays, we can extract minute amounts of DNA from these samples and match it to the DNA of our suspects. Unfortunately, we cannot construct a **DNA profile** with only trace amounts of DNA, but by using the polymerase chain reaction (PCR), we can increase the total amount of testable genetic material.

DNA profiling the process of identification using genetic information. Also known as **DNA fingerprinting**

short tandem repeats (STR) short, repeated sequences of nucleotides found in the non-coding regions of nuclear DNA

lesson link Refer back to ***lesson 15B*** if you wish to revise the polymerase chain reaction.

While it is possible to sequence an entire genome from this material to match a DNA sample to an identity, this method is both costly and time-consuming. Instead, it is currently much easier to analyse **short tandem repeats (STRs)** in a piece of DNA. These STRs are small sections of repeated nucleotides found in the non-coding areas of autosomal chromosomes which vary in length between people. Because they are found in non-coding regions, they are not affected by natural selection, and many hundreds of variant STRs can be found in the DNA of each person. If the STRs in two pieces of DNA match, we can say with confidence that the two pieces of DNA belong to the same person.

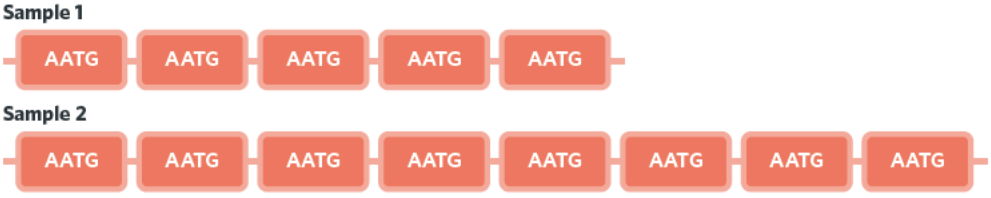


Figure 3 Two variants of the common TPOX STR. Sample 1 repeats five times, and sample 2 repeats eight times.

Using DNA profiling, we can also discover how related two people are. This is particularly useful in parental testing, when the identity of one of the parents is not known. Because many of the STRs that we use are found exclusively on autosomal chromosomes, the child must inherit half of their STRs from each one of their parents. In addition to identifying criminals and parental testing, DNA profiling has been used to identify dead bodies, match potential organ donors, or find lost relatives.

One of the ways scientists construct a DNA profile is by using gel electrophoresis. Scientists run a gel focusing on particular STRs, where each variant of a STR will separate according to size. If the individual is heterozygous for a STR it will appear as two bands in the gel and if they are homozygous it will appear as one thick band in the gel (Figure 4). In this way, scientists can accurately and efficiently match two samples of DNA.

Conclusions

- DNA from the victim and individual 2 were found at the crime scene.
- DNA from individuals 1 & 3 match, so they must be either from the same person or identical twins.
- DNA from individuals 3 & 4 share at least one STR for every locus, and would be related by a parent-child or sibling relationship.

Table 1 The DNA profiles of a victim, crime scene and four other individuals using short tandem repeat (STR) analysis. Numbers indicate the number of repeats.

	victim	crime scene	1	2	3	4
CSF1PO	7, 13	7, 12, 12, 13	10, 14	12, 12	10, 14	8, 10
TPOX	12, 12	6, 7, 12, 12	10, 12	6, 7	10, 12	12, 12
THO1	5, 11	5, 9, 11, 13	7, 7	9, 13	7, 7	7, 11

Case study

After disasters such as the 2002 Bali bombings, the 2004 Thai tsunami, and the 2001 September 11 attacks, the bodies of victims were often in a state too dire to identify conventionally. In these cases, DNA profiling proved effective at identifying bodies.

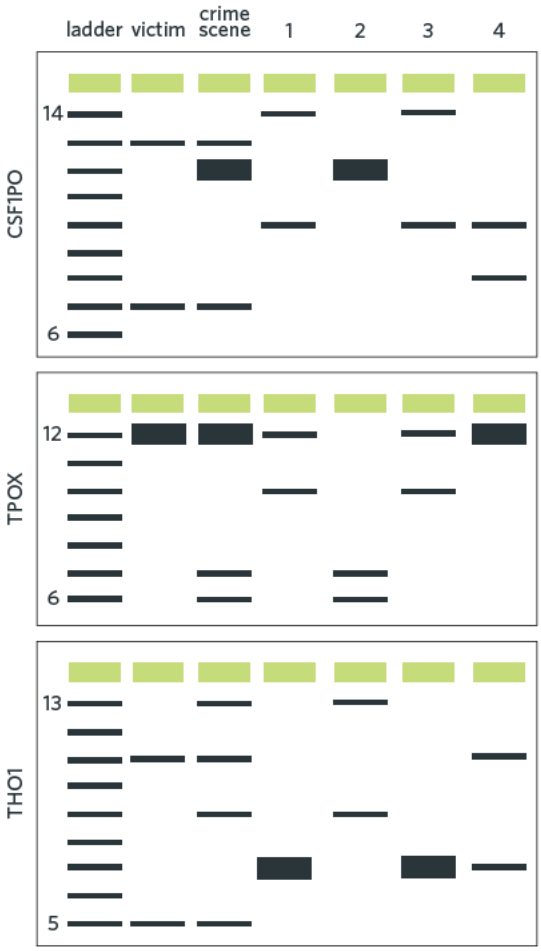


Figure 4 Gel electrophoresis sample using DNA samples from a victim, crime scene, and four other individuals

Social and ethical implications of DNA manipulation 4.2.5.4

OVERVIEW

Gene manipulation technologies, including those of gene cloning, genetic screening, and DNA profiling, have proven to be extremely useful tools in today's world. However, if used improperly or irresponsibly, the potential social and ethical consequences would be massive, and must be considered fully if further integration of these procedures into our society is to occur.

social implications consequences that affect economics, politics, or society

ethical implications considerations based on moral or religious beliefs

THEORY DETAILS

Table 2 Key social and ethical benefits concerning the use of gene cloning, genetic screening, and DNA profiling

	Social benefits	Ethical benefits
Gene cloning	• Treating diseases using gene cloning may reduce pressure on hospitals • An increase in population size may benefit the economy	• Gene cloning facilitates the efficient production of vital proteins such as insulin, removing the need to rely on animals • Gene cloning and therapies may save lives and increase the life expectancy of patients
Genetic screening	• The early identification of diseases could reduce pressure on overburdened hospitals	• Genetic screening can allow people to prepare for or treat a genetic disease • Genetic screening can help parents make an informed choice on whether to continue a pregnancy
DNA profiling	• It can be used to identify and convict perpetrators of crimes	• It can determine parental lineage • It can identify the deceased after tragedies for family closure and burial • It can assist in matching organ donors and patients

Table 3 Key social and ethical consequences concerning the use of gene cloning, genetic screening, and DNA profiling

	Social consequences	Ethical consequences
Gene cloning	• Will need tight regulation by government bodies as heritable gene therapies could have widespread negative impacts on a population's fitness • Will there be equity of access? • An increase in population size may result in overpopulation	• May be considered 'playing God' by many groups and people • Which diseases and gene therapies should be researched?
Genetic screening	• May result in genetic based discrimination from employers and insurance agencies • Governments may construct a genetic database, which can be considered an invasion of privacy • Requires policy regarding the selection of pregnancies	• Potential to harm foetus and mother • Groups may object to genetic testing and associated pregnancy termination • Many people may not want to know what diseases they will develop, or have their genome sequenced
DNA profiling	• What organisations have access to genetic data? • Who has ownership of the genetic data?	• People may object to having their DNA sequenced • Personal DNA data may be leaked • The results are not always reliable

Theory summary

DNA manipulation technologies can be used to shape and manipulate our world. Gene cloning technologies could have a massive impact within the medical field in the future. Genetic screening could change the way we deal with genetic diseases. Finally, DNA profiling can assist in the identification of criminals and families. However, before any of these technologies can be accepted into our society, we must weigh up their benefits and dangers to ensure we integrate these technologies in the most efficient, safe, and moral way possible.

16A QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ sections of DNA found in non-coding regions that are commonly used in DNA profiling
b _____ these experimental processes do not take place inside an organism
c _____ a genetically identical sequence of nucleotides or organism
d _____ the use of DNA manipulation techniques to treat a genetic disease
e _____ these experimental processes take place within the organism
f _____ analysing a sequence of DNA to determine identity or parental lineage
g _____ genetic alterations using DNA manipulation techniques
h _____ the process of analysing the genetic makeup of an individual to determine genetic diseases

Question 2

Which of the following is not an example of an *in vivo* process?

A Using viral vectors to insert a DNA fragment into nuclear DNA without first extracting cells.
B Treating a genetic disease using CRISPR techniques during in-utero embryonic development.
C Extracting bacterially synthesised proteins for use in therapies.
D Using the Cas9 protein to insert a DNA fragment into cells within an organism.

Question 3

Which of the following statements regarding DNA technologies is false?

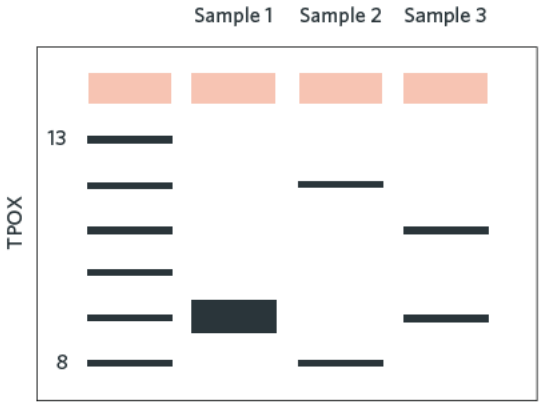
A DNA profiling uses viral vectors to insert foreign genes.
B Genetic screening can allow for early treatment of certain diseases.

C Many people object to gene therapy on moral grounds.

D Short tandem repeats are commonly used to identify individuals in DNA profiling.

Question 4

Scientists can use DNA profiling to identify individuals or determine relatedness.



Fill in the blanks in the following sentences.

Sample 2 is _____**I**_____ at the allelic locus for the TPOX _____**II**_____. The DNA profile for this individual at the TPOX locus is _____**III**_____.

	I	II	III
A	Homozygous	Gene	7, 9
B	Heterozygous	STR	8, 12
C	Homozygous	Gene	9, 9
D	Heterozygous	STR	9, 11

Question 5

Choose the most correct classification of the following statements.

I Rachel decided to terminate the pregnancy after discovering her unborn foetus was positive for trisomy 21, acting against her religious beliefs.

II Patients rarely have ownership over their sequenced DNA data.

III Laws may need to be established which prevent insurance companies from discriminating against individuals based on their genetic screening results.

IV Paternity testing could occur without the consent of all parties.

V Certain religious demographics may object to genetic engineering technologies.

VI Taxes may decrease due to a reduction in hospitals upkeep after the widespread use of gene therapy.

VII Gene therapy may increase the life expectancy of treated individuals.

VIII Government organisations may construct a database of citizen's genetic information.

IX Due to gene cloning, we no longer harvest rennet from calves for the production of cheese, reducing unnecessary suffering.

	Social consideration	Ethical consideration
A	I, II, IV, VI, VIII	III, V, VII,
B	II, VI, VIII	I, III, IV, V, VII, IX
C	I, III, V, VIII, IX	II, IV, VI, VII
D	III, V, VI, VIII	I, II, IV, VII, IX

Exam-style questions

Within lesson

Question 6 (1 MARK)

Advances in DNA technology have made it possible to carry out genetic screening for particular genetic diseases. Some people may decide not to have children based on the result of their genetic screening. This decision will

A increase the frequency of disease-causing alleles and will, therefore, have an impact on future human evolution.

B have no impact on future human evolution since there are no new selection pressures.

C alter the structure of particular alleles and, therefore, have an impact on future human evolution.

D decrease the genetic variation within the human population and will, therefore, have an impact on future human evolution.

Adapted from VCAA 2015 Section A Q39

Question 7 (1 MARK)

Defective alleles may result in genetic defects.

The replacement of a defective allele with a normal allele is called

A genetic engineering.

B DNA profiling.

C CRISPR.

D gene therapy.

Adapted from VCAA 2011 Exam 2 Section A Q3

Question 8 (1 MARK)

The main purpose of screening programs for newborn babies is to

A identify the risks of certain diseases and enable early treatment.

B record and document complete genetic screenings for all babies born in Australia.

C splice out malfunctioning DNA and replace it with healthy genotypes.

D allow parents to make informed choices to continue with a pregnancy.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q34

Use the following information to answer Questions 9 and 10.

Sufferers of the disease cystic fibrosis (CF) produce thick, sticky mucus in their airways. Scientists are trialling a gene transfer technique to introduce the normal allele for the gene *(CFTR)* into some CF diseased airway cells. The normal allele for the gene is introduced into the airway cells in delivery particles that have been built using highly modified components of the HIV-1 (AIDS) virus.

Question 9 (1 MARK)

Scientists are using the modified HIV-1 virus because

A viruses readily accept foreign DNA into their nuclei.

B viral DNA can insert itself into a host's nuclear DNA.

C HIV positive individuals are immune to cystic fibrosis.

D the HIV-1 virus will express the healthy *CFTR* gene once inside the cell.

Question 10 (1 MARK)

In this example of gene therapy, the treatment is successful if the

A patient is infected with the HIV-1 virus.

B HIV-1 virus does not trigger an immune response.

C viral DNA is inserted into the nuclear DNA of the host.

D airway cells begin expressing the normal *CFTR* gene.

Adapted from VCAA 2012 Exam 2 Section A Q9

Question 11 (1 MARK)

Congenital adrenal hyperplasia (CAH) encompasses a group of autosomal recessive genetic diseases arising from mutations in genes encoding for proteins associated with the production of several hormones by the adrenal gland. CAH is most common among individuals of Native American and Inuit descent.

CAH is screened for in the USA, but not in the UK or Victoria, Australia.

A factor that would influence the decision by the Victorian state government health department to not carry out screening for CAH is that

A it is unethical to inflict the pain necessary to carry out the screening test.

B the disease can be effectively treated after birth and therefore does not need to be screened for.

C the percentage of individuals affected with CAH in Victoria is low.

D the screening test for CAH commonly returns a false positive.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q35

Question 12 (1 MARK)

The following diagram summarises the steps involved in the production of a cloned sheep.

Sheep Q suffers from an autosomal recessive disease that inhibits healthy liver function. Sheep M and N do not have the same recessive allele as Sheep Q.

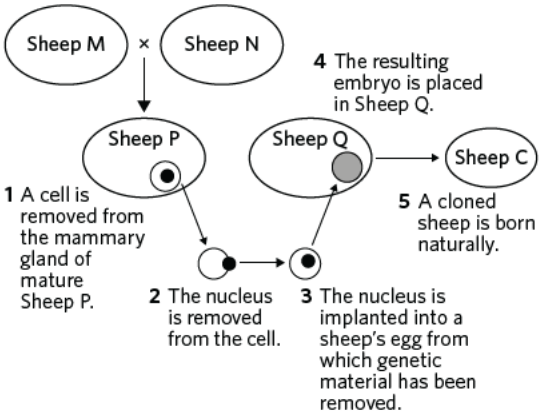
What is the chance that Sheep C suffers from this liver disease?

A 0%

B 25%

C 50%

D 100%



Adapted from VCAA 2017 Sample Exam Section A Q40

Question 13 (1 MARK)

Genetic screening can allow doctors and parents to assess the risk of an infant suffering from or developing certain genetic diseases. The process of genetic screening takes place in many countries across the world.

Which of the following is not an ethical concern regarding genetic screening?

A The fitness of an individual may decrease by altering their DNA.

B Many individuals may not want to know if they will develop a disease.

C Parents may terminate a pregnancy based on the results of the genetic screening.

D The genetic screening procedure has a small chance to harm the infant.

Question 14 (1 MARK)

DNA profiling uses short tandem repeats (STR) in a person's DNA, to help determine the genetic relationship between individuals.

STR	Individual 1	Individual 2	Individual 3	Individual 4	Individual 5
CSF1PO	8, 10	9, 10	9, 10	6, 9	9, 10
TPOX	11, 12	5, 13	11, 13	11, 15	5, 14
D21S11	24, 31	24, 31	24, 31	5, 33	5, 24
D8S1179	7, 12	12, 13	12, 12	8, 12	8, 13

	Individual 1	Individual 2	Individual 3	Individual 4	Individual 5
Gender identifier	male	female	female	female	male

DNA profiles based on four STRs for five individuals are shown. The results of a gender identifier are also shown.

Which one of the following conclusions can be made using the information given?

A Individual 1 could be the mother of Individual 2.

B The parents of Individual 3 could be Individual 1 and Individual 2.

C Individual 5 could be the child of Individual 2 and Individual 4.

D The parents of Individual 2 could be Individual 4 and Individual 5.

Adapted from VCAA 2017 Section A Q39

Question 15 (3 MARKS)

Citrus greening is a disease that affects citrus trees, such as orange trees. The disease is caused by the bacterium *Candidatus Liberibacter asiaticus.* These bacteria are transferred to the trees when insects called psyllids feed on the sap in the leaves. The bacteria live in the plants' nutrient-conducting tissues (phloem) causing the slow death of the trees.

A solution to this disease uses a gene from a spinach plant, which codes for a defensins protein. The defensins protein binds to and punches holes in the bacteria, breaking them apart.

Genetic engineers have inserted the defensins gene into a viral vector. The viral vector is a modified form of a virus that normally infects citrus trees. The genetically engineered viral vectors were placed in many orange trees through small incisions in the trees' bark. After several years growth, all of the treated trees were very healthy while all of the untreated trees nearby were affected by citrus greening.

a Explain how the viral vector has been used to promote resistance to citrus greening in treated trees. (2 MARKS)

b Resistance to citrus greening can be seen in the offspring of individuals treated with the viral vector. Identify one ethical concern scientists may have regarding this treatment. (1 MARK)

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q39

Multiple lessons

Question 16 (1 MARK)

The steps taken to produce genetically engineered insulin are in the wrong order.

1 Using filters, locate and identify transformed bacteria

2 Make the gene which encodes for the production of human insulin

3 Cut the plasmid using restriction enzymes or Cas9

4 Determine the amino acid sequence of human insulin

5 Expose bacteria to the recombinant plasmids

6 Extract and isolate insulin from human cells

7 Devise a relevant nucleotide sequence using the amino acid sequence

8 Culture transformed bacteria; harvest and purify the insulin

9 Insert constructed gene into cut plasmids

The correct sequence of steps when producing insulin is

A 7, 2, 3, 4, 9, 5, 1, 8, 6.

B 2, 3, 9, 5, 1, 8, 6, 4, 7.

C 6, 4, 7, 2, 5, 9, 3, 1, 8.

D 6, 4, 7, 2, 3, 9, 5, 1, 8.

Adapted from VCAA 2013 Section A Q34

Question 17 (1 MARK)

Bacteria are used in gene cloning because they

A can accept and replicate foreign plasmids in a short period of time.

B can insert their DNA into the host's nuclear genome.

C replicate and evolve quickly.

D readily infect living organisms.

Adapted from VCAA 2015 Section A Q25

Question 18 (1 MARK)

Genetic testing can be used to test for the allele for Huntington's disease (HD). The onset of HD predominantly occurs in adulthood.

Eight foetuses were screened for HD. The diagram shows the gel electrophoresis results of a test for the presence of the allele. Individuals 3 and 5 have been identified as being likely to suffer from HD now or in the future.

Which other individual is likely to suffer from HD now or in the future?

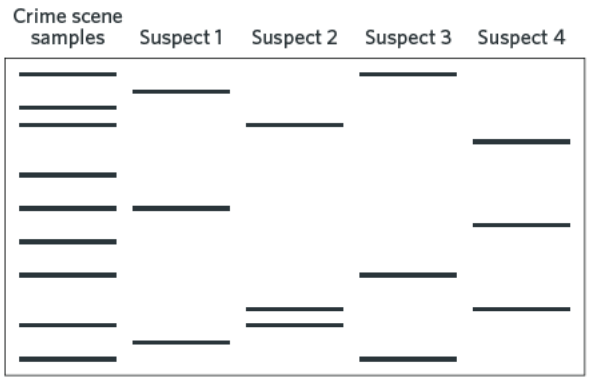
A 1
B 4
C 6
D 8

Adapted from VCAA 2018 Section A Q34

Question 19 (4 MARKS)

Following a break-in, police found multiple blood samples at the scene of the crime which did not match any of the owners. The police compared extracted DNA from the blood samples with DNA from a list of four potential suspects, using gel electrophoresis.

All five samples were loaded into five different wells. The results of the gel electrophoresis are shown.



a Identify the suspect who was most likely at the crime scene. (1 MARK)

Adapted from VCAA 2017 Sample Exam Section A Q37

b The police used polymerase chain reaction (PCR) during the DNA profiling process. Explain why the police used PCR. (1 MARK)

c While some scientists have recognised the potential benefits of using DNA profiling to assist identification in the future, other scientists have expressed concern.

State one potential benefit some scientists have recognised and one concern other scientists have had. (2 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section B Q9e

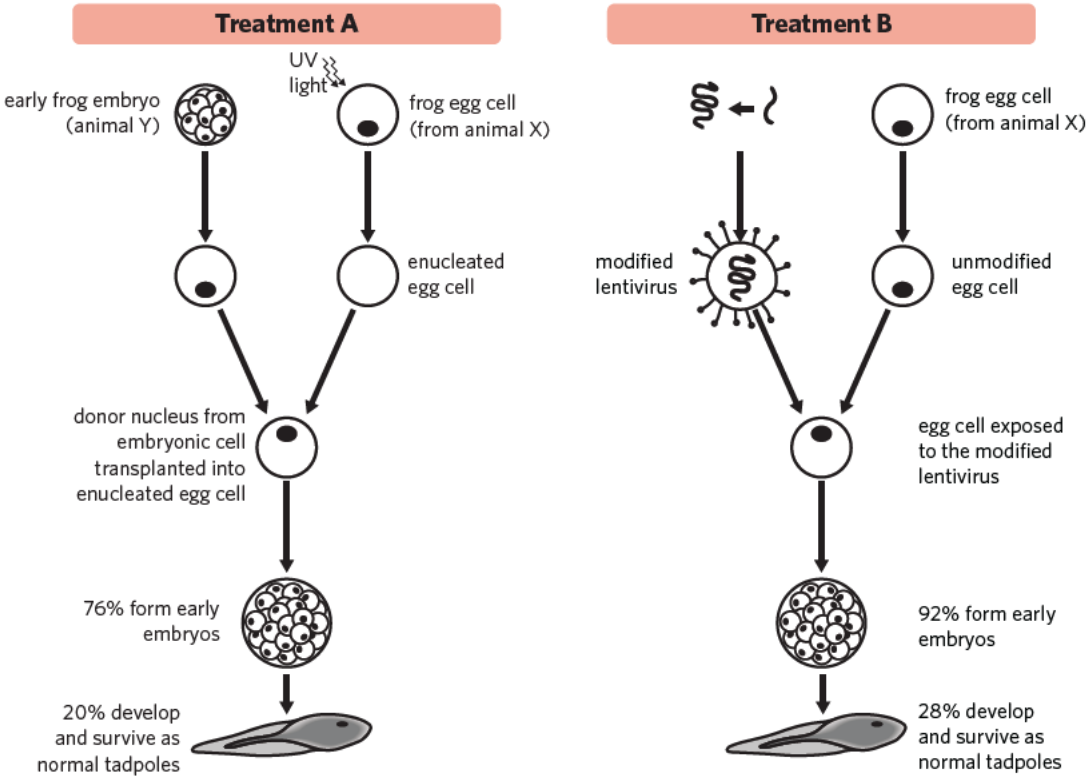
Key science skills

Question 20 (8 MARKS)

Frog X suffers from a genetic disease which inhibits the early growth of embryos. The genetic disease is caused by a mutation which prevents the expression of a single gene. A group of scientists performed an experiment to test the effectiveness of two potential treatments of the disease.

a Describe the difference between *in vivo* and *ex vivo*. (1 MARK)

b Both treatments are summarised in the flowchart.



i Compare the genetic makeup of the final tadpole in treatment A with animal Y and the final tadpole in treatment B with animal X. (2 MARKS)

ii What were the scientists testing in the experiment? Using the information in the flow chart, explain what the scientists likely concluded. (2 MARKS)

iii The scientists did not use a control in their experimental design.

Design an experimental control and explain its use in the context of this experiment. (2 MARKS)

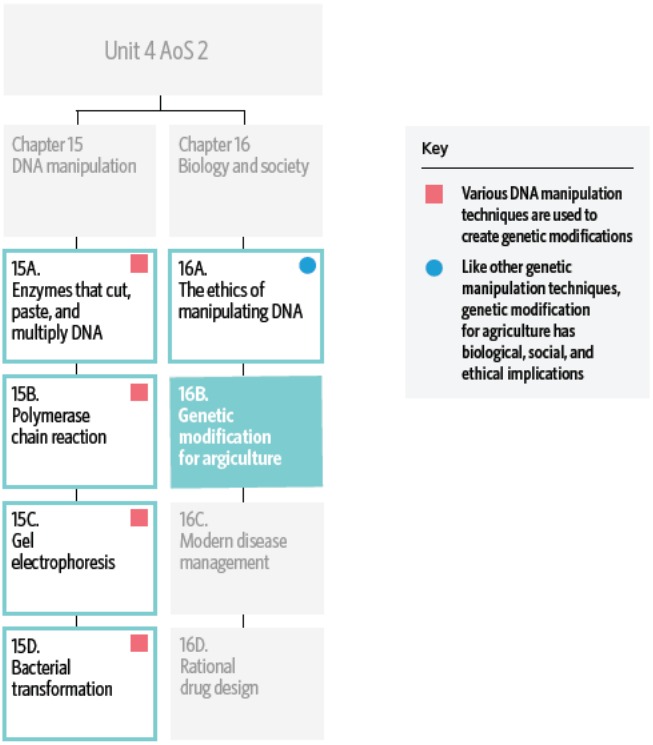
Adapted from VCAA 2013 Exam Section B Q12

iv Scientists decided to test the success rate of interspecies nuclear transfer techniques by modifying treatment A. The modified treatment A involved sourcing a donor nucleus from an embryonic cell of a different species.

Compare the likely outcome of the modified treatment A with the current treatment A. (1 MARK)

16B GENETIC MODIFICATION FOR AGRICULTURE

From making glow-in-the-dark fish to tomatoes that stay fresh, there is a world of possibilities with genetic modification.



In this lesson you will learn about the different types of genetically modified organisms (GMOs) that are possible, and look at some real-world applications of GMOs. We will also cover the biological, ethical, and social implications of GMO use.

Study design dot point

- the distinction between genetically modified and transgenic organisms, their use in agriculture to increase crop productivity and to provide resistance to insect predation and/or disease, and the biological, social, and ethical implications that are raised by their use

Key knowledge units

Transgenic vs GMO	4.2.6.1
How we use GMOs	4.2.6.2
Issues surrounding GMOs	4.2.6.3

Transgenic vs GMO 4.2.6.1

OVERVIEW

Here you will learn the difference between genetically modified and transgenic organisms.

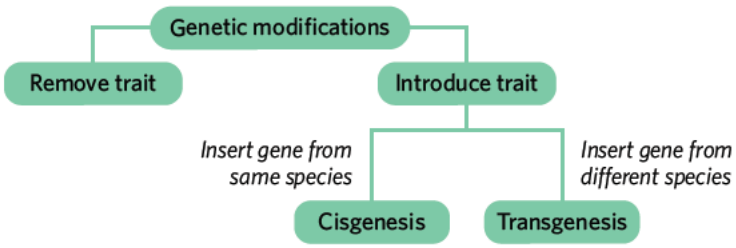


Figure 1 Diagram showing the relationship between genetic modification and transgenesis

THEORY DETAILS

Genetic modification, also known as genetic engineering, is a broad term describing the alteration of an organism's genome using technology in order to give them desirable traits.

Genetic modification may involve genes being:

- inserted into the genome
- removed from the genome
- silenced post-transcriptionally
- altered by replacing single nucleotides.

An organism that contains one of these genetic modifications is referred to as a **genetically modified organism (GMO)**. This process is typically done using viral vectors that incorporate DNA into the genome of the host organism. The process of inserting a gene from the same species into the genome of an organism is called cisgenesis. If the inserted gene comes from a different species then it is called transgenesis. An organism containing DNA from another species is termed a **transgenic organism (TGO)**. Therefore, all TGOs are GMOs, but not all GMOs are TGOs.

Scientists have genetically modified bacteria, plants, and animals since the early 1970s for academic, medical, agricultural, and industrial purposes. In this lesson, we will be focussing primarily on the agricultural uses of GMOs.

genetically modified organism (GMO) an organism with genetic material that has been altered using gene engineering technology

transgenic organism (TGO) a type of GMO that contains genetic material from another species that has been artificially introduced

Case study

Genetically modified (GM) salmon

In 1989, salmon were genetically modified so they could grow all year-round instead of mostly only during spring and summer. The increased growth rate of these GM salmon meant they could be sold earlier, making them cheaper to grow compared to non-GM salmon. Scientists created these salmon by inserting a growth hormone-regulating gene from another salmon species which was attached to a promoter gene from another fish called a pout (Figure 2a). This DNA construct results in higher expression of growth hormone in all tissues of the fish, following the same widespread expression pattern as the promoter from the pout. The resulting DNA construct was injected into newly fertilised salmon eggs, where it incorporated into the genome (Figure 2b). This method results in a transgenic salmon that is able to express the growth hormone-regulating gene all year round and pass down this trait to its offspring (Figure 2c).

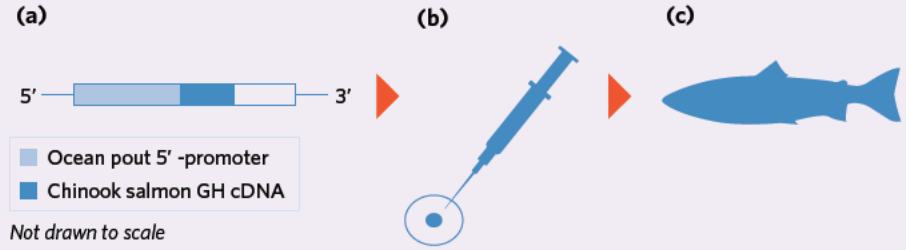


Figure 2 **(a)** The DNA construct containing a promoter from pout and a growth hormone-regulating gene from salmon. **(b)** Injection of the DNA construct into a fertilised salmon egg. **(c)** A GM salmon with increased growth ability.

lesson link Humans have been using selective breeding ***(lesson 11E)*** regimes for thousands of years to increase desired traits within domestic crop and animal populations. Although this technique may result in similar outcomes to gene modification techniques, it is not considered genetic modification since direct manipulation of the genome using gene technology is not involved.

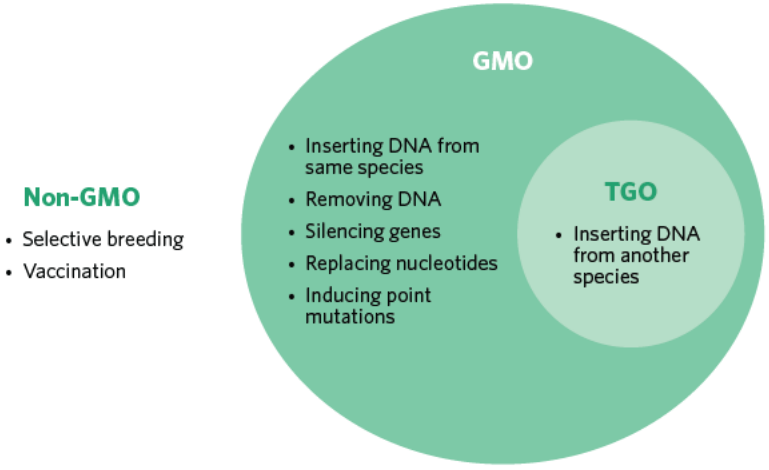


Figure 3 Venn diagram showing the distinctions between GMOs, TGOs, and non-GMOs

Tip VCAA does not explicitly test your knowledge of how GMOs are made. However, they do expect you to be able to identify whether an organism is GMO, TGO, or non-GMO based on a description of how it was made.

How we use GMOs 4.2.6.2

OVERVIEW

Currently, there are over 26 GM crops that are commercially grown worldwide. The following table shows some of the major GM crops.

Table 1 The most widely used GM crops worldwide

GM Crop	Introduced traits	Hectares grown worldwide in 2017
Soybean	• herbicide tolerance • increased oleic acid	94.1 million
Maize	• herbicide tolerance • insect resistance • increased lysine • drought tolerance	59.7 million
Cotton	• herbicide tolerance • insect resistance	24.1 million
Canola	• herbicide tolerance • high laurate	10.2 million
Tomato	• delayed ripening • salt tolerance	< 1 million
Rice	• increased beta-carotene	< 1 million
Papaya	• virus resistance	< 1 million
Potato	• virus resistance • reduced asparagine	< 1 million

Adapted from The International Service for the Acquisition of Agri-biotech Applications [ISAAA], 2017

THEORY DETAILS

The use of GMOs in agriculture has increased dramatically since the first GM crop, Flavr Savr tomatoes, was put on the market in 1994. In 1996, GM crops took up only 1.7 million hectares of land area worldwide. By 2017, this figure had increased to 189.8 million hectares. In this section we will look at some of the major genetic modifications to crops.

Bt crops

Bacillus thuringiensis (Bt) is a bacterium that produces protein crystals that are toxic to many insect species that affect crop plants but are not toxic to humans. If ingested, the toxin activates in the insect's intestines, causing it to die within a couple of days. Scientists have cloned the crystal toxin genes from Bt and introduced them into crops, allowing the plants to produce their own Bt toxin. This modification creates transgenic plants that have **insect resistance**. These toxins are activated once they are ingested by insects, which stop feeding on the plant within a few hours. Plant species such as canola, cotton, maize, tobacco, rice, and eggplant are modified to contain Bt toxins.

insect resistance a trait that gives plants extra chemical defences that kill attacking insects

Golden rice

Golden rice was developed in response to vitamin A deficiency, which is a major cause of preventable blindness in children. Vitamin A deficiency is particularly prevalent in developing countries that don't have good access to expensive vitamin A-rich foods such as eggs, dairy, and liver. Rice is a staple food in many of these countries, which inspired scientists to develop a strain of rice with increased vitamin A content to provide people with an easily accessible source of vitamin A.

Figure 4 Golden rice compared to regular rice

Golden rice was developed by inserting two genes into its genome: the *PSY* gene from a daffodil (*Narcissus pseudonarcissus*) and the *CRTI* gene from a soil bacterium (*Pantoea ananatis*). These genes cause the rice to store beta-carotene, a precursor of vitamin A, in the rice grains rather than in the leaves as normal rice would. This results in rice with a higher beta-carotene content, giving them their distinct yellow colour. Since the two genes inserted into the rice genome come from different species, golden rice is considered transgenic.

Roundup Ready

Roundup Ready plants were developed in 2003 to give agricultural crops **herbicide tolerance**. Roundup Ready crops contain a gene from a bacterium (*Ochrobactrum anthropic*) that gives them tolerance to the chemical glyphosate, which is the active ingredient in the herbicide called Roundup. Farmers can spray their crops with Roundup to kill weeds, but their GM Roundup Ready crops remain unharmed.

Herbicide tolerance with Roundup Ready is widely used in soybeans, maize, canola, sugar beetroot, cotton, and alfalfa. Since the gene inserted into Roundup Ready crops comes from a different species, they are considered transgenic.

herbicide tolerance a trait that increases a plant's resistance to chemicals typically toxic to plants

GM food genetically modified crops that are used for human or animal consumption

Issues surrounding GMOs 4.2.6.3

OVERVIEW

Like with many new technologies, GMOs have been criticised due to various biological, social, and ethical implications.

THEORY DETAILS

Tomato paste made with genetically modified Flavr Savr tomatoes appeared on the market in 1996. It initially outsold non-GM paste due to its lower price; reduced processing costs made GM tomato paste 20% cheaper. In 1998, sales dropped dramatically after perceptions of **GM foods** began to turn negative, largely due to a television broadcast involving Dr. Arpad Pusztai. He claimed that feeding GM potatoes to lab rats caused major negative health effects. Although his claims were later disproven before a committee, the negative public perceptions towards GM foods still remain. Whilst there are many serious biological and social consequences of using GM crops, this example illustrates that there are also many misconceptions regarding GMOs that have shaped the public's view.

Now you will take a look at the three GMOs that were discussed in the previous section and look at their biological, social, and ethical implications in detail.

Tip VCAA exams do not test your memory of facts relating to the examples given, these are just examples that are commonly used in exams. VCAA typically gives their own explanation of a GM crop and then tests your understanding of:

- whether the crop is transgenic or not.
- why was this GM crop developed? What issue is it addressing?
- biological, social, and ethical implications of the GM crop.

Bt crops

PROS

Bt crops contain a genetic modification that confers resistance to insect pests, the main pest in Australia being the cotton bollworm (*Helicoverpa armigera*). In Australia, GM cotton requires only 15% of the insecticides needed for non-GM cotton, reducing costs for farmers. Fewer pesticides also means less damage to ecosystems and non-target species such as ladybugs and spiders. Bt cotton leads to higher crop yields due to less predation from pests.

CONS

A major problem with Bt cotton is that it has become less effective since its introduction due to increased resistance among *Helicoverpa* populations. There are also other pest species that are not affected by Bt toxin which may actually increase in number due to fewer insecticides being sprayed over Bt crops. In Australia, cotton is picked using machines but in India it is picked by hand, where some workers have developed skin allergies, which they believe are due to the Bt proteins. Additionally, it is illegal for farmers to keep Bt cotton seeds to use in the next season as the seeds are declared the legal property of the biotechnology company that made them. As a result, farmers must buy new seed each year, which may cost more than the money saved by using them.

Table 2 Summary of the biological, social, and ethical implications of Bt crops

	Explanation
Biological implications	• Requires less pesticide use, which is better for the environment • Less damage to ecosystems and non-target species • Higher crop yields • Pest species have evolved resistance • Pests unaffected by Bt may thrive • Cross-pollination between GM and non-GM crops
Social implications	• Requires less pesticide use which saves farmers money • Workers may develop skin allergies • Farmers must buy expensive seeds each season
Ethical implications	• Farmers have fewer rights since they don't own the seed

biological implications consequences that affect ecosystems, environments, or public health

social implications consequences that affect economics, politics, or society

ethical implications considerations based on moral or religious beliefs

Golden rice

PROS

Golden rice has increased beta-carotene content, which may help people in developing countries avoid vitamin A deficiency. Less vitamin A deficiency means fewer incidences of preventable blindness and fewer deaths, resulting in increased socioeconomic levels and public morale. Golden rice seeds can even be kept and replanted the next season, making it significantly cheaper than other GM seeds. Trials of golden rice have also shown that it is safe to eat. It has also been shown that cross-pollination between GM rice and non-GM rice is unlikely as rice plants predominantly self-pollinate.

CONS

Some groups are worried that widespread use of golden rice could reduce crop biodiversity. In terms of GM crops, golden rice has received little backlash from the public.

Table 3 Summary of the biological, social, and ethical implications of golden rice

	Explanation
Biological implications	• Improves health • Reduced incidence of blindness • Fewer deaths • Widespread use could reduce crop biodiversity
Social implications	• Fewer deaths results in improved socioeconomic levels • Farmers may save rice for next harvest, increasing profits
Ethical implications	• There are many misconceptions about the safety of eating golden rice and some people choose not to eat them

Roundup Ready

PROS

Roundup Ready plants are glyphosate-tolerant. This means that glyphosate, the active ingredient in Roundup herbicide, may be sprayed over farmers' crops to kill weeds without killing the crop. Doing this means less manual labour is required to remove weeds, which saves on labour costs. Furthermore, weeding loosens the soil and increases runoff when it rains, which can pollute nearby water systems. Widespread use of glyphosate could also be beneficial since it is less toxic to wildlife than other herbicides.

CONS

A major issue with Roundup Ready is that many weeds, termed 'superweeds', have developed resistance to glyphosate, making the Roundup herbicide ineffective. To combat this, GM crops containing tolerance to multiple different herbicides are used in combination with a cocktail of herbicides. Some people are concerned that Roundup Ready crops could pass on the herbicide tolerance trait to weeds. While this is somewhat plausible for some plants such as canola, most crops are not sexually compatible with weeds. Cross-pollination between Roundup Ready crops and nearby non-GM crops is possible though, and can result in the non-GM farmer being sued since they do not own the rights to grow that GM crop.

Table 4 Summary of the biological, social, and ethical implications of Roundup Ready

	Explanation
Biological implications	• Reduces soil runoff • Less toxic than other herbicides • Evolution of "superweeds" makes it less effective • Cross-pollination between GM and non-GM crops
Social implications	• Requires less labour • Farmers must buy expensive seeds each season
Ethical implications	• Some people consider charging farmers in poorer countries for expensive GM seeds each year is unethical

Field trials

In Australia, only two GM crops have been approved for cultivation: Bt canola and Bt cotton. For a GM crop to be approved, it must first go through rigorous testing and field trials before it can be approved by the Office of the Gene Technology Regulator (OGTR), which approves all GMOs in Australia.

Field trials are vital as they assess:

- the effects of GM crops on wildlife such as pests and non-target insects
- the effects of GM crops on nearby non-GM crops
- how well a GM crop actually grows in an agricultural setting.

Field trials are an important step in the process of ensuring the safety, ecological impact, and public trust in Australian-grown GM crops.

Tip VCAA exams do not expect you to memorise implications for specific GM crops, but they do expect you to use common sense to suggest implications based on a scenario. Therefore, it would help to know some implications that apply generally to most GM crops and also to practice thinking of logical implications for GM crops not discussed in this book.

Theory summary

One of the most important uses of GMOs is in agriculture, where traits such as insect resistance and herbicide tolerance are introduced into crops to benefit people. The use of GMOs in agriculture has many biological, social, and ethical implications that must be weighed against each other to decide if a GMO is worth using or not.

Table 5 Summary of some of the biological, social, and ethical implications of GMOs

	Explanation
Biological implications	PROS • GM crops usually have better crop productivity than non-GM crops. This means that more food can be grown using less land, reducing habitat loss due to land clearing • Insect-resistant GM plants require fewer pesticides, which is better for the environment • GM foods can be made to have improved nutritional content, improving the health of individuals CONS • GM crops may lose their effectiveness if weeds or pests evolve resistance • Widespread use of GM crops could result in loss of genetic diversity within crop populations • Cross-pollination between GM crops and wild species or weeds may cause genes to spread
Social implications	PROS • Increased crop productivity means more food can be produced, leading to better food security • Crops that are able to grow in more adverse conditions (e.g. drought-tolerant corn) protect against famine, improving food security • Herbicide-tolerant crops reduce labour demands as farmers don't need to pull weeds by hand • Increased crop yields result in larger profits for farmers • GM foods can be made to have improved flavour and texture, giving consumers a more appealing product • GM foods can be made to have improved nutritional content. This leads to reduction in nutritional deficiencies, creating healthier populations CONS • Having to buy new seeds each season may be costly for farmers • Complex legal issues surrounding the use of GM products may cause farmers stress
Ethical implications	PROS • Some people believe that not using a technology such as genetic modification to improve agriculture and ultimately peoples' lives is wrong CONS • Some people consider GMOs to be unnatural, or like we are 'playing God' • Some people believe that GM foods are unsafe to eat and choose not to eat them as a result • Some people believe that genetically modifying animals for human benefit is inhumane — many anti-animal GMO arguments apply to animal agriculture in general • The fact that companies can own the rights to GM crops is considered by some to be unethical due to companies making unfair demands of farmers – Cross-pollination of non-GM crops by nearby GM crops could result in the non-GM farmer being sued by the patent-owner – Farmers can't reuse seeds from some GM crops and must buy new expensive seed each year from biotechnology companies

16B QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ crops used for human and animal consumption that have been genetically modified

b _____ implications of GM foods that relate to individuals' personal beliefs

c _____ an organism whose DNA has been altered using gene technology

d _____ implications of GM foods that affect society, politics, and economics

e _____ an organism that has had DNA inserted from a different species using genetic engineering technology

f _____ implications of GM foods that have environmental or health consequences

Question 2

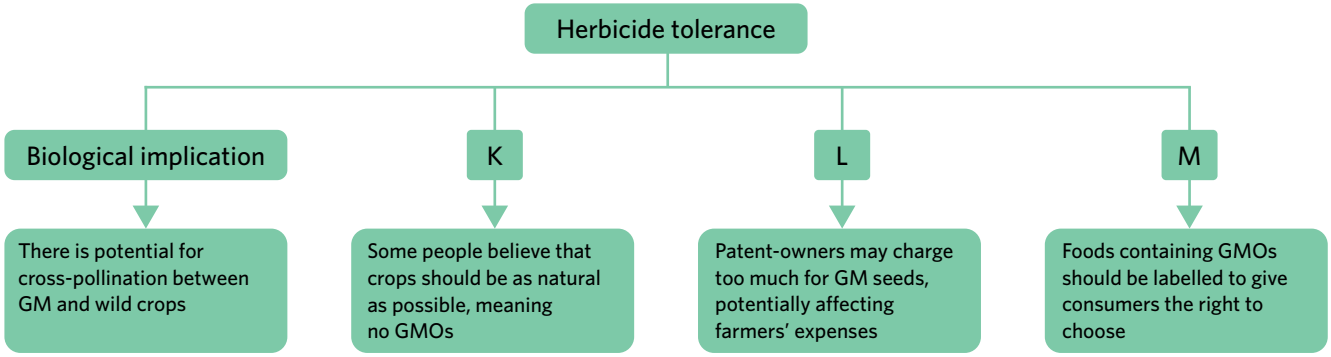
What belongs in the spaces X, Y, and Z in the table?

Product name	Introduced trait	Transgenic?
GM salmon	Grows faster	Yes
Bt cotton	X	Yes
Golden rice	Improved beta-carotene	Z
Roundup Ready corn	Y	Yes

	X	Y	Z
A	Herbicide tolerance	Insect resistance	Yes
B	Insect resistance	Herbicide tolerance	Yes
C	Herbicide tolerance	Insect resistance	No
D	Insect resistance	Herbicide tolerance	No

Question 3

The diagram shows four implications of herbicide-tolerant GM foods. What type of implications do K, L, and M represent?



	K	L	M
A	Biological implication	Social implication	Ethical implication
B	Ethical implication	Ethical implication	Social implication
C	Ethical implication	Social implication	Ethical implication
D	Biological implication	Ethical implication	Social implication

Question 4

Classify each of the following statements as either non-GMO, GMO, or TGO in the table.

NOTE: The GMO column excludes TGOs.

I A gene is removed from the genome

II A single nucleotide base is changed from a guanine to a thymine

III A gene from a different species is inserted into the genome

IV An allele from a different individual of the same species is inserted into the genome

V The organism is crossed with a closely related species to produce hybrid offspring

VI A gene in the organism is silenced

VII A vaccine containing an attenuated virus is injected into a patient, causing their immune system to give them resistance

VIII Scientists design a vector that inserts DNA from a different species into the genome of germ cells

IX Selective breeding is used to increase the frequency of a trait in a population

	non-GMO	GMO	TGO
A	V, VII, IX	I, II, IV, VI	III, VIII
B	IX	I, II, VI	III, IV, V, VII, VIII
C	IX	I, V, VIII	II, III, IV, VI, VII
D	V, VI, IX	I, II, III, IV	VII, VIII

Question 5

Which of the following options contains all correct statements about golden rice?

A	It is a transgenic organism	It is a good source of vitamin A	An ethical implication is that it improves nutrition by increasing vitamin A intake	A social implication is that farmers must buy new seeds each year, which can be expensive
B	It is not a transgenic organism	It is an accessible source of vitamin A	A social implication is that farmers can save rice to be used in the next harvest	The genes inserted into golden rice occur in other species naturally, therefore it is not transgenic
C	It is a transgenic organism	It contains high levels of beta-carotene	The *PSY* gene from daffodil is considered a transgene when inserted into golden rice	A biological implication is that its large-scale adoption may pose a threat to crop biodiversity
D	It is not a transgenic organism	It is an accessible source of vitamin A	A biological implication is that herbicide resistant genes may spread to weeds	An ethical implication is that creating GM foods is 'tampering with nature'

Exam-style questions

Within lesson

Question 6 (1 MARK)

All genetically modified organisms

A contain at least some genetic material obtained from another species.

B produce at least some mRNA that is not naturally produced in that species.

C have at least one gene that is removed or silenced.

D have at least one section of their DNA that has been altered by scientists.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q31

Question 7 (1 MARK)

All transgenic organisms

A contain at least some genetic material obtained from another species.

B have at least one gene that is removed or prevented from being transcribed.

C contain a gene from another species that gives them herbicide tolerance.

D have at least one gene that is silenced by genetic material obtained from another species.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q31

Question 8 (1 MARK)

Some people object to the use of GM animals on the grounds that the animals are genetically modified for human benefit and not for the animal's benefit. This would be an example of

A a biological implication.

B an ethical implication.

C a social implication.

D a legal implication.

Use the following information to answer Questions 9 and 10.

Cotton is an Australian crop grown for its fibres that may be spun to produce clothing, towels, and other fabrics. Due to the large number of insect pests that feed on cotton, particularly the cotton bollworm, insecticides must be extensively used in its production. These insecticides harm non-pest insect species, are expensive, and may have effects on human health too. A solution to this is Bt cotton, a strain of cotton that contains two genes from the soil bacterium *Bacillus thuringiensis*. These genes encode proteins that disrupt the digestive system of the cotton bollworm. If a cotton bollworm eats part of a Bt cotton plant, these proteins will enter its gut and kill it.

Question 9 (1 MARK)

Which of the following statements regarding Bt cotton is false?

A Bt cotton is transgenic because it contains genes from a bacterium.

B Bt cotton requires less pesticide use than regular cotton.

C Yields from Bt cotton crops will be lower than regular cotton due to the *B. thuringiensis* genes having a negative effect on plant growth.

D The proteins encoded by the *B. thuringiensis* genes are harmful to cotton bollworms.

Question 10 (1 MARK)

The role of the inserted genes from *B. thuringiensis* are to

A improve the fibre density of cotton.

B give Bt cotton resistance to insecticides that are routinely used.

C kill cotton bollworms that ingest Bt cotton.

D stimulate the plant's immune system to help fight off cotton bollworms.

Use the following information to answer Questions 11 and 12.

The *Anopheles* genus of mosquito are vectors for the malaria parasite *Plasmodium*. In an attempt to reduce the spread of malaria, researchers in the lab have developed sterile male *Anopheles* that are unable to produce sperm. These mosquitoes were created by using CRISPR technology to remove a gene that is vital for sperm development. Female *Anopheles* only mate once, so mating with these sterile males would result in that female producing no offspring.

Question 11 (1 MARK)

Which of the following statements is true?

A The lab strain of *Anopheles* is not transgenic since no foreign DNA has been introduced.

B The *Anopheles* male mosquitoes developed in the lab are transgenic since they contain DNA from another species.

C The removal of the gene in lab *Anopheles* does not count as genetic modification since the fitness of the mosquito is not improved.

D The *Anopheles* strain developed in the lab is considered transgenic since its genome has been altered.

Question 12 (1 MARK)

A likely biological implication of introducing sterile male *Anopheles* into the wild is that

A the wild *Anopheles* population would decrease due to non-viable matings between wild females and sterile males.

B the introduced DNA in the sterile males could spread to other *Anopheles* species.

C wild *Anopheles* may inherit the gene that makes males sterile resulting in extinction of the species.

D the spread of malaria will decrease due to the introduced gene found in the sterile male mosquitoes.

Question 13 (6 MARKS)

Should we grow GM crops?

by Mary Nguyen

More than 25 years after genetically modified (GM) food first appeared, growing GM crops remains a hotly debated topic. Some people argue that GM crops are the only way to feed the growing world population and to minimise environmental harm. Other people express different views.

Bt cotton is a type of cotton that contains two genes from a soil bacterium, *Bacillus thuringiensis*, enabling it to produce insect-resistant proteins. Australian farmers of Bt cotton use only 15% of the quantity of the insecticide that was once needed to protect their cotton crops. However, Bt cotton is not as resistant to the main insect pest of cotton crops, *Helicoverpa*, as it has been in the past.

In Australia, Bt cotton is picked by machine, but in India, it is picked by hand. Workers in India have developed skin allergies, which have been attributed to Bt cotton proteins.

Traditionally, farmers have saved money by keeping seed from one year's crop to plant the following year. However, it is illegal for farmers to keep Bt cotton seeds because these seeds have been declared the legal property of the company Monsanto. Every year, cotton farmers must buy more seeds from Monsanto.

Unlike Monsanto, the company that produces the GM food crop Golden Rice allows farmers to replant the rice they harvested the previous year. By inserting a gene from the bacteria *Erwinia uredovora* and another from a daffodil, *Narcissus pseudonarcissus*, into white rice, scientists produced Golden Rice – a rice variety containing higher levels of vitamin A. People who eat Golden Rice avoid vitamin A deficiency. Trials conducted in several countries have shown that Golden Rice is safe to eat.

Source: CSIRO, Paine et al. (2005), & Coghlan (2018), as cited by VCAA 2018 Section B Q10.

a People have different views when it comes to GM foods. State one ethical implication of GM foods. (1 MARK)

b Explain how planting golden rice can lead to improved public health in poorer countries. (1 MARK)

c Using information from the article:

- **i** Describe one biological implication that supports the use of golden rice. (1 MARK)
- **ii** Describe one social implication that supports the use of golden rice. (1 MARK)
- **iii** Describe one biological implication that supports the use of Bt cotton. (1 MARK)
- **iv** Describe one biological implication that opposes the use of Bt cotton. (1 MARK)

Adapted from VCAA 2018 Section B Q10

Multiple lessons

Question 14 (6 MARKS)

Coral reefs are found in oceans around the world. Corals are animals that build up calcium carbonate skeletons. Single-celled algae live within the coral tissues. Queensland scientists have reported that many of the corals in a region of the Great Barrier Reef have recently become bleached. Bleaching occurs when the single-celled algae leave the coral tissues due to environmental changes. Corals turn white without the algae and may die. This bleaching has been attributed to an increase in water temperature and acidity.

Two approaches have been proposed to help reverse the bleaching occurring in the coral reefs.

a **Approach 1**

Scientists introduce a particular gene from bacteria that survive in highly acidic sulfur pits into the algae. Particular corals with modified algae are then reintroduced into the coral reef.

i Explain how genetic modification using this approach may help reverse coral bleaching. (2 MARKS)

ii State one social implication of this approach. (1 MARK)

b Approach 2

Scientists get algae of the same species found in these corals that are adapted to warmer climates and release them onto the Great Barrier Reef.

i Explain whether this approach is considered genetic modification or not. Justify your response. (2 MARKS)

ii State one biological implication of this approach. (1 MARK)

Adapted from VCAA 2017 Northern Hemisphere Exam Section B Q11

Key science skills

Use the following information to answer Questions 15–17.

Genetically modified crops are used in 24 countries across the world, including Australia and the USA. Australia only plants two GM crops while the USA plants over nine. The four largest GM crops are listed in the table (adapted from ISAAA, 2017) as well as the genetic modifications available in each species and the area of land (hectares) each GM crop covers in both the USA and Australia.

GM crop	GM traits available in crop	Hectares grown in 2017	
		USA	Australia
Cotton	• herbicide tolerance • insect resistance	4 580 000	432 000
Maize	• herbicide tolerance • insect resistance • increased lysine • drought tolerance	33 840 000	not approved
Soybean	• herbicide tolerance • increased oleic acid	35 050 000	not approved
Canola	• herbicide tolerance • high laurate	876 000	492 000

Question 15 (1 MARK)

From this information, it can be concluded that

A maize is not planted in Australia.

B use of GM crops has increased over the past five years.

C soybean takes up the most area of any GM crop in the USA.

D there are only four GM crops planted in the USA.

Question 16 (1 MARK)

The most widely used GM trait is

A insect resistance.

B herbicide tolerance.

C drought tolerance.

D increased oleic acid.

Question 17 (1 MARK)

Insect-resistant GM crops generally work by introducing a gene that encodes a protein that kills insects that feed on the plant. There is a concern that insects will evolve resistance to these toxic proteins and reduce the effectiveness of GM crops.
In recent years, a variety of GM maize has been developed that contains multiple different toxic proteins in order to reduce the likelihood of resistance evolving in pests. The commercial introduction of this GM maize would

A have little effect on Australian agriculture.

B increase the lysine content of maize.

C decrease maize crop productivity.

D increase the rate of mutation in insect pests.

Question 18 (6 MARKS)

Citrus greening is a disease that affects citrus trees, such as orange trees. The disease is caused by the bacterium *Candidatus Liberibacter asiaticus*. These bacteria are transferred to the trees when insects called psyllids feed on the sap in leaves. The bacteria live in the plants' nutrient-conducting tissues (phloem), causing slow death of the trees.

A solution to this disease uses a gene from a spinach plant, which codes for a defensins protein. The defensins protein binds to and punches holes in the bacteria, breaking them apart. Genetic engineers have inserted the defensins gene into a viral vector. The viral vector is a modified form of a virus that normally infects citrus trees.

The genetically engineered viral vectors were placed in many orange trees through small incisions in the trees' bark. They also kept several orange trees that did not receive the treatment to act as controls. After several years' growth, the scientists checked the trees for citrus greening. They found that none of the treated trees were affected by citrus greening while all of the untreated trees nearby were affected by citrus greening.

a Identify the independent and dependent variables in this experiment. (1 MARK)

b State what the genetic engineers' hypothesis would be. (1 MARK)

c Outline two measures that would need to be taken to ensure the results of this experiment are reliable. (2 MARKS)

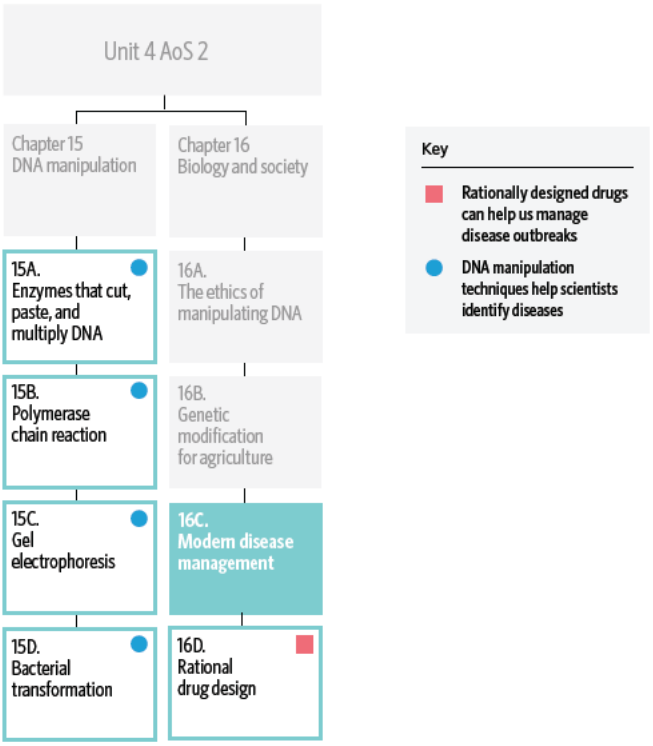
d Before governments allow the commercial production of these citrus greening-resistant orange trees, extensive field trials must be carried out by scientists.

Give two reasons why extensive field trials are necessary for GM crops. (2 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q39

16C MODERN DISEASE MANAGEMENT

How do you defeat an enemy that keeps changing and evolving? That's the challenge faced by scientists and doctors who are leading humanity's fight against pathogens and disease.



In this lesson you will learn how scientists and governments identify and deal with disease outbreaks.

Study design dot points

- strategies that deal with the emergence of new diseases in a globally connected world, including the distinction between epidemics and pandemics, the use of scientific knowledge to identify the pathogen, and the types of treatments
- the use of chemical agents against pathogens including the distinction between antibiotics and antiviral drugs with reference to their mode of action and biological effectiveness

Key knowledge units

Epidemics vs pandemics	4.2.7.1
Identifying pathogens	4.2.7.2
Strategies that deal with disease	4.2.7.3
Chemical agents of disease management	4.2.9.1

Epidemics vs pandemics 4.2.7.1

OVERVIEW

An epidemic is an outbreak of a disease that affects many people in one location. A pandemic is the spread of an epidemic to many locations globally.

THEORY DETAILS

It's scary to think about, but new **infectious diseases** are emerging all the time around the world. Many of these new diseases occur when a **pathogen** (for example, a bacteria, virus, protist, or fungus) undergoes a mutation that increases its **virulence**. If this virulent pathogen is able to go on and infect a large number of people, it is also considered highly **contagious**.

If a pathogen infects an unexpectedly large group of people it is called an outbreak.

infectious disease a disease that is caused by a microorganism and can be transmitted between individuals

pathogen an agent that causes disease

virulence the potential of a pathogen to cause harm

contagious a property of disease meaning that it can be transmitted from one organism to another through direct or indirect contact

We can classify it into one of two categories based on the geographic spread of people it has infected.

These groups are:

- **epidemic** – a sudden increase in the occurrence of a disease amongst a specific population in a specific location
- **pandemic** – an epidemic that has spread to different countries and/or continents. As such, pandemics typically affect many more people than epidemics and are much more difficult to control.

epidemic a dramatically increased occurrence of a disease in a particular community at a particular time

pandemic an epidemic that has spread across multiple countries and/or continents

Table 1 lists some important examples of epidemics and pandemics that have happened throughout human history.

Table 1 Significant epidemics and pandemics throughout history

Outbreak	Cause	Status	Distribution and Impact
The Black Death/ The Plague	*Yersinia pestis* bacteria spread from rats via fleas	Pandemic	Occurred between 1347 and 1353 throughout Europe and Asia. Killed between 30% to 60% of Europe's population during this time.
The Spanish Flu	H1N1 Influenza virus	Pandemic	Occurred between 1918 and 1920. Thought to be responsible for the deaths of 50 – 100 million people worldwide.
AIDS/HIV	Human immunodeficiency virus (HIV) spread via blood or sexual secretions	Pandemic	First reported in 1981, AIDS/HIV has gone on to infect more than 36.7 million people around the world, and has resulted in over 1 million deaths.
2015-2016 Zika fever	Zika virus spread via mosquitoes	Epidemic	A widespread epidemic of Zika fever spread from Brazil throughout South and North America.
2018 Kivu Ebola outbreak	Ebola virus	Epidemic	Outbreak of Ebola in the Democratic Republic of Congo resulting in approximately 1 000 cases.

There are a number of factors that help diseases evolve into epidemics and pandemics. These include:

- poor hygiene and sanitation – this increases the likelihood of transmission (see Table 3), especially in densely populated areas
- increased travel between populations – this allows carriers and vectors to spread pathogens over greater distances
- climate change – this may alter the distribution of pathogens and vectors
- misuse of antimicrobials – doctors sometimes prescribe antimicrobials when they are not needed. Additionally, some places around the world do not tightly regulate the use of antimicrobials. This exposes pathogens to antimicrobials more frequently or at ineffective doses and potentially allows them to develop resistance.

Tip You don't need to memorise Table 1 – its purpose is to provide context. In the past, VCAA have provided background information on a disease before testing your understanding of how pathogens are identified and what strategies could be used to overcome the outbreak.

Identifying pathogens 4.2.7.2

OVERVIEW

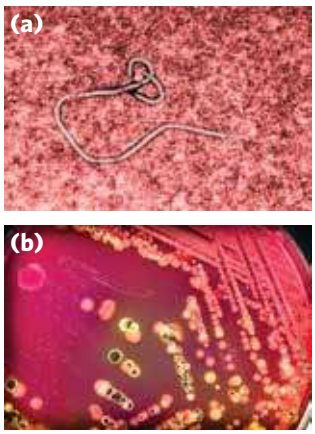
Using a variety of physical, immunological, and molecular techniques, scientists are able to identify pathogens that cause disease.

THEORY DETAILS

Pathogen identification helps scientists and health professionals know how to treat those who are already sick and limit the spread of the disease. Some of the methods scientists use to identify pathogens are summarised in Table 2.

Table 2 Methods of identifying pathogens

Method	Description
Physical	Visualising pathogens using microscopes to determine structure (Figure 1a)
	Biochemical testing, including using different media to culture the pathogen (Figure 1b)
Immunological	**Enzyme-linked immunosorbent assay** (ELISA) – scientists anchor antigens from a pathogen to a plate, then add a patient's blood to the plate. If the patient has been exposed to the pathogen, they will have antibodies that bind to the antigen. Scientists can visualise the binding of antibodies to antigens with a colour-change test.
Molecular	Hybridisation-based detection – labelled segments of genetic material that are complementary to a pathogen's genetic material are added to a sample. If a signal is generated, it means a pathogen is present.
	Amplification-based detection – PCR is used to amplify segments of DNA specific to the pathogen.
	Whole genome sequencing – provides detailed information about the pathogen, including information pertaining to its resistance.



Images: Studio_3321/Sirirat/Shutterstock.com

Figure 1 **(a)** Ebola virus visualised under microscope; **(b)** bacteria growing on selective growth media

enzyme-linked immunosorbent assay (ELISA) a technique used to identify a pathogen by determining the presence of antigen or antibodies in a sample

Strategies that deal with disease 4.2.7.3

OVERVIEW

The approach to managing a disease is complex and depends on the pathogen. Generally, strategies include identification of the pathogen, prevention, measures to control the spread of the pathogen, and treatment of those who are already sick.

THEORY DETAILS

The expression 'teamwork makes the dream work' is applicable to many things in life, and is especially relevant to disease management. When faced with a disease outbreak, many different groups of people work together to control the spread of disease and treat those who are affected.

There are many different facets of disease management, and they vary depending on the disease in question. In general, however, some of the key steps in disease management include:

- Prevention – taking steps to prevent diseases from emerging at all. Preventative measures include improving hygiene and sanitation via handwashing, sterilising surfaces and tools, ensuring access to clean water and food, and using items such as gloves and masks when dealing with sick people. Laws controlling immigration and food imports from affected populations can also prevent new outbreaks. Additionally, prevention includes vaccination, if a vaccine exists for the disease in question (Figure 2a), and educating people about how to prevent infection.
- Ongoing surveillance of disease indicators – for example, governments keep tabs on medication sales at pharmacies and look for changes that might indicate the prevalence of certain symptoms or illnesses have increased.
- Quarantine and isolation – once a person becomes ill, or has the potential to become ill (e.g. is returning home from visiting an affected area overseas), they may be separated from healthy people to ensure they don't spread their disease to them (Figure 2b).
- Identification of the pathogen – using the methods outlined in Table 2, scientists can identify the pathogen that is making people sick. This information provides guidance for managing the disease outbreak and treating the disease.
- Identify and control method of spread – if the disease is spread via a **carrier** (e.g. cattle infected with mad cow disease) or a vector (e.g. mosquitoes and yellow fever) then targeted control of the carrier/vector population can control the spread of disease. Alternatively, if the disease is spread via contaminated water (see case study) then providing access to clean water may prevent disease. Table 3 outlines common modes of pathogen transmission.
- Treatment – treatment includes symptom management, like pain relief and rehydration, and specific curative treatment, including the use of medications such as **antibiotics** and **antivirals** to target the pathogen.

Image: Rawpixel.com/Shutterstock.com

Figure 2 **(a)** vaccines are an important preventative measure against disease; **(b)** the crew of Apollo 11 in quarantine after returning from the moon.

carrier an organism that is infected with and spreads a disease

antibiotics medications used to kill bacteria or slow their growth

antivirals medications used to treat viral infections

In a coordinated response to an outbreak of a disease, all of these steps should be occurring simultaneously. By rapidly identifying a pathogen and responding to it appropriately, diseases can be managed before they become epidemics or pandemics. The specific methods of management, however, largely depend on how the disease is transmitted. Table 3 describes some of the main ways diseases are transmitted. For example, if a disease was spread via the faecal-oral route, one of the most important steps in managing the disease would be to ensure appropriate sanitation procedures, such as hand washing after toilet use, are in place.

Table 3 Summary of modes of disease transmission

Transmission route	Description
Airborne and droplet transmission	Pathogens spread in air droplets (from sneezing, coughing, or talking) or on dust particles. They can stay in the air for relatively long time periods. The flu, measles, and the common cold are spread in this manner.
Faecal-oral route	Contaminated faeces from an infected person are ingested by another person. Occurs, for example, when someone infected with a disease uses the bathroom and then opens a door without washing their hands. The cycle is complete when another person comes along, touches the contaminated doorknob, and then bites on a fingernail. Pathogens in food or water can be spread by the faecal-oral route.
Bodily fluids	Spreads pathogens such as hepatitis B and glandular fever when fluids (e.g. blood, semen, saliva, or urine) from infected individuals come into contact with the mucous membranes or blood of an uninfected individual.
Direct contact	Some pathogens, like head lice or chickenpox, are spread directly when individuals come into contact with the skin of an infected person or surface.
Vector	Occurs when diseases are not spread by infected individuals, but by contact with a **vector** in which the pathogen is living. For example, Ross River virus and malaria are spread by mosquitoes, and dogs are the vectors for rabies. Climate change may alter the distribution of vectors.

vector an organism that is not affected by a disease but spreads it between hosts

Case study

'Snow more cholera

John Snow was an English physician who was living in London during the cholera outbreak in Soho in 1854 (Figure 3). At the time, a cholera pandemic was sweeping the globe, and people thought the disease was spread via airborne particles called "miasmata." John Snow, however, investigated the distribution of cholera in a street called Broad Street and determined that the illness was not due to people breathing "bad air." Rather, by speaking to people who had been ill and tracing their movements prior to becoming ill, Snow figured out that the source of the illness was contaminated water coming from the public water pump on the corner of Broad Street. The water from this pump was being contaminated by an old cesspit that had begun to leak faecal bacteria into the water.

Snow's evidence convinced the local parish to remove the handle off the pump, preventing people from using it. Not surprisingly, cholera rates rapidly decreased. This event is considered the founding event of modern epidemiology and is a great example of how studying a disease, identifying a pathogen, and finding a way to prevent its spread are vital components of disease management.

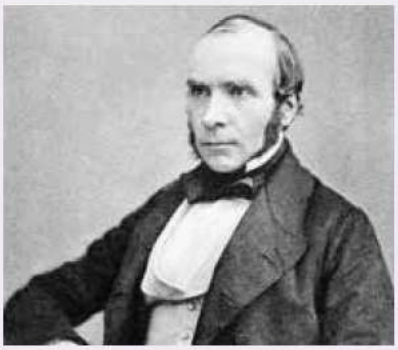


Figure 3 The man himself, John Snow

Chemical agents of disease management 4.2.9.1

OVERVIEW

Chemical agents are one of our most powerful tools in disease management. These include antibiotics and antivirals, which are used to combat bacteria and viruses, respectively.

THEORY DETAILS

Disinfectants/antiseptics

Disinfectants and **antiseptics** are used preventatively to reduce the numbers of pathogens. Disinfectants kill pathogens in the environment, whereas antiseptics are used to kill pathogens that are on the body. For example, disinfectants would be used when cleaning your kitchen bench at home, whereas the hand sanitiser you use at the hospital is an antiseptic agent. Both disinfectants and antiseptics are non-specific and affect a wide range of pathogens, including bacteria, viruses, and fungi.

disinfectant a substance that is applied to non-living materials to kill or slow the growth of microorganisms

antiseptic a substance that is applied to living tissue to kill or slow the growth of microorganisms

Antibiotics

Antibiotics are medicines that can be used to treat diseases caused by bacteria. They either work by killing bacteria (called bactericidal) or by slowing bacterial growth (called bacteriostatic). **Broad-spectrum** antibiotics affect a number of different types of bacteria, whereas **narrow-spectrum** antibiotics affect only a few specific varieties.

broad - spectrum agent a type of antimicrobial agent that affects a wide variety of microorganisms

narrow - spectrum agent a type of antimicrobial agent that affects a small variety of microorganisms

In order for antibiotics to be useful to us, we need them to be selective for bacteria. That is, we need them to target bacterial cells without harming the cells of the patient. We do this by ensuring that the antibiotic's mechanism of action targets a biochemical pathway or component that is unique to bacteria and that is not present in patient cells. Different classes of antibiotics work by targeting different components of bacterial cells. Figure 4, however, shows five key targets for antibiotics that are unique to bacteria and aren't present in humans.

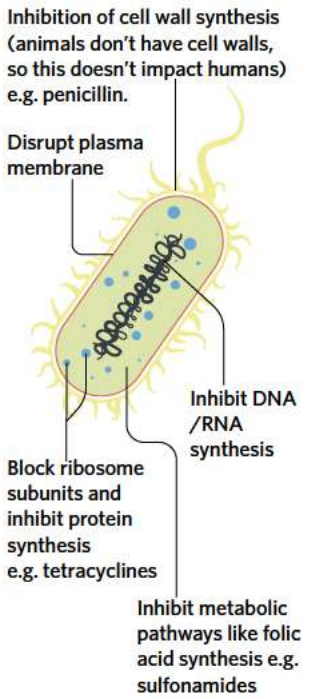


Figure 4 Key targets of antibiotics

Antivirals

Antivirals are medicines that can be used to treat diseases caused by viruses. Like antibiotics, in order for antivirals to be useful, we need them to target viruses and not the cells of the infected organism. This is a little tricky with viruses, however, because viruses are non-cellular pathogens that hijack living cells to replicate. Nevertheless, there are some good pathways that antivirals can target that are unique to viruses. These are shown in Figure 5.

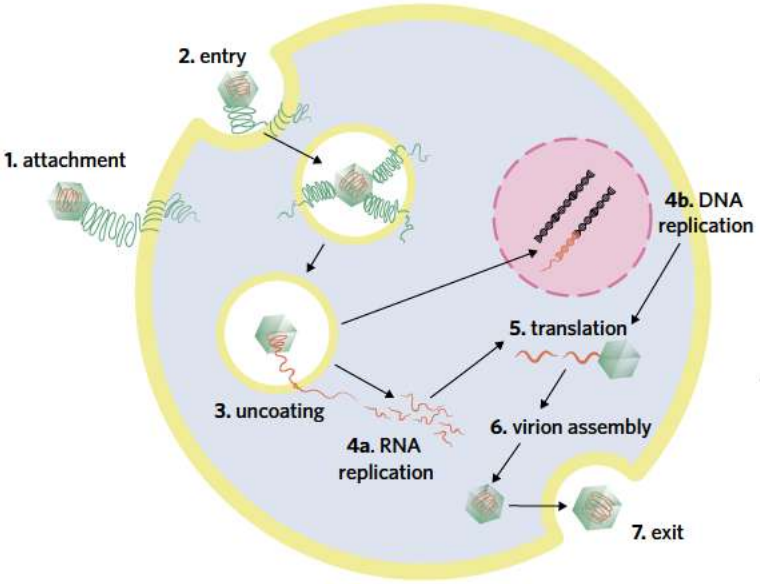


Figure 5 Key targets of antivirals

lesson link Relenza, discussed in ***lesson 16D***, is an example of an antiviral drug. It works by stopping the exit (7) of the virus from the host cell.

Resistance to chemical agents

Unfortunately, just as we get better at fighting pathogens, pathogens get better at fighting back against us. One of the most problematic areas in modern medicine is the issue of **antimicrobial resistance**.

antimicrobial agent an agent that kills or slows the growth of microorganisms. Includes antiseptics, disinfectants, antifungals, antivirals, and antibacterial agents

antimicrobial resistance the ability of a microorganism to survive exposure to an antimicrobial agent

conjugation process in which bacteria exchange genetic material via direct cell-to-cell contact

Pathogens have evolved resistance to all forms of chemical agents. Some pathogens have evolved to have extra thick, waxy cell walls that prevent them from being killed by disinfectants and antiseptics. Some bacteria have evolved ways of deactivating and/or degrading enzymes used in antibiotics. Resistance to antivirals can also evolve in viruses.

It is very important to understand how this resistance comes about. Genes encoding traits that provide resistance to antimicrobial agents may already exist in a pathogen or arise from spontaneous mutations. These genes are passed on through replication and through **bacterial conjugation**. This is a process in which bacteria can transfer plasmids that contain antimicrobial resistance genes to bacteria of the same, or a similar, species.

When we expose a patient to an antibiotic, for example, all of the bacteria that are susceptible to that antibiotic will be killed. If some bacteria, however, are resistant they will survive the exposure to the antibiotic and will go on to replicate. Not only this, they will share these antibiotic-resistant genes to other bacteria via transformation. In this way, the next generation of bacteria in this population will all have antibiotic resistance! (Figure 6)

Tip The evolution and development of antimicrobial resistance is an example of natural selection. Antibiotics do not cause bacteria to evolve resistance. Rather, resistance already exists amongst the population and bacteria with resistance genes are better able to survive in an environment that has exposure to that antibiotic compared to bacteria that don't have those genes.

Antimicrobial resistance can develop in pathogens through a number of different mechanisms. These are summarised in Figure 7.

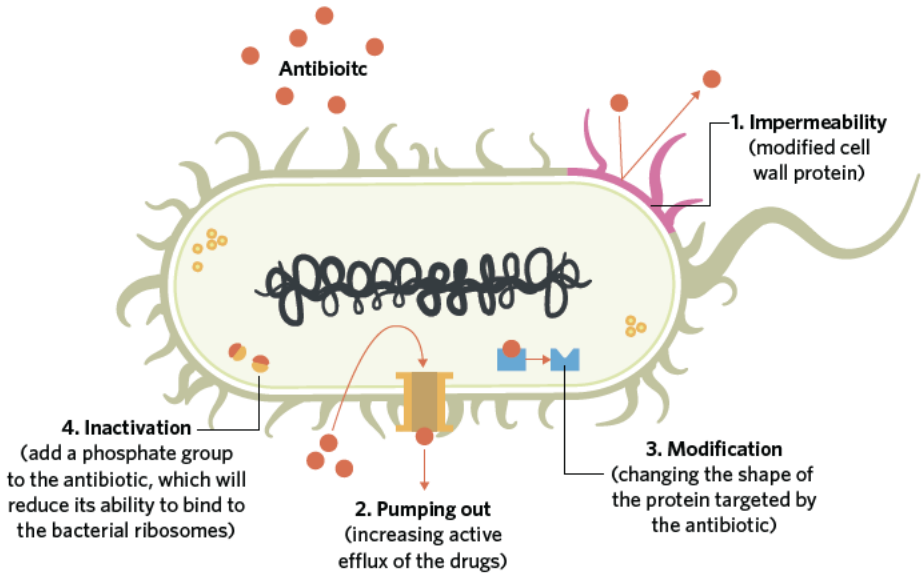


Figure 7 Mechanisms of bacterial resistance

Antimicrobial resistance is a big problem for humanity and is something that we must all work together to prevent. Steps that can be taken include limiting the use of antibiotics strictly to only when they're needed, and improving sanitation and hygiene standards so that fewer people become ill and require antibiotics.

Theory summary

Management of emerging diseases includes identifying the pathogen and containing the spread of disease. One of the main ways we do this is through the use of chemical agents, including antibiotics and antivirals. Using these management steps, we aim to prevent epidemics and pandemics from occurring.

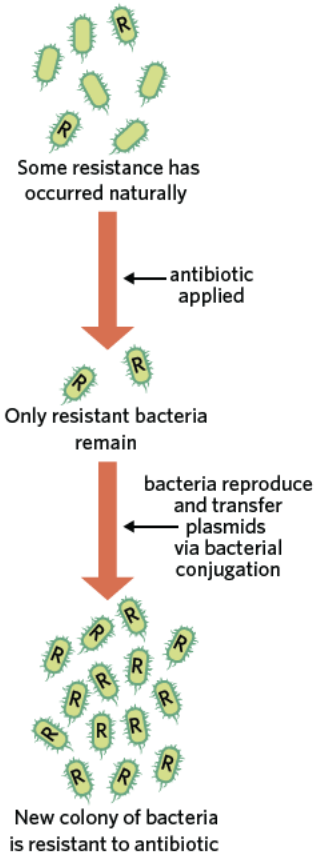


Figure 6 Effect of antibiotic exposure on a population of bacteria

16C QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ the name given to a disease that has affected multiple countries

b _____ drugs that are only effective against bacteria

c _____ term given to drugs that affect a small selection of specific microbes

d _____ when microbes are no longer/less affected by antimicrobials

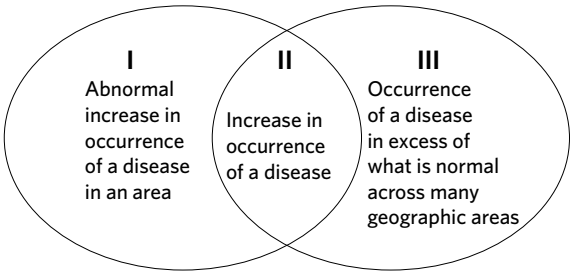
e _____ when the occurrence of a disease increases in a specific place

f _____ an organism that spreads a pathogen

Question 2

Which terms correctly describes the roman numerals I, II, and III?

	I	II	III
A	outbreak	epidemic	pandemic
B	epidemic	outbreak	pandemic
C	pandemic	outbreak	epidemic
D	epidemic	infection	pandemic



Question 3

Which of the following is not a technique to identify pathogens?

A Visualising the pathogen with a microscope.

B Using human antigens that recognise pathogen antibodies in the blood, if the human has been previously exposed.

C Enzyme-linked immunosorbent assay.

D Testing for the presence of pathogen genetic material with PCR and gel electrophoresis.

Question 4

Which of the following options contains all true statements about strategies to deal with disease?

A	Prevention involves taking steps to stop diseases spreading	Governments track medication sales and communicate with health professionals to monitor for outbreaks	Vectors show symptoms of the disease, so controlling them limits the spread of the disease
B	Quarantine involves separating ill people from healthy people	Governments take regular surveys of populations to monitor disease outbreaks	All infectious diseases are contagious, so all sick people must be isolated
C	Prevention includes sterilising surfaces	To identify pathogens, doctors must quarantine sick people	If a disease is spread via contaminated food source, access to uncontaminated food would help control the disease
D	Preventative measures include vaccination	Education campaigns increase social awareness of disease symptoms and treatments	Treatments include antimicrobial medications

Question 5

Which of the following options contains all true statements about these antimicrobial agents?

	Disinfectants	Antiseptics	Antibiotics	Antivirals
A	A type of antimicrobial	A type of antibiotic	Can prevent a bacterium from synthesising its cell wall	Can prevent a virus from replicating inside a host cell
B	Used to kill or slow the growth of pathogens on the body	A type of antimicrobial	Can prevent a bacterium from creating folic acid	Can prevent a virus from entering a host cell
C	Used to kill or slow the growth of pathogens on surfaces	Used to treat septic injuries	A type of antimicrobial	Are only broad-spectrum
D	Used to kill or slow the growth of pathogens in the environment	Used to kill or slow the growth of pathogens on the body	Can be broad-spectrum or narrow-spectrum	Can prevent a virus from attaching to a host cell

Exam-style questions

Within lesson

Question 6 (1 MARK)

Researchers are trying to develop new antiviral therapies. These therapies could include

A a drug that stops the spindle fibres forming during mitosis.

B providing amino acid supplements to promote flagella development.

C a drug that prevents virus attachment and entry.

D a drug that inhibits a bacterial-specific metabolic pathway.

Adapted from VCAA 2013 Section A Q40

Use the following information to answer Questions 7 and 8.

Malaria is a disease caused by a eukaryotic parasite spread by mosquitoes. Female *Anopheles* mosquitoes transmit an infective form of the parasite into the bloodstream when they bite a vertebrate host such as a human.

Question 7 (1 MARK)

Using the information given, it can be concluded that

A antibiotics would be effective against malaria.

B all people bitten by a female *Anopheles* mosquito will contract malaria.

C mosquitos are acting as the pathogen's vector.

D a person could be infected by coming into contact with a person with malaria.

Adapted from VCAA 2013 Section A Q16

Question 8 (1 MARK)

Based on the information provided, which of the following would not be an effective method of stopping the spread of malaria?

A Culling of mosquitoes

B Using nets to cover a person while they are asleep

C Providing an infected population with access to antimalarial medication

D Isolating infected people

Question 9 (6 MARKS)

The table compares how eight diseases spread and the number of people likely to be infected by one other infected person.

Disease	measles	whooping cough	rubella	polio	smallpox	mumps	severe acute respiratory syndrome (SARS)	Ebola
How it spreads	airborne droplets	airborne droplets	airborne droplets	fecal-oral route	airborne droplets	airborne droplets	airborne droplets	bodily fluids
Number of people infected from one other person	12 to 18	12 to 17	6 to 7	5 to 7	5 to 7	4 to 7	2 to 4	1 to 4

Source: Thomson Reuters (2018), adapted by VCAA 2018 Section A Q32

a Using the information provided, identify an effective method for the prevention of the spread of polio during an outbreak. (1 MARK)

Adapted from VCAA 2018 Section A Q32

b Based on the information provided, which disease is the least contagious. (1 MARK)

c In 2018 an outbreak of Ebola in Kivu was referred to by scientists as an epidemic rather than a pandemic.

i What does this suggest about the spread of the disease? (1 MARK)

Adapted from VCAA 2017 Sample Exam Section B Q10a

ii Name and describe a modern method that scientists could have used when identifying the pathogen in the Kivu outbreak. (1 MARK)

Adapted from VCAA 2017 Sample Exam Section B Q10e

iii There is currently no known treatment for Ebola. Explain what course of action Australian authorities may take for a person wanting to re-enter Australia after visiting Kivu during the epidemic, and state why this action would be taken. (2 MARKS)

Adapted from VCAA 2012 Exam 1 Section B Q7c

Multiple lessons

Question 10 (1 MARK)

The following diagram represents various types of pathogens.

With respect to these pathogens, it would be reasonable to state that

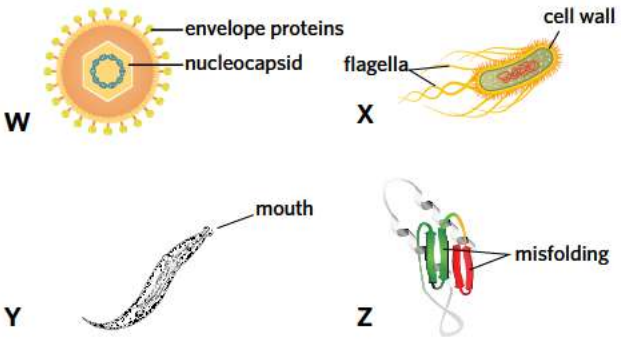
A antibiotics would be effective against Pathogen W.

B antibiotics would be effective against Pathogen X.

C antivirals would be effective against Pathogen Y.

D antivirals would be effective against Pathogen Z.

Adapted from VCAA 2014 Section A Q17



Images: (w, x) VectorMine/Shutterstock.com, (y) Andcurrant/Shutterstock.com, (z) Designua/Shutterstock.com

Question 11 (1 MARK)

The rise in the incidence of antibiotic-resistant bacteria is due to

A selection for antibiotic resistance.

B mutations caused by antibiotics.

C bacterial T cells fighting antibiotics.

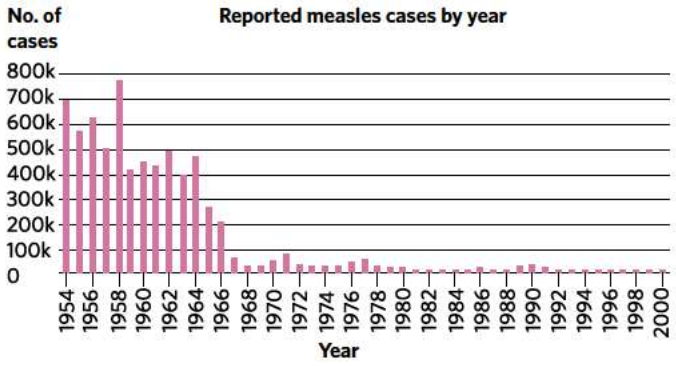
D selection against antibiotic resistance.

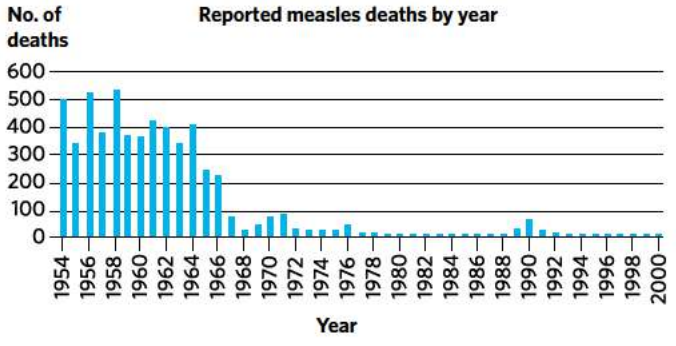
Adapted from VCAA 2013 Section A Q39

Question 12 (8 MARKS)

Measles is a highly infectious and dangerous disease. Young children and individuals with impaired immunity are especially susceptible to measles. It is caused by the measles virus and is spread via airborne droplets.

Analyse the following graphs that show the number of people in the United States of America (USA) who were infected with measles during the period 1954—2000 and the number of people who died as a result of having measles during the same period.





Source: ProCon, adapted by VCAA 2018 Section B Q5

a Which year had the greatest number of reported measles deaths? (1 MARK)

Adapted from VCAA 2018 Section B Q5ai

b A person with measles visits a doctor and asks for treatment for their disease. Would antibiotics be an effective treatment? Justify your response. (2 MARKS)

Adapted from VCAA 2018 Section B Q8c

c In Australia, the government is aiming to achieve a vaccination rate of 95 per cent in the Australian population.

i What kind of immunity is the government trying to achieve in this population with this high vaccination rate? (1 MARK)

Adapted from VCAA 2017 Sample Exam Section B Q5bi

ii How does this type of immunity protect the 5 per cent of the population who have not been vaccinated? (2 MARKS)

Adapted from VCAA 2017 Sample Exam Section B Q5bii

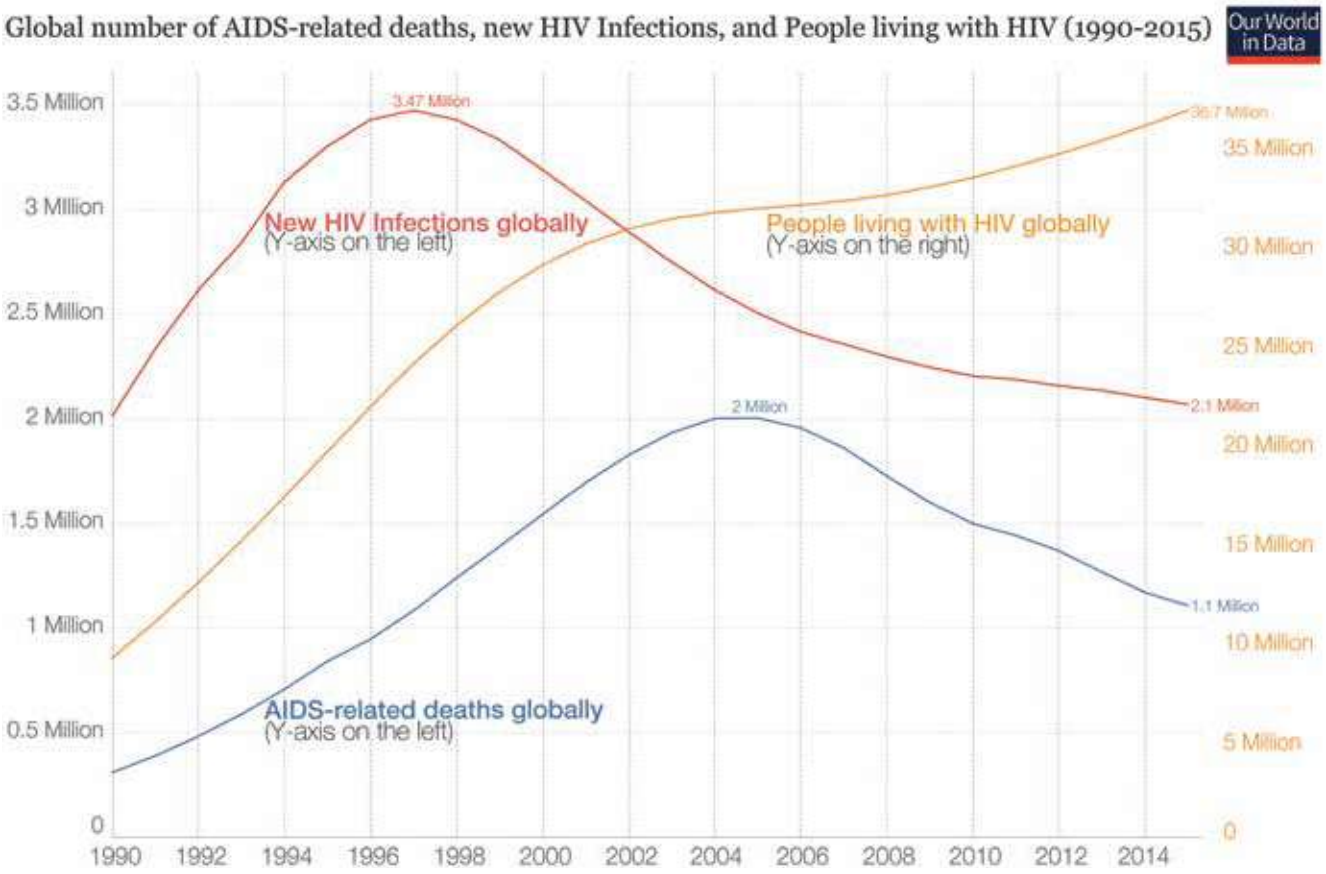
d Describe two ways in which the innate immune system of a person's body would protect against an infection by this virus. (2 MARKS)

Adapted from VCAA 2012 Exam 1 Section B Q7c

Key science skills

Question 13 (1 MARK)

The graph shows the death rates from acquired immune deficiency syndrome (AIDS) and also the number of people infected with the human immunodeficiency virus (HIV). Before 2004 many people infected with the HIV virus went on to develop AIDS, which led to their deaths.



Source: UN AIDS (2015), adapted by Ortiz-Ospina and Roser (2019)

Based on the information in the graph, which of the following statements is true?

A The number of deaths peaked in 1997 at 3.47 million.

B The number of people living with HIV infection increased at the fastest rate between 2002 and 2014.

C The number of people living with HIV infection is highest in 2014 at 36.7 million.

D The number of deaths in 2004 was approximately 20 million.

Adapted from VCAA 2018 Section A Q29

Question 14 (9 MARKS)

Sharon wanted to investigate the effectiveness of an antibiotic against the bacterium *Escherichia coli*. She prepared five different concentrations of the antibiotic.

She wrote the following method:

1 Put on a pair of disposable gloves.

2 Collect the five agar plates containing nutrient agar.

3 Label each agar plate with the five different concentrations of the antibiotic.

4 Collect a sample of *E. coli* in a broth culture.

5 Measure 0.5 mL of broth in a pipette and place in the centre of the first agar plate.

6 Spread the bacteria evenly over the agar plate with the spreader provided.

7 Place a drop of the antibiotic in the centre of the agar plate.

8 Close the lid of the agar plate and tape the lid to the bottom of the agar plate with sticky tape.

9 Repeat steps 6 to 8 with the other four concentrations of the antibiotic.

10 Place the agar plates on the side bench and leave overnight.

11 Wash your hands and dispose of the gloves.

a What difference would you expect to see between the agar plates prepared by Sharon? (1 MARK)

b In her experiment, Sharon was using a ruler with 1 cm markings to measure the zone of inhibition of bacterial growth. What sort of error could using this tool create in her results? Justify your response, and suggest how it could be reduced. (3 MARKS)

c Identify the dependent variable in the experiment. Justify your answer. (2 MARKS)

Adapted from VCAA 2017 Sample Exam Section B Q11b

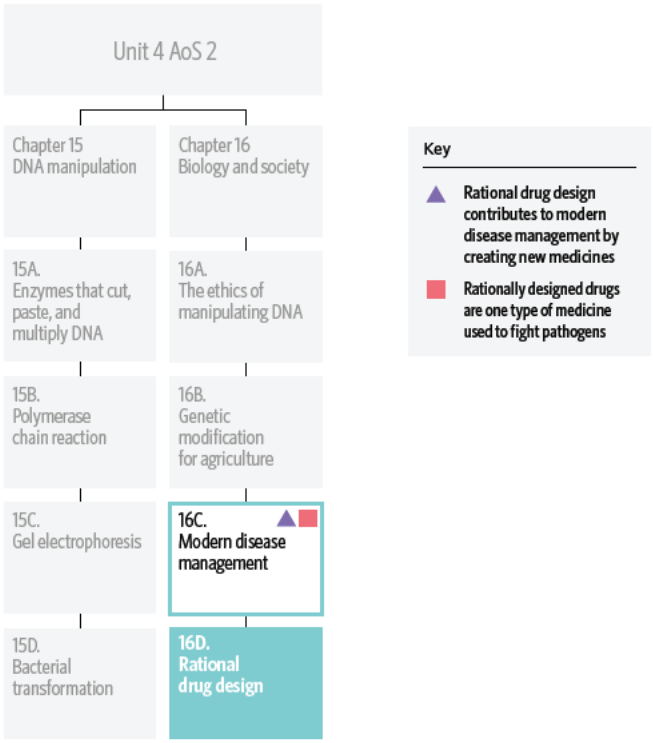
d Sharon decides to conduct a different experiment where she repeats the procedure outlined above but does so with two different types of bacteria – *Escherichia coli* and *Clostridium difficile*. What is her hypothesis in this experiment? (1 MARK)

e Sharon wanted to repeat the experiment to test the effectiveness of an antifungal drug against *E. coli*. She prepared five different concentrations of the antifungal drug and followed the same steps that she used for the antibiotic. Explain the results that Sharon would be expected to obtain. (2 MARKS)

Adapted from VCAA 2017 Sample Exam Section B Q11d

16D RATIONAL DRUG DESIGN

They say the best way to win a war is to know your enemy. This applies in medicine too where in order to treat diseases, we must understand them!



In this lesson you will learn what rational drugs are and how they are made. You'll also be looking at a rationally designed drug called Relenza, which was specifically made to combat influenza.

Study design dot point

- the concept of rational drug design in terms of the complementary nature (shape and charge) of small molecules that are designed to bind tightly to target biomolecules (limited to enzymes) resulting in the enzyme's inhibition and giving rise to a consequential therapeutic benefit, illustrated by the Australian development of the antiviral drug Relenza as a neuraminidase inhibitor

Key knowledge units

How rational drug design works	4.2.8.1
Relenza	4.2.8.2

How rational drug design works 4.2.8.1

OVERVIEW

Rational drug design is the process used by scientists to create a medication that specifically targets the cause of a disease.

THEORY DETAILS

It's a bit scary to think about, but many modern drugs were discovered by accident or trial and error. The most famous example of this is the drug penicillin discovered by Alexander Fleming in 1928. After returning from a holiday, Fleming noticed some mould growing on one of his staphylococci–infested Petri dishes that he'd accidentally left uncovered on his bench. This mould, it turned out, prevented the growth of *Staphylococcus* – it had antibacterial properties! Fleming was able to use this to create the drug penicillin, one of the most important medicines ever produced. Turns out taking time off work is important!

More recently scientists have come up with a more targeted and deliberate approach to designing new drugs. This process is called **rational drug design** and represents a massive step forward in modern medicine. In rational drug design, scientists identify the molecular cause of a disease or disorder and then design a medication that uses a complementary shape of the molecule to interfere with its functioning.

In real life, scientists design drugs to work on a number of different molecules in different ways, however VCAA will only ask you about designed drugs in relation to the **inhibition** of enzymes. Therefore, the steps of rational drug design that you need to know are:

1. Identification of a target enzyme – scientists identify an enzyme of a **pathogen** that is the cause of a disease/disorder and that is unique to that pathogen. They then hypothesise about the role this enzyme plays in the disease, and whether inhibiting it will have an effect on the disease process.
2. Study of the target enzyme – using sophisticated techniques such as **x-ray crystallography** scientists study the enzyme, characterising the shape and charge of its **active site**.
3. Design of a complementary molecule to the active site – scientists design a molecule with a complementary shape and charge to the enzyme's active site. This molecule binds to the enzyme and inhibits it, stopping it from interacting with the substrate. This prevents the enzyme from causing disease, resulting in a therapeutic benefit.

By inhibiting a specific enzyme that is central to the disease process, designed drugs are highly effective and selective. When trying to understand the mechanism of a designed drug, it helps to think of it in terms of its target, effect, and benefit:

- Target – for VCE Biology this will usually be the active site of an enzyme, but technically could also be the allosteric site
- Effect – for VCE Biology this will only be the inhibition of the target enzyme
- Benefit – this is the therapeutic benefit of the drug in question and is usually a reduction in symptoms or treatment of a disease.

An example of a rationally designed drug is **Relenza**. We'll take a closer look at this drug now.

rational drug design a process in which scientists study the shape and charge of a target molecule and design a complementary-shaped drug that gives rise to a therapeutic benefit

enzyme inhibition the inactivation of an enzyme by a molecule that binds to the enzyme and prevents it from interacting with the substrate

pathogen an agent that causes disease

x-ray crystallography a technique used to determine the structure of target molecules

active site the part of the enzyme to which the substrate binds

Relenza a drug designed to combat the influenza virus

If you have forgotten what enzymes and enzyme inhibition are, ***lessons 5A and 5B*** explore these concepts in more detail.

Relenza 4.2.8.2

OVERVIEW

Relenza is an example of a rationally designed drug that was made to combat **influenza**.

influenza an illness caused by infection with the influenza virus. Also known as **the flu**

THEORY DETAILS

One of the most important examples of a rationally designed drug is Relenza. First made by a team of Australian scientists in 1989, Relenza (also called zanamivir) is an antiviral drug designed specifically to combat influenza. It is usually taken orally via inhalation.

In order to understand how Relenza works, we must first look at the influenza **virus** and find out how it functions. This will enable us to identify the target enzyme of Relenza. Figure 1 is a representation of the influenza virus.

virus an infective agent composed of genetic material enclosed in a protein coat that requires a host cell to multiply

host cell an animal or plant cell that has a pathogen living inside it

haemagglutinin a protein on the surface of the influenza virus that attaches the virus to the host cell

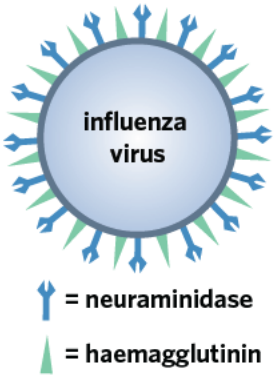


Figure 1 Diagrammatic representation of the influenza virus

When people infected with influenza cough or sneeze they emit the influenza virus into the air. If someone inhales this virus it can invade and replicate within their cells. These invaded cells are now **host cells** and the person has contracted the influenza virus.

Once the virus has replicated inside the host cell it must spread to other cells. Influenza virus buds on the outside surface of the host cell (Figure 2a). However the virus remains attached to the host cell, through an interaction between **haemagglutinin** and receptors on the host cell (Figure 2b).

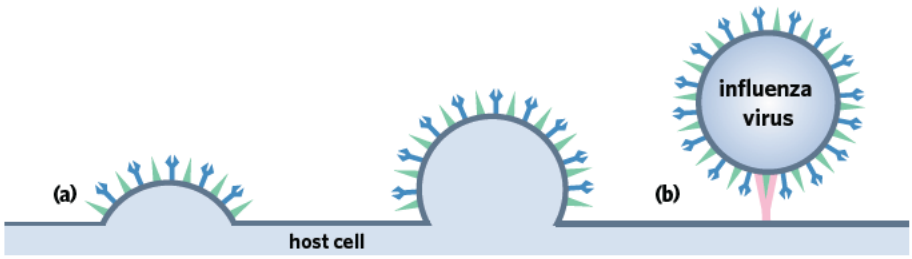


Figure 2 **(a)** Influenza virus budding on the outside of a host cell but **(b)** still remaining attached via haemagglutinin

An enzyme on the surface of the influenza virus called **neuraminidase** acts like a pair of scissors and 'cuts' the connection between haemagglutinin and the host cell (Figure 3a). The influenza virus is then free to travel and infect another cell (Figure 3b).

neuraminidase an enzyme on the surface of the influenza virus that releases the virus from the host cell

prophylaxis a measure taken to prevent the onset of an illness

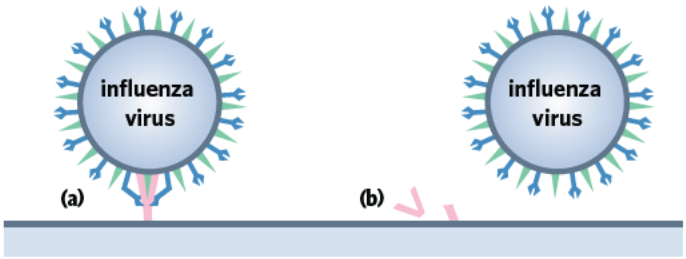


Figure 3 **(a)** Neuraminidase cutting the connection with the host cell, **(b)** allowing the virus to go off and infect other cells

This is where Relenza comes into action. Using techniques such as x–ray crystallography, scientists characterised the active site of the enzyme neuraminidase and designed Relenza to block it. Relenza prevents neuraminidase from cutting the connection between the influenza virus and the host cell (Figure 4a). Because the influenza virus can't detach itself from the host cell, it can't go off to infect other cells (Figure 4b). The spread of the virus is slowed down, allowing the body's immune system to kick in and remove it. In this way it can prevent a person from becoming sick with the flu if given as **prophylaxis**, or can limit the severity of their symptoms if administered just after the infection begins.

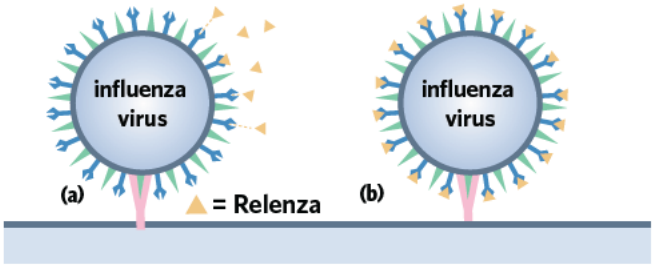


Figure 4 **(a)** Relenza blocking the active site of neuraminidase **(b)** preventing the virus from infecting other cells

We can summarise the mechanism of Relenza using the target–effect–benefit model outlined earlier:

- Target – the active site of the neuraminidase enzyme on the surface of the influenza virus
- Effect – Relenza blocks the active site of neuraminidase
- Benefit – the influenza virus cannot spread to other cells, preventing the person from becoming sick or reducing the severity of their symptoms.

Theory summary

Rational drug design is a process in which scientists identify a molecule that is unique to a pathogen and study its shape and charge to design a complementary–shaped molecule to it. This molecule is usually an enzyme, with scientists designing a molecule that is complementary to its active site to inhibit the enzyme. Relenza is a rationally designed drug made to combat influenza by inhibiting the active site of the enzyme neuraminidase.

Memory device To remember the roles of the influenza surface proteins think **n**euraminidase '**s**nips' and haema**gg**lutinin '**g**rips'

16D QUESTIONS

Theory review questions

Question 1

What are the key terms from the lesson that match the following definitions?

a _____ enzyme on the surface of the influenza virus that cuts the connection with the host cell

b _____ process of designing a medicine that targets a specific molecule

c _____ virus that causes the flu

d _____ cell that is used by the virus to replicate

e _____ this drug prevents the release of influenza virus by inhibiting neuraminidase

f _____ a protein on the surface of the influenza virus that attaches to the host cell

Question 2

Which of the following statements regarding rational drug design is false?

A Rational drug design involves identifying a target molecule.

B Rational drug design was the process that led to the development of Relenza.

C Rational drug design involves designing a molecule with a complementary shape and charge to an enzyme's active site.

D Rational drug design can only be used when designing an antiviral drug.

Question 3

Order the following steps of rational drug design.

1 Designing a molecule with a complementary shape to the active site

2 Studying the active site via x-ray crystallography

3 Searching a database of known compounds for a complementary molecule to the active site

4 Hypothesising about the role of a target molecule in a disease

The correct order is

A 1, 4, 2, 3

B 4, 2, 3, 1

C 4, 2, 1, 3

D 3, 2, 1, 4

Question 4

Fill in the blanks in the following sentences.

During the development of Relenza, scientists identified _____**I**_____ as a target molecule and designed Relenza to block the _____**II**_____ of the _____**III**_____ via _____**IV**_____. Doing this stops the virus from leaving the _____**V**_____.

	I	II	III	IV	V
A	haemagglutinin	active site	enzyme	competitive inhibition	host cell
B	neuraminidase	active site	enzyme	competitive inhibition	host cell
C	neuraminidase	virus	pathogen	non-competitive inhibition	body
D	a virus	active site	pathogen	non-competitive inhibition	body

Exam-style questions

Within lesson

Question 5 (1 MARK)

Relenza was one of the first drugs developed using rational drug design.

Which of the following statements about Relenza is false?

A Relenza binds to and blocks the active site of the viral enzyme neuraminidase.

B Relenza prevents the release of newly synthesised influenza viruses from an infected cell.

C Relenza binds to and blocks the active site of the viral enzyme haemagglutinin.

D Relenza can be used to treat early-stage influenza and as a prophylaxis.

Adapted from VCAA 2017 Sample Section A Q19

Question 6 (1 MARK)

Which of the following statements about rationally designed drugs is true?

A Rationally designed drugs provide life-long immunity against a disease.

B Rationally designed drugs have a high chance of creating herd immunity.

C Rationally designed drugs are made to target a specific site on an enzyme.

D Rationally designed drugs disrupt the cell wall of bacteria.

Question 7 (1 MARK)

Which of the following is not a step in the process of rational drug design?

A inactivation of the pathogen

B identification of the target molecule

C design of a complementary molecule to the active site of an enzyme

D studying the active site of an enzyme to determine shape and charge

Question 8 (5 MARKS)

Imatinib is a rationally designed drug used to treat some forms of leukaemia. These forms of leukaemia occur as a result of a chromosomal mutation that creates an abnormal chromosome 22. This abnormal chromosome is called the Philadelphia chromosome. The Philadelphia chromosome codes for an abnormal enzyme called bcr-abl that drives abnormal cell division and growth leading to cancer.

a What is meant by the term 'rational drug design'? (2 MARKS)

b What does the information suggest about the structure of Imatinib? (1 MARK)

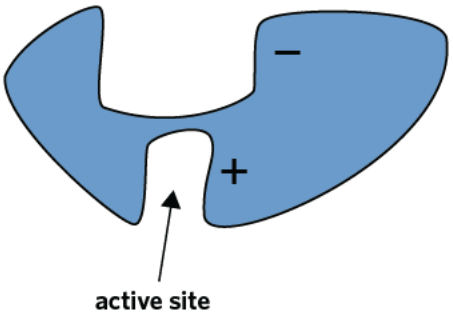
c Explain why Imatinib is an effective treatment for leukaemia patients that have the Philadelphia chromosome. (2 MARKS)

Adapted from VCAA 2017 Section B Q3

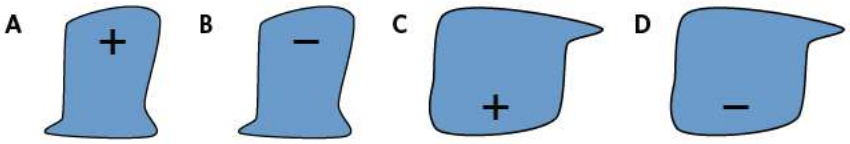
Multiple lessons

Question 9 (1 MARK)

A drug molecule has been designed to inhibit the activity of an enzyme. The shape of the enzyme is shown in the diagram. The position of the active site is labelled.



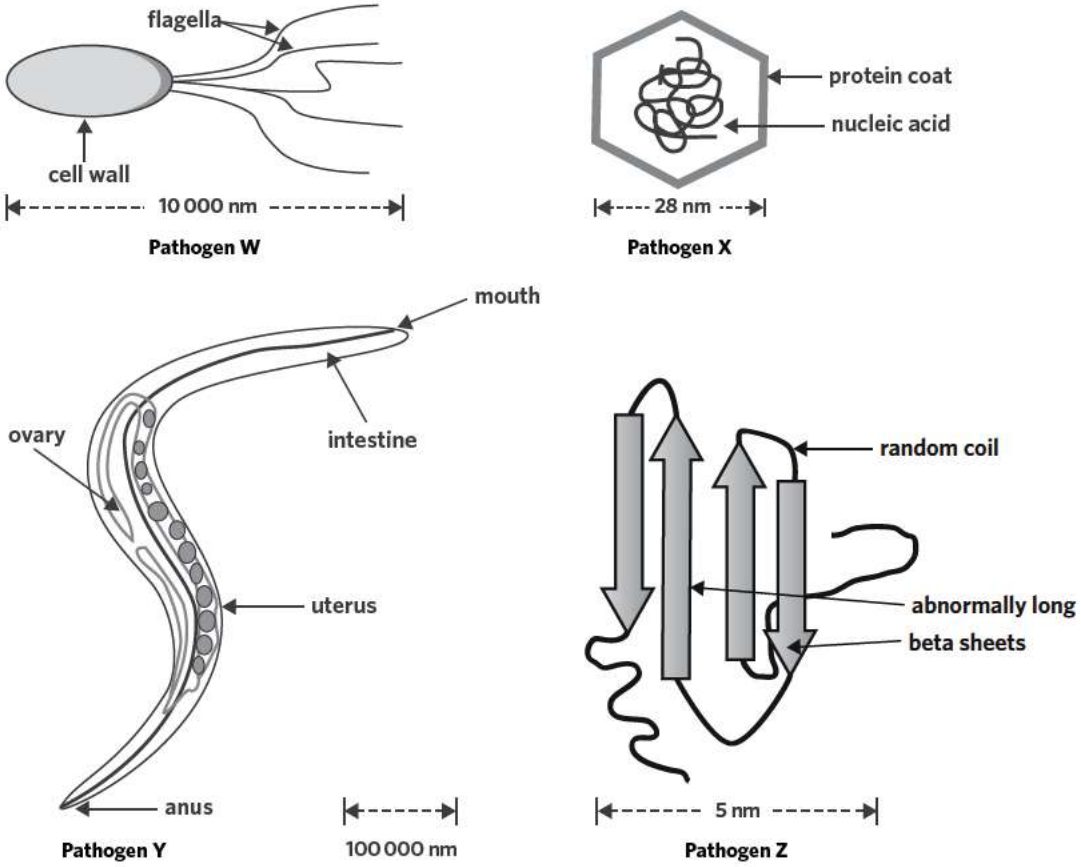
What is the most likely shape and charge for the drug molecule that is capable of competitive inhibition of this enzyme?



Adapted from VCAA 2013 Section A Q1

Question 10 (1 MARK)

The following diagrams represent various types of plant and mammal pathogens. Their approximate size is indicated by a scale bar.



Which of the pathogen types shown represents the type of pathogen the rationally designed drug Relenza is designed to combat?

A Pathogen W
B Pathogen X
C Pathogen Y
D Pathogen Z

Adapted from VCAA 2014 Section A Q17

Question 11 (9 MARKS)

Antiviral drugs such as Relenza act differently from the influenza vaccine.

a Explain, at a molecular level, how Relenza prevents the spread of the influenza virus. (3 MARKS)

b Complete the table by comparing the designed drug Relenza and the influenza vaccine. (6 MARKS)

	Relenza	Influenza vaccine
Method of administration		
Mechanism of action		
Purpose of administration		

Adapted from VCAA 2018 Northern Hemisphere Section B Q10

Key science skills

Question 12 (7 MARKS)

Is Tamiflu a waste of money?

On 19 March 2014 the journal *Lancet Respiratory Medicine* published a study showing that the influenza drugs Tamiflu and Relenza save lives. On 14 April 2014, another journal, the *British Medical Journal (BMJ),* published a review saying these influenza drugs do not save lives.

The *Lancet* researchers focused on the 2009 H1N1 global swine flu pandemic that claimed up to 575 400 lives worldwide. They asked whether Tamiflu and other neuraminidase inhibitor drugs prevented deaths during the pandemic. Looking at data from over 29 000 patients in hospital, they concluded the drugs saved lives. A comparison between patients who received the drug early, and those who received it late, suggested early treatment halved the death rate.

The *BMJ* researchers looked at general populations recovering from mild to moderate seasonal influenza. In their study the same drugs had only a minor effect, reducing the length of illness from seven to six-and-a-half days. There was no reduction in hospital admissions but there was an increased risk of side effects from using these drugs.

The *BMJ* study limited itself to the data obtained from randomised control studies. They carefully allocated comparable groups of people to receive either the real drug or a placebo. The *Lancet* study observed what took place in hospitals during the pandemic; observational studies like this are generally open to more criticism. But randomised control studies cannot be done during a pandemic on hospitalised patients at risk of dying from influenza.

Source: Finkel (2014) as cited by VCAA 2018 Northern Hemisphere Exam Section B Q10

a Identify the independent variable in the *BMJ* study. (1 MARK)

b Identify and explain one difference between the two studies that would have led to their different conclusions. (2 MARKS)

c Explain why hospitalised patients at risk of dying from influenza must be excluded from the randomised control study. (2 MARKS)

d Should the government of a country currently experiencing a low severity influenza pandemic purchase and distribute Relenza to their population? Justify your response using evidence from the article. (2 MARKS)

Adapted from VCAA 2018 Northern Hemisphere Section B Q10

ACTIVITY

Laura's day of disease

Huntington's disease is a dominant genetic disease that causes a devastating neurodegenerative condition by damaging neurons in parts of the person's brain. This leads to shaky movements, dementia and, eventually, complete loss of body control. Currently, there is no known effective treatment or cure.

A person is born with the allele for Huntington's disease, although the symptoms typically don't start to appear until the person is in their 30s or 40s. The disease is caused by a series of nucleotide repeats within the *ITI5* gene. A healthy person has fewer than 27 repeats; an at risk person has between 28 and 39 repeats; and a Huntington's disease sufferer has between 40 and 120.

Laura has just become engaged to her high school sweetheart Rob and plans to marry him in November. Rob is a builder's apprentice with a year left in his apprenticeship. Laura and Rob currently rent a one-bedroom flat, but once he finishes his apprenticeship and starts earning more money as a builder, they hope to build a house out near Coldstream. Laura and Rob are considering having a baby, but Laura is nervous because she knows that her family has a documented history of Huntington's disease.

Kerry (Laura's identical twin sister) is in her final year of a postgraduate medicine degree at Melbourne University. Eventually, she plans to specialise in surgery. She and Laura meet on the weekends to discuss recent occurrences. During this week's meeting, Laura mentions that she is considering being screened for Huntington's disease, a prospect that Kerry strongly objects to. Despite Kerry's objection, Laura books in the screening test anyway.

On the way to the screening clinic, Laura passes by a malnourished homeless man and is instantly taken aback by his likeness to her father, Erik. She approaches the man and asks for his name, learning that he is called Marcus. Attempting to spark a conversation, Laura asks how Marcus is doing, to which he responds "not great, I'm deficient in vitamin A". Convinced this man is her long lost brother, and remembering her year 12 biology education, she begins to explain short tandem repeats but Marcus appears disinterested. Already running late for her screening appointment, Laura resolves to return and find Marcus later.

Questions

1 What reasons might Laura have for wanting to have the test?

2 What reasons might Kerry have for not wanting Laura to have the test?

3 Explain how short tandem repeats can be used to determine if Marcus is Laura's long lost brother.

4 How might genetically modified organisms be used to assist with Marcus' vitamin A deficiency?

5 Suggest how gene therapy may be used to treat Huntington's disease.

When Laura arrives at the screening clinic, she happens to sit next to a man discussing his career as an epidemiologist with the woman next to her. This man, named Thomas, attempts to explain how the black plague (the most infamous pandemic in history) could never happen in today's society. The woman, named Sharon, quickly retorts that poor hygiene, lackluster funding, and less-than-ideal educational systems currently facilitate epidemics in many developing and developed countries, which could easily lead to a pandemic.

6 What distinguishes an epidemic from a pandemic?

7 Explain the different strategies that could be used by a country that is

a currently suffering from an epidemic.

b at risk of an epidemic in the future.

8 Explain how countries can use rational drug design to combat infectious diseases, by using Relenza as an example.

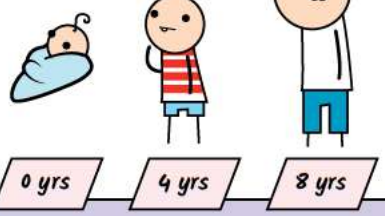
The UNFORTUNATE life & times of IAN FECTION

Because of her advanced age, Ian's mum decided to have **amniocentesis** done. No abnormalities were detected.

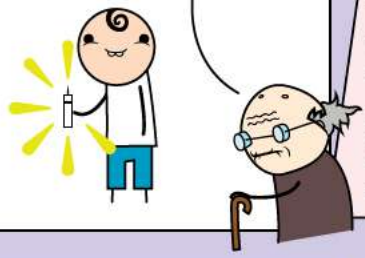
Another form of prenatal testing is **chorionic villus sampling**. **Both** have risks associated with them, but many doctors recommend them in high-risk pregnancies to determine if a dangerous genetic abnormality is present.

Unfortunately, a **blood test** done on Ian after birth reveals he has **Phenylketonuria (PKU)**, a genetic disease. Not to worry - little Ian should be fine so long as he avoids foods containing **phenylalanine!**

Ian grows up, and at age 8 is diagnosed with **diabetes**. **Oh no!**



But don't worry - once he learns how to use his **insulin** properly, he begins to feel **much better!**

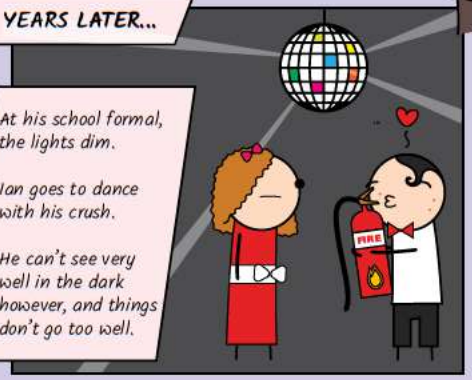


YEARS LATER...

At his school formal, the lights dim.

Ian goes to dance with his crush.

He can't see very well in the dark however, and things don't go too well.

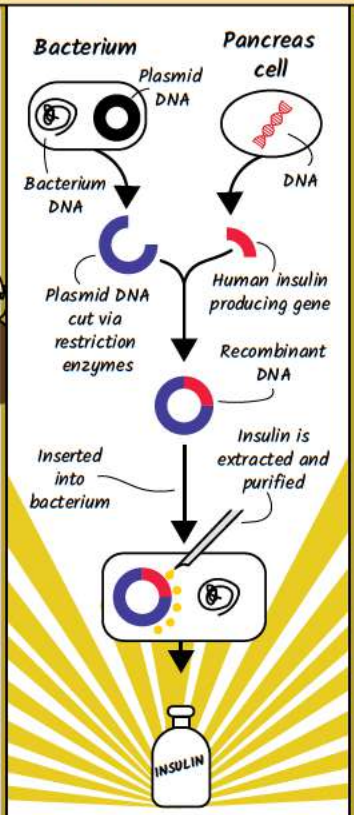


A visit to the doctor about his poor night vision reveals that Ian is suffering from a **vitamin A** deficiency.

Ian's mum orders a bag of **golden rice**. After eating it for a short period of time, his **Vitamin A** deficiency is corrected!

Ian graduates high school, and decides to go on a gap-year to celebrate.

The squeeze on insulin

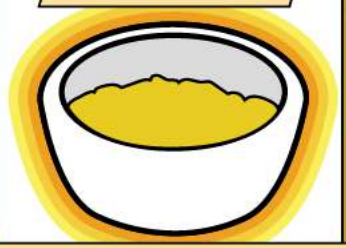


The production of insulin using transformed bacteria is an example of **gene cloning**. Other examples of genetic-based treatments for diseases exist, such as **in vivo** and **ex vivo** gene therapies.

CHAPTER SUMMARY

Rotate page

Rice & shine!



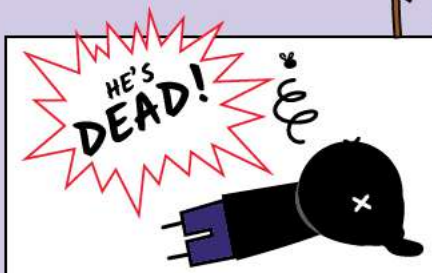
Golden rice is a **GMO**, created by inserting 2 genes to increase the amount of **Vitamin A** contained in the rice. This has resulted in fewer incidents of blindness and death; however, **some** people worry that it could reduce crop biodiversity.

There are many **biological**, **social**, and **ethical** implications of **GMOs!** Biological implications consider how actions may affect ecosystems, environments, and public health. Social implications include the consequences on society, economics, and politics. Ethical implications include considerations based on moral or religious beliefs.

Surveillance of other people entering the country is put into place, and people are educated about **Ebola, however...**

Ian **loves** his time in Kivu! **However...**

..on his way back to the airport to fly home, he gets mugged, and all of his belongings are **stolen!**



The doctors analyse his blood using microscopy and ELISA to look for a pathogen. They find out that the mugger died from **EBOLA!** Fearing Ian may have been exposed, they try to contact him, **however...**

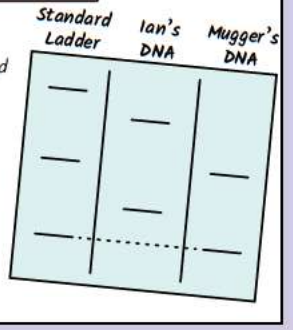
It's not long before it spreads throughout Australia!

Ian has accidentally brought the **Kivu Ebola epidemic** back home, turning it into a **PANDEMIC!**

After a few months, cases of Ebola subside.

The police find some of both Ian's and his attacker's blood at the crime scene

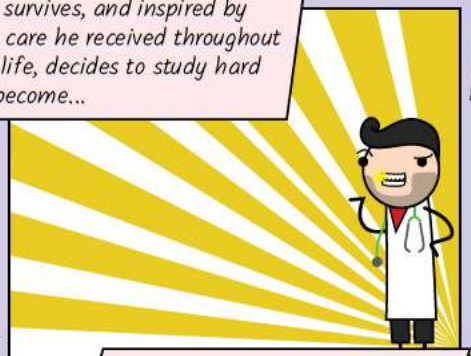
Using **gel electrophoresis**, they are able to find the perpetrator. The police go to arrest him, **but...**



...Ian has already arrived home, and he's **already** feeling unwell!

Diagnosis: EBOLA!

Ian survives, and inspired by the care he received throughout his life, decides to study hard to become...



Doctor Ian Fection

By the way, I'll have you know, DNA profiling has a number of advantages, such as identifying criminals, or assisting with matching organ donors and receivers. However, there are a number of ethical concerns raised by its use, including issues relating to who has access to or has ownership of the genetic information!

Now where was I? Oh, that's right..."

Ian is **immediately quarantined.** He receives supportive treatment, and is given an experimental anti-viral drug.

Dr. Ian Fection is in his office one day, when a mother to-be comes in...

...requesting **amniocentesis.**

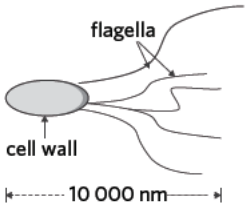
THE END.

CHAPTER REVIEW QUESTIONS

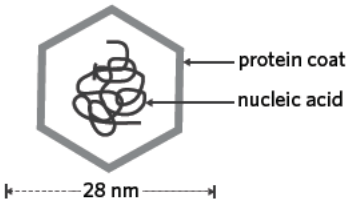
SECTION A (15 MARKS)

Use the following information to answer Questions 1 and 2.

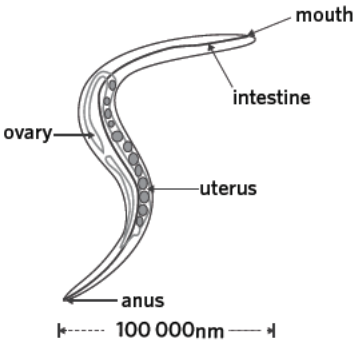
The following diagrams represent various types of plant and mammal pathogens. Their approximate size is indicated by a scale bar.



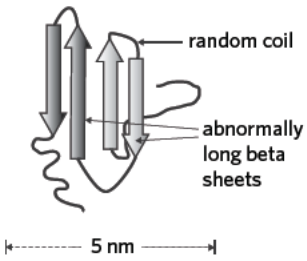
Pathogen W



Pathogen X



Pathogen Y



Pathogen Z

Question 1 (1 MARK)

It would be true to say that

A Pathogen X accepts foreign genetic material into its genome.

B Pathogen Y is a member of the kingdom Archaea.

C Pathogen W is a modified plant cell.

D Pathogen Z is a protein.

Adapted from VCAA 2014 Section A Q17

Question 2 (1 MARK)

Pathogen X is an influenza virus.

An effective treatment for a patient infected with the influenza virus would be to

A administer a dose of the drug Relenza.

B inject the patient with the influenza vaccine.

C give the patient antibacterial drugs.

D use remedial crystals to apply firm pressure to the patient's temples.

Question 3 (1 MARK)

Plant viruses are a major problem for farmers growing crops. A particular plant virus can infect many different plant species. Scientists are trialling a spray treatment on tobacco crops. The treatment does not alter the DNA of the tobacco plants.

During this treatment, tobacco plants are sprayed with clay nanoparticles containing double-stranded RNA (dsRNA). The dsRNA released from each of the clay nanoparticles enters the plant cells. Inside each cell the dsRNA silences a gene from the virus by causing viral RNA to break down.

In this technique

A the dsRNA plasmid would have to be inserted into a bacterial cell.

B the dsRNA would silence a gene from the virus by cleaving parts of the viral genome.

C extended field trials wouldn't be performed to determine long term impacts.

D sprayed tobacco plants would not be regarded as transgenic organisms.

Adapted from VCAA 2017 Section A Q40

Question 4 (1 MARK)

Defective alleles may result in genetic disease.

A plasmid with artificially inserted genetic material is called

A a genetically modified organism.

B a recombinant plasmid.

C gene therapy.

D a transformed bacterium.

Question 5 (1 MARK)

Ross River fever is caused by a virus that lives in kangaroos and wallabies. When a female mosquito bites an infected animal, it picks up viral particles. When the mosquito bites a human, the virus enters the human's bloodstream. The virus then reproduces in blood cells, resulting in fever, rashes, and joint pain.

Using the information given, it can be concluded that

A Relenza would be an effective early preventative treatment for the Ross River virus.

B the Ross River virus can be transmitted through sneezing.

C people living close to kangaroo and wallaby populations are at an increased risk from the Ross River virus.

D the human blood cells act as a viral vector.

Adapted from VCAA 2013 Section A Q16

Use the following information to answer Questions 6 and 7.

Scientists have developed genetically modified salmon that are able to grow to market size in 16 months rather than three years. Raising GM salmon in aquaculture serves as a viable alternative to wild-caught salmon and may reduce overfishing of wild salmon populations.

Question 6 (1 MARK)

Reducing the impact on wild salmon populations would be an example of

A a biological implication.

B an ethical implication.

C a social implication.

D a legal implication.

Question 7 (1 MARK)

Reducing the time and cost required to raise farmed salmon would be an example of

A a biological implication.

B an ethical implication.

C a social implication.

D a legal implication.

Question 8 (1 MARK)

The Australian government is considering a free genetic testing program for all young adults.

Which of the following would not be an ethical concern when designing the program?

A Discomfort to the patient during the procedure.

B The cost of running the program compared to the amount of money saved by reducing hospital visits.

C What organisations have access to the data.

D False predictions may cause unnecessary stress for many individuals.

Question 9 (1 MARK)

Tetracyclines are a class of medication used against a number of infections in humans. Tetracyclines attach to cytoplasmic ribosomes inside bacteria and interfere with their replication.

From this information, it is correct to state that tetracyclines are

A a vaccine.

B an antiviral.

C an antifungal.

D an antibiotic.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q32

Use the following information to answer Questions 10 and 11.

Vitamin A deficiency is a major cause of preventable blindness in children, particularly in poorer countries. This is due to insufficient vitamin A in their diet, which consists largely of rice. To fix this issue, scientists developed golden rice. Golden rice is a strain of rice that contains high levels of beta-carotene, a precursor of vitamin A. The *PSY* gene from daffodils *(Narcissus pseudonarcissus)* and the *CRTI* gene from a soil bacterium *(Pantoea ananatis)* were inserted into a strain of rice *(Oryza sativa),* which altered the beta-carotene biosynthesis pathway. These genes cause beta-carotene to be stored in the rice grains which people eat, rather than in the leaves as would occur in regular rice.

Question 10 (1 MARK)

Which of the following statements indicates that golden rice is a transgenic organism?

A The golden rice genome contains segments of DNA that have been altered.

B The *CRTI* gene in golden rice comes from *P. ananatis*.

C Golden rice is a different colour to regular rice.

D *O. sativa* naturally stores beta-carotene in the leaves.

Question 11 (1 MARK)

One advantage of using a genetic engineering solution to increase beta-carotene content in golden rice is that it will

A give rice resistance to pests that suck vitamin A out of rice.

B avoid public concern about the possible risks of genetically modified food.

C remove the need to increase insecticide applications in rice crops.

D provide an easily accessible source of vitamin A in poorer countries.

Question 12 (1 MARK)

Yellow fever is a viral disease that is transmitted primarily by mosquitoes.

An unusually large outbreak of yellow fever was reported to have occurred in an area of Brazil in January 2017. This outbreak was reported to be spreading to other areas within Brazil.

Which one of the following is a false statement about this outbreak of yellow fever?

A Eliminating mosquito breeding sites in areas with yellow fever could reduce the number of individuals affected.

B This outbreak of yellow fever is considered to be an epidemic.

C Environmental conditions favouring the breeding of mosquitoes would not have an effect on the spread of the disease.

D Mosquitos are acting as a vector for yellow fever virus.

Adapted from VCAA 2017 Section A Q37

Question 13 (1 MARK)

In the United States of America (USA) genetic screening of newborn babies is conducted for around 60 conditions. In the United Kingdom (UK), nine conditions are screened for and in the state of Victoria in Australia, 25 conditions are screened for. The following table provides data on the most frequent genetic conditions identified from screening newborn babies in the USA, the UK, and Victoria, Australia.

	Incidence (no. of babies born with condition: total no. babies born)		
Genetic condition	**USA**	**UK**	**Victoria, Australia**
phenylketonuria (PKU)	1 : 10 000 – 15 000	1 : 10 000	1 : 12 000
galactosaemia	1 : 30 000 – 60 000	not screened	not screened
primary congenital hypothyroidism (CH)	1 : 2 000 – 4 000	1 : 3 000	1 : 2 200
sickle-cell disease (SCD)	1 : 500 African Americans	1 : 2 000	not screened
congenital adrenal hyperplasia (CAH)	1 : 15 000	not screened	not screened
cystic fibrosis (CFTR)	1 : 2 500 – 3 500 Caucasians	1 : 2 500	1 : 3 300

Source: Genetics Home Reference, National Health Service, Victorian Clinical Genetics Services, as cited by VCAA 2018 Northern Hemisphere Exam Section A Q33

From this information it can be concluded that

A the frequency of PKU is highest in Victoria, Australia.

B the most frequent genetic condition that affects newborn babies in the UK is SCD.

C CAH is only present in the USA.

D CH in newborn babies is more prevalent in the UK than in Victoria.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q33

Question 14 (1 MARK)

Relenza was one of the first drugs developed through rational drug design.

Which one of the following statements is true of Relenza?

A Relenza prevents the influenza virus from spreading to unaffected cells.

B Relenza prevents the virus from passing through the cell membrane.

C Relenza binds to and blocks the active site of the viral enzyme haemagglutinin.

D Relenza is an antifungal drug.

Question 15 (1 MARK)

A disease is more likely to be screened for if

A the disease significantly impacts quality of life.

B there is no cure for the disease.

C the screening test is expensive.

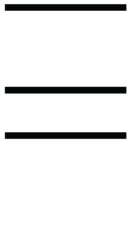
D the screening test has a high rate of error.

SECTION B (25 MARKS)

Question 16 (4 MARKS)

In 1991, the body of a man was found frozen beneath a glacier in Italy. Researchers named him Ötzi. It was determined that Ötzi died 5 300 years ago and that his body is one of the oldest mummified human bodies ever found. Scientists have successfully extracted DNA from the nucleus of his frozen cells.

Using gel electrophoresis, scientists discovered that there were five different human blood samples on Ötzi's clothes. Their results were as follows:

Ötzi's blood taken from his blood vessels	Blood sample 1 from Ötzi's clothes	Blood sample 2 from Ötzi's clothes	Blood sample 3 from Ötzi's clothes	Blood sample 4 from Ötzi's clothes	Blood sample 5 from Ötzi's clothes
					

a Which blood sample on Ötzi's clothes belongs to Ötzi? (1 MARK)

b Scientists have concluded that blood samples 1 and 4 are from individuals who likely suffered from the genetically linked disorder 'Phenylketonuria'. Identify another blood sample from an individual who is likely to suffer from this disorder. (1 MARK)

c DNA extracted from Ötzi's blood was hybridised with DNA from a chimpanzee. The melting temperature (T_m) of the hybrid DNA was less than that of both pure DNA samples. Explain why the melting temperature was lower for the hybridised DNA. (2 MARKS)

Question 17 (4 MARKS)

Scientists are trying to develop a drought-tolerant strain of corn (*Zea mays*) for agricultural use in increasingly warmer climates. Drought-tolerant crops are able to produce yields in mild drought conditions, whereas regular crops produce little to none in the same conditions. The first approach the scientists considered was to breed the drought tolerance trait into *Z. mays* by crossing them with a wild corn species that had natural drought tolerance.

a Explain how developing drought-tolerant corn would increase crop productivity. (1 MARK)

b The scientists found that the cross between *Z. mays* and the wild corn species resulted in no viable offspring due to the two species being too distantly related. Scientists studied this wild corn species further and found that the drought tolerance trait was due to three genes called NOT, TOO, and HOT.

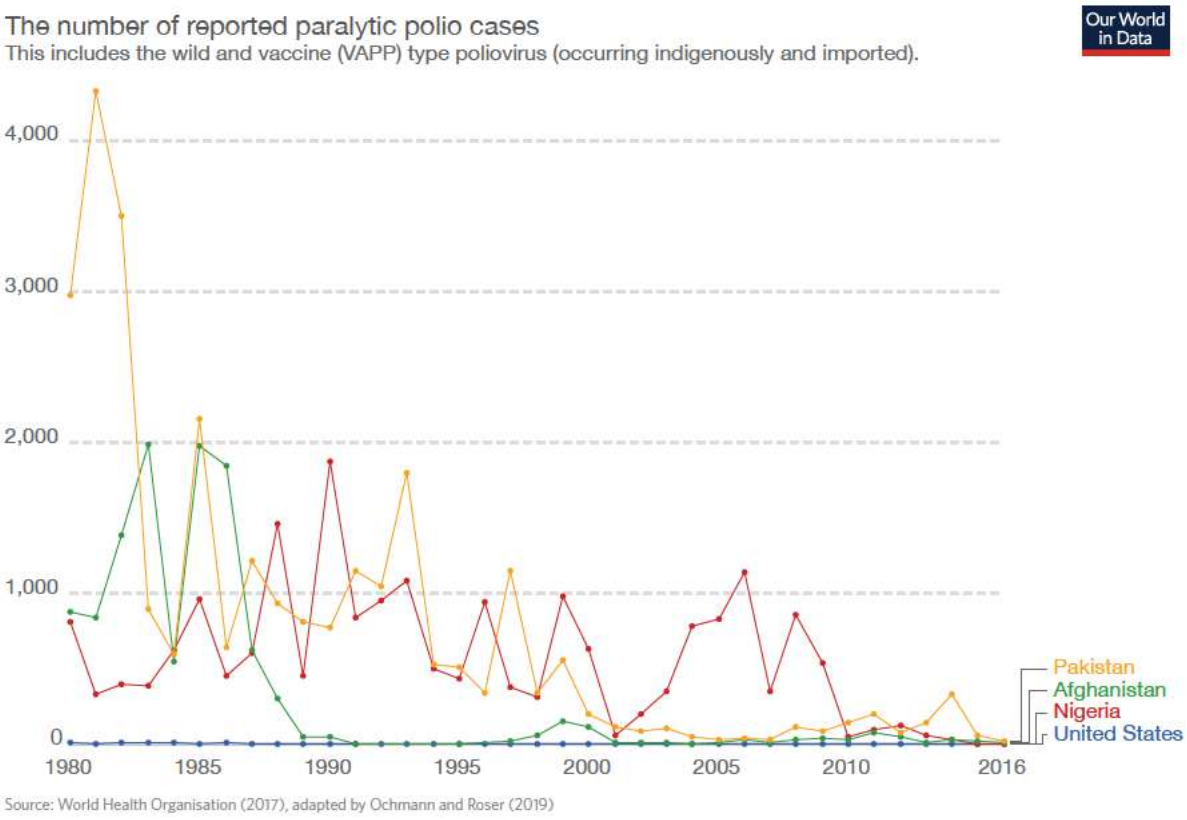
i State one advantage of using CRISPR-Cas9 over restriction enzymes. (1 MARK)

ii Refer to the information above to suggest how scientists might use genetic engineering technology to develop drought-tolerant *Z. mays*. (1 MARK)

iii What is a disadvantage of using genetically engineered *Z. mays*? (1 MARK)

Question 18 (10 MARKS)

Polio used to be one of the most widespread and severe viral diseases. 1 in 200 individuals infected with polio develop irreversible paralysis which commonly results in death. The graph shows the number of reported paralytic polio cases in several countries since the 1980s.



a In 1983, which country reported the highest number of polio infections? (1 MARK)

b Many public health officials warn about the potential dangers of epidemics and pandemics in human populations.

i What is meant by the term epidemic? (1 MARK)

ii Does this graph suggest that there may have been a polio pandemic between the years of 1990 and 1995. Why/why not? (2 MARKS)

c A survey was run in hospitals to measure the discomfort of polio-affected individuals. One surveyer constantly rated patient discomfort level on average two points higher than other surveyors.
What type of error does this represent? (1 MARK)

d Another infectious viral disease is the influenza virus, also known as the flu. Scientists have synthesised the rationally designed drug Relenza to combat influenza infections.

i Explain how Relenza was designed to combat the infectious disease influenza. (2 MARKS)

ii To deal with bacterial infections, scientists have previously relied on administering antibiotics, which prevent the growth of certain bacteria. Many healthcare professionals warn against the overprescription of antibiotics. Explain how bacteria can develop a resistance to certain antibiotics. (3 MARKS)

Question 19 (7 MARKS)

Advances in DNA technology have made it possible to correct faulty alleles in patients with genetic disorders using gene therapy. Gene therapy involves replacing a disorder-causing allele with a healthy allele in living patients. Some patients living with genetic disorders may choose to use gene therapy to correct faulty alleles in their germline. This would prevent their children from inheriting the faulty allele and would improve their quality of life.

a Children that result from germline gene therapy would be considered genetically modified organisms, but would they also be transgenic organisms? Justify your response. (2 MARKS)

b Explain the effect that widespread use of germline gene therapy could have on allele frequencies within the human population and therefore future human evolution. (2 MARKS)

c Using the information above, describe two ethical implications and one biological implication relevant to the use of germline gene therapy. The same implication should not be used twice. (3 MARKS)

1A What is a key science skill?

Theory review questions

1 **a** Experimental group / treatment group
b Systematic error
c Valid
d Accurate
e Confounding factor/variable
f Outlier
g Control group or negative control group
h Random error
i Precise
j Reproducible
k Repeatable
l Dependent variable
m Independent variable

2 C
3 D
4 B
5 D
6 C
7 D

Exam-style questions

Key science skills

8 C
9 D
10 B
11 B
12 A
13 D

14 **a** [The independent variable is distance between GM and non-GM fields. The dependent variable is the percentage of seeds produced at various positions as a result of cross-pollination.[1]]

✓ ✗ I have correctly identified the independent variable and the dependent variable.[1]

b [A control group was not used in this experiment.[1]] [Control groups are not exposed to the IV.[2]] [An example of a control group would be setting up two fields of non-GM crops next to each other, and measuring the percentage of seeds produced at various positions as a result of cross-pollination.[3]]

Other acceptable responses include:

- A control group could be a non-GM crop set up in an isolated space e.g. a greenhouse.

✓ ✗ I have stated that there was no control group.[1]

✓ ✗ I have described the nature of control groups.[2]

✓ ✗ I have outlined what a control group would look like this experiment.[3]

✓ ✗ I have used appropriate biological terminology such as: IV, control, percentage.

c [The general trend is that the further the distance between crops, the less cross-pollination.[1]] [The most cross-pollination occurred when there was no gap between plots (10% cross-pollination at edge of crop, 2% 10m into crop).[2]] [There was little difference between placing the crops 5 and 7m apart (both had 1% cross-pollination at edge of plot), except the plots 7m apart had only 0.3% cross-pollination 10m into the non-GM crop (as opposed to 0.5%).[3]]

✓ ✗ I have outlined the general trend of the data.[1]

✓ ✗ I have stated where cross-pollination was most common.[2]

✓ ✗ I have stated where cross-pollination was least common.[3]

✓ ✗ I have used data from the table to support my response.

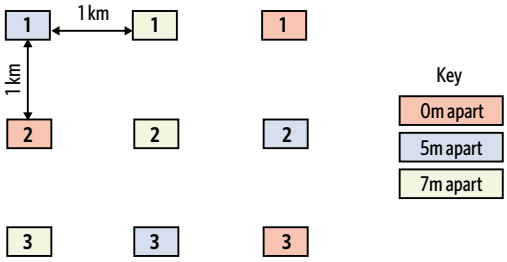
d **i** [Replication allows you to take a mean of a group, so outliers or results influenced by random error have less impact on your results.[1]] [Replication also helps scientists to understand the precision of their measurements.[2]]

✓ ✗ I have stated that replication reduces the impact of outliers and random error.[1]

✓ ✗ I have stated that replication gives a measure of precision.[2]

✓ ✗ I have used appropriate biological terminology such as: random error, outliers, precision.

ii [If they wished to replicate each experimental group three times, the farmers would need more plots and land.[1]] [They could set up each group a great distance (e.g. 1 km) apart from each other to ensure they are not affecting each other, and plant three of each plot type.[2]]



✓ ✗ I have drawn and described an appropriately replicated experiment.[1]

✓ ✗ I have recognised that the replicates may affect each other, and attempted to overcome this issue in the design.[2]

e [By having the trials run at different times, different treatments may be exposed to different weather conditions (e.g. rain, light, temperature, wind).[1]] [This could reduce the accuracy of the results[2]] [and be a potential confounding factor.[3]]

✓ ✗ I have identified factors that may be uncontrolled over time.[1]

✓ ✗ I have stated this could make the results less accurate.[2]

✓ ✗ I have identified this problem as a confounding factor/variable.[3]

f [Farmer Y is benefitting from GM crops, but Farmer X is the individual who pays for the GM crops.[1]] [The farmers should consider if this situation adheres to the ethical principle of justice.[2]]

Other acceptable responses include:

- Despite their initial agreement, Farmer Y is being forced to use GM crops. Even if she isn't too bothered by this, there may be effects on Farmer Y's crop of which she is not yet aware. The farmers should consider if this situation adheres to the ethical principle of respect.

- If Farmer Y's crop is becoming GM, then even more farms nearby may be affected. The farmers should consider the impact of their actions on others, and if the situation adheres to the ethical principles of beneficence and justice.
- Farmer Y may still be advertising her crops as non-GM. This is dishonest, and the farmers should consider if the situation adheres to the ethical principle of integrity.

✓ ✗ I have identified one ethical issue.[1]

✓ ✗ I have related the issue to the correct ethical principle.[2]

15 a [In this experiment, the IV is treatment with the drug and the DV is the number of individuals with the virus.[1]] [To begin, collect 100 mice[2]][of the same age and genetic strain. They should be raised and kept in the same environmental conditions (e.g. temperature).[3]] [Infect all mice with the virus for which the drug has been designed, then give the drug to 50 of the mice (the experimental group). Make sure these mice are labelled/easily identified as different from the non-treated mice (the control group).[4]][Over the coming days and weeks, the number of mice in each group with the virus should be counted.[5]][If the number of mice in the control group with the virus is significantly greater than the number of mice with the virus in the treatment group, then the drug is most likely effective.[6]]

Other acceptable responses include:

- Give a placebo to the mice in the control group.
- Give groups of mice different concentrations of the drug to characterise its effect in more detail.

✓ ✗ I have identified the IV and the DV.[1]

✓ ✗ I have used a sufficiently large (e.g. >10) number of mice in the experiment.[2]

✓ ✗ I have described the sample population as sharing a number of constant variables.[3]

✓ ✗ I have described the control group and the experimental group, both of which are replicated.[4]

✓ ✗ I have explained how to collect results, including the timing of collection.[5]

✓ ✗ I have indicated what the results mean by referring to the effectiveness of the drug.[6]

✓ ✗ I have ensured that the design does NOT involve administering the drug before the virus.

✓ ✗ I have used appropriate biological terminology such as: control group, treatment group, significant.

b [Firstly, the welfare of the mice before and during the experiment should be considered. By ensuring the mice are fed, kept in clean and low-stress cages, stimulated socially and physically, and able to sleep, the scientists can address this issue.[1]][Secondly, any pain or trauma experienced by the mice should be considered. This can be minimised by reducing the amount of handling and testing the drug for side effects on a smaller group prior to the experiment.[2]]

Other acceptable responses include:

- The scientists should consider what is done with the mice after the experiment. If they can be retired or used in another experiment, this is preferential to euthanasia.
- The scientists should consider how the virus affects the mice. If it causes extreme discomfort, they could use an attenuated version, or euthanise mice before they start to show severe symptoms, or not proceed with the experiment.
- The scientists should consider if there are long-lasting effects from receiving the drug. If there are severe effects, they may need to redesign the drug or halt experimentation.
- The scientists should monitor the side effects of the drug and have a plan for what happens if they occur. If the side effects are severe, they should stop administering the drug.

✓ ✗ I have provided one ethical consideration, and suggested how it could be overcome.[1]

✓ ✗ I have provided a second ethical consideration, and suggested how it could be overcome.[2]

✓ ✗ I have signposted my response using terms such as: firstly, secondly.

c [The scientists should wear gloves and lab coats when handling the mice, to avoid contact with the virus.[1]][They should also ensure the virus is kept in a well-labelled, safe, and lockable location so they can track and control its use.[2]]

Other acceptable responses include:

- They should conduct thorough research into the virus and drug prior to starting, and have processes in place if spillages or accidental infections occur.
- They should practice using syringes and other procedures before the experiment.
- They should keep the cages clean and dispose of waste appropriately to avoid disease.
- They should avoid breaking glassware, and clean it quickly and carefully if breakage occurs.
- They should wash their hands well after handling the mice, drug, and virus.
- They should use an attenuated version of the virus in their experiment, to reduce the chance of human infection.
- They should conduct the experiment in an isolated environment.

✓ ✗ I have identified one reasonable safety precaution for this experiment.[1]

✓ ✗ I have identified a second reasonable safety precaution for this experiment.[2]

1B Assessment of key science skills

Theory review questions

1 a Methodology
b Independent variable
c Correlation
d Discrete data
e Continuous data
f Open inquiry
g Acknowledgements, or references
h Trendline, or line of best fit
i Categorical data
j Raw data

2 B
3 D
4 D
5 A

6 D **7** D

8 B

Exam-style questions

Key science skills

9 C **10** C **11** C

12 D **13** D

14 a [The independent variable is the concentration of antifungal medication,[1]][and the dependent variable is the size of the fungal colony.[2]]

Other acceptable responses include:

- The dependent variable is the diameter of the fungal colony.
- The dependent variable is the amount of fungal growth/survival.

✓ ✗ I have identified the independent variable.[1]

✓ ✗ I have identified the dependent variable.[2]

b [Sterile means aseptic, or free from microorganisms.[1]][Using sterile tools prevents contamination of the agar plates with environmental microorganisms or extra spores from other plates, so the results are more valid.[2]]

✓ ✗ I have defined sterile.[1]

✓ ✗ I have explained that sterile instruments prevent contamination.[2]

✓ ✗ I have used appropriate biological terminology such as: microorganism, aseptic, valid, contamination.

c [Ibrahim replicated each experimental group twice.[1]][This is because he had two agar plates with the same concentration of antifungal medication.[2]]

✓ ✗ I have stated the level of replication.[1]

✓ ✗ I have outlined how Ibrahim replicated his experiment.[2]

✓ ✗ I have used appropriate biological terminology such as: experimental group.

d [Ibrahim did not use a control group.[1]][This means he does not know how much fungal growth occurs without the antifungal medication, so he cannot compare his results to a baseline.[2]][If Ibrahim had two agar plates that were treated exactly the same as the other plates, but to which no antifungal medication was applied, this problem could be fixed.[3]]

Other acceptable responses include:

- Ibrahim should change gloves between each plating to reduce possible contamination/systematic error.

✓ ✗ I have stated one poor experimental choice.[1]

✓ ✗ I have explained why this is a potential problem for the experiment.[2]

✓ ✗ I have suggested a modification to the experimental design to overcome the problem.[3]

e i [Generally, higher concentrations of antifungal medication results in lower mean diameters of fungal colonies.[1]][The mean diameter of fungal colonies is highest (3.2 cm) when treated with the 5 µg/mL fungal medication, and is lower (0.8 cm) at 10 µg/mL.[2]][Then, the mean diameter of fungal colonies actually increases slightly to 1.0 cm at 15 µg/mL,[3]][but decreases again until, at 25 µg/mL, there is zero growth.[4]]

✓ ✗ I have stated the general impact of the IV on the DV.[1]

✓ ✗ I have stated what occurs from 5 to 10 µg/mL.[2]

✓ ✗ I have stated what occurs from 10 to 15 µg/mL.[3]

✓ ✗ I have stated what occurs from 15 to 25 µg/mL.[4]

✓ ✗ I have referred to data from the table in my response.

✓ ✗ I have used the phrase 'mean fungal colony size' rather than just 'fungal colony size'.

ii [Ibrahim's hypothesis would have been that increasing fungal medication concentration decreases the amount of fungal growth.[1]][So, given that mean fungal growth decreases from 3.2 cm to 0 cm as concentration of antifungal medication increases, these results broadly support his hypothesis.[2]][However, the increase in fungal growth between 10 and 15 µg/mL is not in favour of his hypothesis.[3]]

✓ ✗ I have stated what Ibrahim's hypothesis would be.[1]

✓ ✗ I have stated how the results support Ibrahim's hypothesis.[2]

✓ ✗ I have stated when Ibrahim's results do not support his hypothesis.[3]

iii [Graph M is the best representation of Ibrahim's data,[1]][because concentration and diameter are continuous variables.[2]]

✓ ✗ I have stated that Graph M is the best representation.[1]

✓ ✗ I have explained why, with reference to the type of data presented.[2]

Chapter 1 Review

SECTION A

1 C **2** D **3** B **4** B

5 B **6** B **7** B **8** B

9 D **10** A

SECTION B

11 a [The independent variable is glucose concentration.[1]][The dependent variable is the temperature change of yeast mixture.[2]]

✓ ✗ I have identified the independent variable.[1]

✓ ✗ I have identified the dependent variable.[2]

✓ ✗ I have not stated that fermentation rate is the dependent variable.

b [A control is compared with the treatment group/s, and any differences between the control and the treatment group can be attributed to the IV.[1]][A control for this experiment would be setting up a yeast mixture with no glucose added.[2]]

✓ ✗ I have explained the purpose of a control.[1]

✓ ✗ I have identified a possible control for this experiment.[2]

c i [Group 3 is the most precise[1]][as all results are within 0.5 °C of one another.[2]]

✓ ✗ I have identified the most precise group.[1]

✓ ✗ I have justified why it is the most precise.[2]

ii [Group 4 is the most accurate[1]][as the average thermometer reading is 20°C, which is equal to the true temperature.[2]]

✓ ✗ I have identified the most accurate group.[1]

✓ ✗ I have justified why it is the most accurate.[2]

iii [Reliability refers to the degree to which results can be relied upon to be accurate.[1]][Testing the thermometers means we know if we can rely upon them to give accurate measurements, or if another tool should be used.[2]]

✓ ✗ I have defined what reliability refers to.[1]

✓ ✗ I have explained how testing the thermometers increases reliability.[2]

12 a [The independent variable is sucrose concentration.[1]][The dependent variable is the average final height of each group of plants.[2]]

✓ ✗ I have identified the independent variable.[1]

✓ ✗ I have identified the dependent variable.[2]

b [Some controlled variables include the initial height of every plant being 2 cm, the researchers watering every plant with 5 mL of water each day, and that the experiment uses the same plant species for each group.[1]]

Other acceptable responses include:

- Using 40 plants for each group.
- Having the same number of days of growth for each group.

✓ ✗ I have identified three controlled variables.[1]

✓ ✗ I have used appropriate biological terminology such as: controlled variables.

c i [Saskia's graph is more correct[1]][as she has followed standard practice by plotting the independent variable on the horizontal axis and the dependent variable on the vertical axis,[2]][unlike Gustave who has plotted the inverse.[3]]

✓ ✗ I have stated who has graphed the results correctly.[1]

✓ ✗ I have explained standard graphing practice.[2]

✓ ✗ I have explained why the other person is incorrect.[3]

ii [Increasing sample size makes results more reliable,[1]][because it is less likely they are affected by random outliers or an unrepresentative sample.[2]][By averaging the samples, the researchers gain a more precise result that explains what "most" plants do.[3]]

✓ ✗ I have outlined the effect of increased sample size on reliability.[1]

✓ ✗ I have explained why reliability is affected.[2]

✓ ✗ I have explained the effect of averaging the samples.[3]

d [Accuracy is a measure of how closely the experimentally obtained results match with the true result,[1]][whereas validity means the results measure what they claim to be measuring and exclude the effects of confounding variables.[2]]

✓ ✗ I have explained what is meant by the term accuracy.[1]

✓ ✗ I have explained what is meant by the term validity.[2]

✓ ✗ I have used comparative language such as: whereas.

13 a [Australia.[1]]

Other acceptable responses include:

- New Zealand.
- United Kingdom.
- Ireland.
- Singapore.
- Jamaica.

✓ ✗ I have identified a country that charges more than $10 for a pack of cigarettes.[1]

b [If countries increased the price of cigarettes, individuals would be deterred from buying them.[1]]

✓ ✗ I have stated a potential reason for the WHO's recommendation.[1]

c [These percentages were estimated as it would be unrealistic to sample the entire population.[1]][Instead a sample of individuals that is believed to be representative of the entire population would have been selected and their data used as an estimation.[2]]

✓ ✗ I have stated whether it is realistic to sample the entire population.[1]

✓ ✗ I have explained how the estimation would be calculated.[2]

d i [United States[1]][in 1961.[2]]

✓ ✗ I have stated the country with the highest peak.[1]

✓ ✗ I have identified the year in which this occurs.[2]

ii [The number of cigarettes consumed in Australia increases from 1935 to 1980[1]][with random peaks and troughs throughout.[2]]

[Reaching a maximal peak at approximately 10 cigarettes per adult per day in the late 1980's,[3]][the results then decrease until reaching four cigarettes per adult per day in 2010.[4]]

- ✓ ✗ I have stated that the trend increases between 1935 to 1980.[1]
- ✓ ✗ I have stated there are random peaks and troughs.[2]
- ✓ ✗ I have approximated the maximal point.[3]
- ✓ ✗ I have described the final decrease.[4]
- ✓ ✗ I have used data in my response.

iii [Japan and France's graphs both share a similar shape, increasing between 1935 and 1980, before falling between 1980 and 2010.[1]] [However, the magnitude of the increase in Japan's graph is greater, reaching approximately 9.5 cigarettes per adult per day,[2]] [compared to France's peak at approximately 6.5 cigarettes per adult per day.[3]]

- ✓ ✗ I have explained how both graphs are similar.[1]
- ✓ ✗ I have stated that the magnitude of Japan's graph is greater.[2]
- ✓ ✗ I have made a comparison to France's graph.[3]
- ✓ ✗ I have used data in my response.

2A Cell structure

Theory review questions

1 **a** Nucleus **b** Organelles
c Ribosomes **d** Prokaryotic
e Cytoplasm **f** Flagellum
g Plant cell

2 B **3** C
4 A **5** D

Exam-style questions

Within lesson

6 D **7** B **8** A **9** D

10 **a** [Organelles.[1]]

I have named the smaller components of cells.[1]

b [It is a eukaryotic cell[1]][as it contains a nucleus.[2]]

I have identified the type of cell.[1]

I have justified my response.[2]

c [Cady is correct, it is a plant cell[1]][as it contains one large vacuole instead of many smaller vacuoles.[2]]

Other acceptable responses include:

- It contains chloroplasts.
- It contains a cell wall.

I have identified who is correct.[1]

I have provided one reason to justify my response.[2]

d [Structure L is the rough endoplasmic reticulum[1]][which is responsible for the synthesis and processing of proteins.[2]]

I have named structure L.[1]

I have explained the function of structure L.[2]

e [Structure N is a mitochondrion. It is the site of aerobic cellular respiration and produces ATP.[1]][Structure M is the vacuole, which is responsible for providing structure for the cell and storing fluids, water, and waste.[2]]

I have named the structure responsible for ATP production.[1]

I have described the other organelle.[2]

Key science skills

11 **a** [This organism would be able to move freely as it has a flagellum.[1]]

I have explained whether the organism would be able to move freely.[1]

I have used appropriate biological terminology such as: flagellum.

b [This organism does contain membrane-bound organelles, as it has chloroplasts and vacuoles.[1]]

I have stated whether the organism has membrane-bound organelles.[1]

c [Binary fission.[1]]

I have named the process.[1]

d [This conclusion is correct.[1]][This organism is similar to prokaryotic organisms due to the presence of a flagellum, single-stranded circular DNA, and dividing through binary fission.[2]][However, it cannot be deemed as prokaryotic due to the presence of eukaryotic traits such as vacuoles and chloroplasts.[3]][It also lacks key eukaryotic traits as it is missing a membrane-enclosed nucleus and linear DNA.[4]]

I have agreed with the conclusion.[1]

I have explained the similarities with prokaryotic organisms.[2]

I have explained the differences with prokaryotic organisms.[3]

I have explained the differences with eukaryotic organisms.[4]

2B Biomacromolecules and energy living in things

Theory review questions

1 **a** Polar **b** Covalent
c Monomers **d** Protein
e Nonpolar **f** ATP
g Carbohydrate **h** Lipid
i Polymer **j** Exergonic or catabolic
k Endergonic or anabolic **l** Nucleic acid

2 B **3** A
4 D **5** C
6 D **7** D
8 C

Exam-style questions

Within lesson

9 D **10** A **11** A
12 B **13** B **14** C

15 **a** [This reaction is endergonic, it absorbs energy,[1]][as it can be seen that the products have more energy than the reactants.[2]]

I have stated whether this reaction releases or absorbs energy.[1]

I have explained my answer by referring to the graph.[2]

I have used appropriate biological terminology such as: endergonic, products, reactants.

b [Anabolic.[1]]

✓ ✗ I have stated whether the reaction is anabolic or catabolic.[1]

c [Cells use ATP to carry energy between reactions, where it can release energy for the cell to use.[1]]

✓ ✗ I have described the role of ATP in biological systems.[1]

16 a [Amino acids.[1]]

✓ ✗ I have identified the monomers.[1]

b [Protein.[1]]

✓ ✗ I have identified the type of biomacromolecule produced from this reaction.[1]

c [Collagen.[1]]

Other acceptable responses include:

- Keratin.
- Elastin.
- Amylase.

✓ ✗ I have given an example of a protein.[1]

d [This reaction is not a hydrolysis reaction,[1]][as water is not being consumed, it is being produced. This is a condensation reaction.[2]]

✓ ✗ I have stated whether this is a hydrolysis reaction.[1]

✓ ✗ I have explained the type of reaction.[2]

Key science skills

17 a [The water and oil will not mix due to their differences in polarity.[1]]

Other acceptable responses include:

- The water and oil will mix due to their polarity.

✓ ✗ I have stated a hypothesis the students could be testing.[1]

b i [Lipid.[1]]

✓ ✗ I have identified the type of biomacromolecule.[1]

ii [Nonpolar.[1]]

✓ ✗ I have identified the polarity of this biomacromolecule group.[1]

c [Jed is correct,[1]][as polar substances such as water dissolve in other polar substances but do not mix with or dissolve in nonpolar substances such as oil, and vice versa.[2]]

✓ ✗ I have identified which student is correct.[1]

✓ ✗ I have justified my response by referring to the nature of polar substances.[2]

Chapter 2 Review

Section A

1	C	**2**	A	**3**	D	**4**	D
5	A	**6**	B	**7**	B	**8**	B
9	B	**10**	D	**11**	A	**12**	B

Section B

13 a

Structure	Name	Role
Q	**chloroplast**	uses solar energy to produce glucose
K	ribosomes	**site of protein production**
P	**nucleus**	controls all cellular processes
N	**vacuole**	stores fluids, water, and waste within the cell
R	**Golgi body**	modifies, sorts, and packages protein molecules
L	**cell wall**	**structural support and protection of cell**
O	**mitochondria**	converts glucose into energy
M	plasma membrane	**controls what enters and exits the cell**

✓ ✗ I have identified the correct structures.

✓ ✗ I have identified the correct names.

✓ ✗ I have identified the correct roles.

b [The cytosol is the liquid part of the cell,[1]][whereas the cytoplasm includes the cytosol and all of the organelles excluding the nucleus.[2]]

✓ ✗ I have described what the cytosol is.[1]

✓ ✗ I have described what the cytoplasm is.[2]

✓ ✗ I have used comparative language such as: whereas.

c [Clara is incorrect when stating this cell is prokaryotic[1]][as it contains membrane-bound organelles.[2]][However, she is correct in that this cell is a plant cell[3]][because it contains a cell wall, chloroplasts, and one large vacuole.[4]][Therefore, this cell is a eukaryotic plant cell.[5]]

✓ ✗ I have stated if this cell is prokaryotic.[1]

✓ ✗ I have justified whether it is prokaryotic.[2]

✓ ✗ I have stated if this cell is a plant cell.[3]

✓ ✗ I have justified whether it is a plant cell.[4]

✓ ✗ I have concluded what type of cell this is.[5]

14 a [T- nucleic acids,[1]][U- fats/lipids,[2]][V- carbohydrates,[3]][W- proteins.[4]]

- ✓ ✗ I have identified structure T.[1]
- ✓ ✗ I have identified structure U.[2]
- ✓ ✗ I have identified structure V.[3]
- ✓ ✗ I have identified structure W.[4]

b [Tèa is incorrect[1]][as structure V is a carbohydrate and structure U is a lipid and these biomolecules do not contain nitrogen.[2]]

- ✓ ✗ I have stated that Tèa is incorrect.[1]
- ✓ ✗ I have explained why Tèa is incorrect.[2]
- ✓ ✗ I have referred to the scenario in my response.

c **i** [Smooth endoplasmic reticulum.[1]]

- ✓ ✗ I have identified where structure U is produced.[1]

ii [Ribosomes.[1]]

- ✓ ✗ I have identified where structure W is produced.[1]

d **i** [Hydrophilic.[1]]

- ✓ ✗ I have identified the nature of structure V.[1]

ii [Hydrophobic.[1]]

- ✓ ✗ I have identified the nature of fatty acid tails in structure U.[1]

3A The structure of the plasma membrane

Theory review questions

1 **a** Polar **b** Hydrophilic
c Phosphate head **d** Cholesterol
e Proteins **f** Amphipathic

2 A **3** A

4 D

Exam-style questions

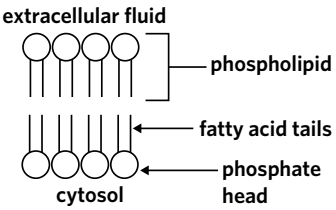
Within lesson

5 D **6** D **7** B

8 A **9** D

Multiple lessons

10 **a**



✓ ✗ I have drawn phospholipids arranged in a bilayer.

✓ ✗ I have drawn the phosphate heads facing outwards and the fatty acid tails on the inside.

✓ ✗ I have labelled phospholipid, fatty acid tails, phosphate head, cytosol, and extracellular fluid.

b [The phosphate head is negatively charged and hydrophilic,[1]] [the fatty acid tails are uncharged and hydrophobic,[2]] [and the phospholipid is amphipathic.[3]]

✓ ✗ I have stated the charge of the phosphate heads.[1]

✓ ✗ I have stated the charge of the fatty acid tails.[2]

✓ ✗ I have stated the charge of a phospholipid.[3]

c [Cholesterol regulates the fluidity of the plasma membrane.[1]] [When it is hot, the cholesterol stops the fatty acid tails from separating too far. When it is cold, the cholesterol disrupts the fatty acids tails so they do not bind too tightly.[2]]

✓ ✗ I have stated the role of cholesterol.[1]

✓ ✗ I have explained how it performs this role.[2]

11 **a**

Molecule	Name	Function
Q	Phospholipid	Membrane stability and structure
R	Cholesterol	Regulates membrane fluidity
S	Glycoprotein	Cell-cell communication, adhesion
T	Channel protein	Transport across the membrane

✓ ✗ I have identified molecules Q-T.

✓ ✗ I have identified the functions of molecules Q-T.

✓ ✗ I have NOT stated that molecule Q is involved in transport.

✓ ✗ I have NOT stated that molecule T is involved in cell-cell communication, adhesion, or enzymes.

b [The middle of the membrane is nonpolar[1]] [so Molecules R and T must also be nonpolar/hydrophobic, where they touch fatty acids in the middle of the membrane.[2]] [However, both Molecules T and R may have hydrophilic regions that are near the phosphate heads or aqueous environment.[3]]

✓ ✗ I have stated the polarity of the middle portion of the membrane.[1]

✓ ✗ I have stated the polarity of portions of Molecules R and T that are near fatty acids.[2]

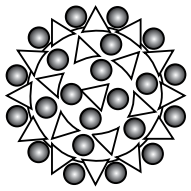
✓ ✗ I have stated the polarity of portions of Molecules R and T that are near hydrophilic substances.[3]

c [The model is described as 'fluid' because the lipids, proteins, and cholesterol can move around - they are not stuck in place. Cholesterol specifically regulates how fluid the membrane is.[1]] [The model is 'mosaic' because there are lots of different proteins embedded in it - for example, glycoproteins.[2]]

✓ ✗ I have explained why the term 'fluid' is used, with reference to cholesterol.[1]

✓ ✗ I have explained why the term 'mosaic' is used.[2]

12 **a**



✓ ✗ I have drawn a cell with protein types evenly dispersed around the membrane

b [That the two protein types will become evenly distributed in the plasma membrane when the two cell types are fused together.[1]]

✓ ✗ I have suggested a realistic hypothesis.[1]

c [The same type of animal cell should be used and the temperature at which the cells are kept prior to fusion should be constant.[1]]

Other acceptable responses include:

- The other types of membrane proteins in the cells
- The number of other membrane proteins in the cells
- The fusion technique
- The amount of cholesterol in the membranes of the cells
- The same number of each type of cell

✓ ✗ I have suggested two factors that should be controlled.[1]

d [The scientists could replicate their experiment.[1]]

✓ ✗ I have identified a suitable way to improve the reliability of the experiment.[1]

3B Transport across membranes

Theory review questions

1 **a** Osmosis **b** Selectively permeable
c Facilitated diffusion **d** Active transport
e Hypotonic **f** ATP
g Solute

2 B **3** B
4 C **5** D

Exam-style questions

Within lesson

6 C **7** C **8** C **9** D

Multiple lessons

10 **a** [It enters straight through the plasma membrane, not through a channel or pump.[1]]

✓ ✗ I have identified a piece of evidence from the diagram.[1]

b **i**

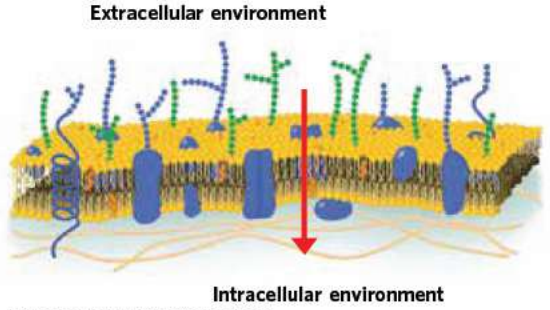


Image: Jamilia Marini/Shutterstock.com

✓ ✗ I have drawn an arrow through the phospholipids.

✓ ✗ I have not drawn an arrow through a transport protein.

✓ ✗ I have drawn an arrow from the extracellular environment to the intracellular environment.

ii [Most of the plasma membrane is hydrophobic,[1]] [because of the fatty acid tails of phospholipids.[2]] [Therefore, other hydrophobic substances like the signalling molecule can pass straight through the membrane without the aid of transport proteins.[3]]

✓ ✗ I have described the polarity of the plasma membrane.[1]

✓ ✗ I have referred to the structure of the plasma membrane.[2]

✓ ✗ I have explained the consequences of membrane structure on the movement of the signalling molecule.[3]

iii [J is a phospholipid. Phospholipids arrange themselves into a bilayer that forms a stable barrier around the cell. They have a role in regulating transport across membranes, and are the structure in which proteins and carbohydrates are embedded.[1]] [K is a carbohydrate attached to a glycoprotein. Its function may be involved in receiving or sending signals and cell-cell adhesion.[2]] [L is the cytoskeleton. The cytoskeleton gives shape and support to the cell and transports molecules around the cell.[3]]

✓ ✗ I have identified and described the role of J.[1]

✓ ✗ I have identified and described the role of K.[2]

✓ ✗ I have identified and described the role of L.[3]

iv [Facilitated diffusion involves glucose moving down its concentration gradient through a protein channel like GLUT2.[1]] [GLUT2 is required because glucose is a relatively large and polar molecule,[2]] [but no energy is required as this is facilitated diffusion.[3]]

✓ ✗ I have described the direction of movement of glucose during facilitated diffusion.[1]

✓ ✗ I have explained why a channel is necessary.[2]

✓ ✗ I have stated if energy is required in the process.[3]

✓ ✗ I have referred to the scenario using terms such as: GLUT2, glucose.

v [Phospholipids are amphiphilic, meaning that they are polar at one end (phosphate head) and nonpolar at the other end of the molecule (fatty acid tails).[1]] [This results in the spontaneous formation of a bilayer, where the fatty acid tails face inwards, protected from the aqueous environment by the phosphate heads on the outside of the bilayer.[2]] [The bilayer is an ideal structure to form the barrier of the cell because it is stable but fluid.[3]] [It won't break apart when molecules are embedded in it or transported across it.[4]]

Other acceptable responses include:

- The nonpolar nature of the membrane allows it to be selectively permeable.

✓ ✗ I have described the charge of the phospholipid bilayer.[1]

✓ ✗ I have described the structure of the phospholipid bilayer.[2]

✓ ✗ I have stated that the bilayer is stable but fluid.[3]

✓ ✗ I have stated that these properties mean that molecules can be embedded in and transported across the bilayer.[4]

Key science skills

11 **a** [That more concentrated corn syrup solutions[1]] [will lead to smaller, lighter, and less firm eggs.[2]]

✓ ✗ I have referred to the independent variable.[1]

✓ ✗ I have referred to the dependent variables.[2]

I have indicated the direction of the relationship using terms such as: more, smaller, lighter.

b [The mass of the eggs at the beginning of the experiment, the amount the solutions were mixed, and the scales used to weigh the eggs.[1]][These three things should be the same across treatments or measured and noted.[2]]

Other acceptable responses include:

- The amount of distilled water.
- The brand of corn syrup used.
- The hen the eggs were from.
- The place the circumference was measured from on the egg.

I have suggested three variables that are reasonable to control.[1]

I have suggested how the variables might be controlled.[2]

I have not suggested controlling for variables that were already controlled in the question such as: amount of corn syrup, time in solution, treatment beforehand.

c [The independent variable is the concentration of corn syrup[1]][and the dependent variables are the circumference, weight, and firmness of the egg.[2]]

I have stated the independent variable.[1]

I have stated the dependent variables.[2]

d [No difference in[1]][egg circumference, weight, or firmness[2]][across the different concentrations of corn syrup.[3]]

Other acceptable responses include:

- An increase in circumference, weight, and firmness of eggs in the corn syrup solution.

I have stated the results that would disprove Kinji's hypothesis.[1]

I have referred to the dependent variables.[2]

I have referred to the independent variable.[3]

e [Kinji could test the eggs in more concentrations of corn syrup.[1]][When she finds a concentration that does not cause the mass and circumference of the egg to change, she will know that concentration is equal to the solute concentration inside the eggs.[2]]

I have suggested testing more concentrations of corn syrup.[1]

I have explained how Kinji will know the solute concentration of the eggs.[2]

I have referred to the scenario in my response.

f [The results may also be due to corn syrup specifically.[1]][To be sure that the eggs would interact the same way in other solutions, treatments with other solutes should have also been used.[2]]

Other acceptable responses include:

- The results may have been due to chance; Kinji would need more replicates to be sure she was observing a reliable pattern.
- The results may be due to the acid treatment given to the eggs beforehand, and not actually due to osmosis. Kinji can't be certain of her results as she did not include an egg that was unexposed to the treatment.

I have identified one explanation to which Rick could be referring.[1]

I have suggested how Kinji could overcome this limitation.[2]

3C Bulk transport

Theory review questions

1 **a** Exocytosis **b** Bulk transport
c Active transport **d** Endocytosis
e Vesicle **f** Golgi body
g Rough endoplasmic reticulum

2 B **3** D
4 B **5** A

Exam-style questions

Within lesson

6 D **7** C **8** A
9 A **10** D **11** B

12 **a** [Ribosomes.[1]]

I have identified the structure.[1]

b [Secretory proteins are made on ribosomes attached to rough endoplasmic reticulum (RER).[1]][They are folded in the RER then transported via vesicles to the Golgi body.[2]][Proteins may be modified here, and then are packaged into another vesicle.[3]][The secretory vesicle moves to the cell surface, fuses with the cell membrane so the contents of the vesicle are released by exocytosis.[4]]

I have stated the proteins are made on ribosomes on RER.[1]

I have described how proteins move from the RER to the Golgi body.[2]

I have stated what happens to secretory proteins at the Golgi body.[3]

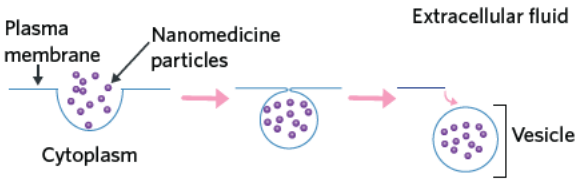
I have described how secretory vesicles evacuate the protein from the cell.[4]

I have used appropriate biological terminology such as: exocytosis, vesicle, Golgi body, rough endoplasmic reticulum, ribosomes.

Multiple lessons

13 C

14 a



- I have drawn the plasma membrane folding back on itself around the nanomedicine.
- I have drawn the nanomedicine packaged into a vesicle.
- I have labelled: nanomedicine, plasma membrane, vesicle, cytoplasm, extracellular fluid.
- I have not drawn exocytosis.

b [Lysosomes may fuse with the vesicle containing nanomedicine.[1]] [Lysosomes contain enzymes which may destroy the nanomedicine.[2]]

- I have stated lysosomes may fuse with the vesicle.[1]
- I have stated the nanomedicine may be destroyed by lysozymes/enzymes.[2]

Key science skills

15 a i [The age of mouse neurons.[1]]

- I have identified the independent variables.[1]

ii [The amount of APP and beta-amyloid in neurons.[1]]

- I have identified the dependent variables.[1]

b [*In vitro* refers to processes taking place in the laboratory, for example in a culture dish or test tube.[1]]

- I have explained what *in vitro* means[1]

c [More endocytosis can lead to a smaller cell membrane surface area, so the idea could be effective.[1]] [However, exocytosis is likely also occurring in those cells,[2]] [and this can increase cell membrane surface area.[3]] [Given that the amount of exocytosis is unknown, this is an uncontrolled factor that would affect the validity of results gained from this measurement.[4]]

- I have stated how endocytosis can affect cell membrane surface area.[1]
- I have identified that exocytosis is also occurring.[2]
- I have explained the effect of exocytosis on the cell surface area.[3]
- I have explained how this affects the validity of the results.[4]
- I have used appropriate biological terminology such as: validity, uncontrolled factor, exocytosis.

d i [The results prove the scientist's hypothesis.[1]] [The age of mouse neurons increased the amount of APP endocytosis by double and beta-amyloid by 50%.[2]]

- I have stated the results prove the hypothesis.[1]
- I have explained how the independent variable affects the dependent variable.[2]
- I have referred to the scenario in my response using terms such as: APP and beta-amyloid.
- I have used data from the scenario.

ii [Larger vesicles mean more APP molecules are being taken up by endocytosis.[1]]

- I have stated that large vesicles indicate more endocytosis of materials.[1]

iii [The experiment was only undertaken *in vitro*[1]] [so we don't know if similar results would occur *in vivo*.[2]]

Other acceptable responses include:

- The experiment was only performed in mice, so we don't know how it would affect humans.
- It appears the experiment was unreplicated, so the results are less reliable.

- I have suggested one limitation.[1]
- I have explained why this limits the experiment.[2]

Chapter 3 Review

SECTION A

1	D	**2**	D	**3**	A	**4**	C
5	C	**6**	C	**7**	D	**8**	D
9	B	**10**	A	**11**	D	**12**	C
13	B	**14**	B	**15**	A		

SECTION B

16 a [Rough endoplasmic reticulum.[1]]

- I have identified the correct organelle.[1]
- I have not written smooth endoplasmic reticulum, or just endoplasmic reticulum.

b [The proteins made by ribosomes on the rough endoplasmic reticulum,[1]] [are folded and packaged into transport vesicles that are taken to the Golgi body.[2]] [Here, the protein may be modified, before it is once more packed into secretory vesicles for secretion.[3]] [The vesicle containing the secretory proteins fuses with the plasma membrane via exocytosis, releasing the proteins from the cell.[4]]

- I have stated that proteins originate at the ribosome.[1]
- I have outlined the role of the rough endoplasmic reticulum in the transportation pathway.[2]
- I have outlined the role of the Golgi body in the transportation pathway.[3]
- I have described the process of exocytosis.[4]
- I have used appropriate biological terminology such as: exocytosis, Golgi body, vesicle.

17 a [A = protein channel, B = phospholipid .[1]]

Other acceptable responses include:

- A = transmembrane protein
- A = transport protein

✓ ✗ I have named the two structures.[1]

b [Cholesterol regulates membrane fluidity.[1]][Carbohydrates are attached to proteins and phospholipids and are involved in cell communication, adhesion, and reception.[2]]

Other acceptable responses include:

- Glycoproteins are involved in cell communication, adhesion, and reception.
- Glycolipids are involved in cell communication, adhesion, and reception.
- Enzymes catalyse chemical reactions.
- Ion pumps that are involved in transporting ions in and out of a cell.
- Transmembrane proteins that are involved in the reception of extracellular signals rather than membrane transport.

✓ ✗ I have identified and explained a role of the first structure.[1]

✓ ✗ I have identified and explained a role of the second structure.[2]

✓ ✗ I have used appropriate biological terminology such as: cholesterol, carbohydrate, phospholipid.

c [This difference in concentration is maintained using active transport.[1]][In active transport, ATP is used by specific protein pumps to transport K^+ against its concentration gradient into the red blood cells, increasing the concentration of K^+ in the cell.[2]][K^+ is charged so cannot easily diffuse across the plasma membrane, meaning the cytoplasm remains hypertonic in K^+ to the blood plasma.[3]]

✓ ✗ I have stated that active transport maintains the concentration gradient.[1]

✓ ✗ I have explained how active transport works.[2]

✓ ✗ I have explained why K^+ can't cross the membrane.[3]

✓ ✗ I have used appropriate biological terminology such as: diffuse, channel, pump, ATP, concentration gradient.

18 a i [Osmosis.[1]]

✓ ✗ I have correctly identified the term used to describe the movement of water into a cell.[1]

ii [Plant cells take in water as they are hypertonic to the water, making them swell like animal cells.[1]][However, plant cells are prevented from bursting by their rigid cell wall made of cellulose.[2]][Instead of swelling, the cells become turgid.[3]]

✓ ✗ I have stated that plant cells also swell.[1]

✓ ✗ I have stated that they do not burst.[2]

✓ ✗ I have described the plant cells as 'turgid'.[3]

b [Guard cells become less turgid when water leaves, which occurs through osmosis.[1]][For osmosis to occur quickly, ion channels open in the membranes of guard cells, and this leads to epidermal cells becoming hypertonic relative to guard cells.[2]][Water will move from the area of low solute concentration (guard cells) to high solute concentration (epidermal cells).[3]]

✓ ✗ I have stated that the change in turgidity occurs due to osmosis.[1]

✓ ✗ I have explained how solute concentration could be used to induce osmosis.[2]

✓ ✗ I have outlined the direction in which water moves.[3]

19 a

Organelle/structure	Role
Ribosome	Synthesises protein
Rough endoplasmic reticulum	Folds protein and packages it in transport vesicles destined for the Golgi body
Golgi body	Modifies and packages protein into secretory vesicles for further transport

Other acceptable responses include:

Organelle/structure	Role
Mitochondria	Provides energy for protein transport and synthesis
Vesicle	Transports protein to and from Golgi body
Plasma membrane	Allows protein to exit the cell via exocytosis

✓ ✗ I have completed the table by correctly identifying three organelles and their roles.

b i [Mohsin is correct,[1]][because glucose will usually have a lower concentration in cells than in plasma, as it is continuously being used up.[2]][This means glucose is transported with the concentration gradient via facilitated diffusion, which is a type of passive transport.[3]]

✓ ✗ I have stated who is correct.[1]

✓ ✗ I have justified why they are correct.[2]

✓ ✗ I have described the process of passive transport of glucose.[3]

ii [GLUT4 is a protein, so it is made by ribosomes, folded and transported by RER, modified and packaged by the Golgi body, then transported by a vesicle to the plasma membrane.[1]][To ensure GLUT4 embeds in the membrane, the GLUT4 would be packed into the membrane of the vesicle rather than the lumen of the vesicle.[2]][So, when the vesicle and plasma membrane fuse, GLUT4 ends up embedded in the plasma membrane.[3]]

✓ ✗ I have described protein synthesis and the secretory pathway.[1]

✓ ✗ I have stated where in the vesicle the GLUT4 would exist.[2]

REVIEW

- ✓ ✗ I have outlined how GLUT4 ends up in the plasma membrane during exocytosis.[3]
- ✓ ✗ I have used appropriate biological terminology such as: vesicle, plasma membrane.

iii [Pinocytosis begins by the cell membrane folding inwards to form a cavity that is filled with extracellular fluid.[1]][The cell membrane then pinches and fuses together to trap the extracellular fluid inside the newly formed vesicle.[2]][This vesicle then detaches from the cell membrane and can be transported around the cell.[3]]

- ✓ ✗ I have outlined the folding stage of pinocytosis.[1]
- ✓ ✗ I have outlined the trapping stage of pinocytosis.[2]
- ✓ ✗ I have outlined the budding stage of pinocytosis.[3]
- ✓ ✗ I have used appropriate biological terminology such as: extracellular fluid, cell membrane, vesicle.

4A Protein function and structure

Theory review questions

1 **a** Antibody or immunoglobulin
b Protein
c Amino acid
d Condensation reaction
e Secondary
f Hormone
g Primary
h The proteome

2 C

3 D

4 B

Exam-style questions

Within lesson

5 A **6** C **7** A

8 C **9** C

10 **a**

Structural level of protein	Diagram (W,X, Y, or Z)
primary	Y
secondary	X
tertiary	W
quaternary	Z

✓ ✗ I have identified the correct level of protein structure for diagrams W, X, Y, and Z .

b [Amino acid.[1]]

✓ ✗ I have identified the correct subunit.[1]

c [A condensation reaction occurs.[1]] [This involves water forming[2]] [when the -OH on a carboxyl group of one amino acid binds with an -H on the amino group of another amino acid.[3]] [Then the two amino acids bind together to form a dipeptide, held together by a peptide bond.[4]]

✓ ✗ I have correctly named the reaction that occurs.[1]

✓ ✗ I have stated that water is formed.[2]

✓ ✗ I have explained that the -OH of the carboxyl group binds to the -H of the amino group of adjacent amino acids.[3]

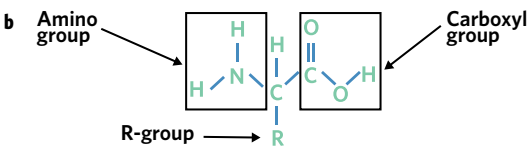
✓ ✗ I have stated that this forms a peptide bond between the two amino acids.[4]

✓ ✗ I have used appropriate biological terminology such as: water, condensation reaction, peptide bond, amino acid.

11 **a** [Peptide bond.[1]]

✓ ✗ I have identified the correct bond .[1]

b



✓ ✗ I have drawn the correct structure.

✓ ✗ I have identified the amino, carboxyl, and R-groups.

c [Tertiary structure is the overall 3D shape of the protein.[1]] [If a protein is made up of more than one polypeptide chain, then it is said to have quaternary structure.[2]]

✓ ✗ I have explained what is meant by tertiary structure.[1]

✓ ✗ I have explained what is meant by quaternary structure.[2]

✓ ✗ I have used appropriate biological terminology such as: 3D shape, polypeptide chain.

Multiple lessons

12 A **13** D

Key science skills

14 **a** [Lipids are hydrophobic,[1]] [so are not attracted to and do not interact with hydrophilic substances.[2]] [The outer R-groups of albumin are hydrophilic, so albumin will not interact with and dissolve in lipids.[3]]

✓ ✗ I have stated that lipids are hydrophobic.[1]

✓ ✗ I have stated that hydrophobic substances do not interact with hydrophilic substances.[2]

✓ ✗ I have explained why albumin will not dissolve in lipids.[3]

✓ ✗ I have used appropriate biological terminology such as: hydrophobic, hydrophilic, R-group, dissolve.

b [Proteins transport substances across membranes and defend against pathogens.[1]]

Other acceptable responses include:

- Chemical messengers/hormones.
- Receive and tranduce cell signals.
- Structural.
- Storage of amino acids and ions.
- Motor/contractile.
- Enzymes.

✓ ✗ I have identified two functions of proteins.[1]

c **i** [Ten.[1]]

✓ ✗ I have identified the number of patients with albumin levels outside the normal range.[1]

ii [Personal error.[1]]

✓ ✗ I have identified the correct type of error.[1]

iii [The doctor is correct.[1]] [Given that high blood albumin is normally due to dehydration,[2]] [rehydrating the patients with high albumin levels would lead to 20/25 patients having normal amounts of albumin. 20/25 = 80%.[3]]

✓ ✗ I have stated if the doctor is correct.[1]

✓ ✗ I have explained why rehydration might help her patients.[2]

✓ ✗ I have outlined why 80% is the correct proportion.[3]

iv [No, the results are not precise, especially given that they were taken during the one doctor visit.[1]][Precision refers to how closely two or more measurement values agree with each other.[2]][The patient's blood albumin levels vary widely both below and above the normal healthy range (from 3.21 to 5.75 g/dL), so these are not precise measurements.[3]]

✓ ✗ I have stated whether the results were precise.[1]

✓ ✗ I have referred to the definition of precision to justify my answer.[2]

✓ ✗ I have used data from the scenario to justify my answer.[3]

4B Nucleic acid function and structure

Theory review questions

1 **a** Nucleic acid **b** RNA **c** Ribosomal RNA or rRNA **d** Antiparallel **e** DNA **f** Transfer RNA **g** Phosphodiester bond **h** Nucleotide

2 D **3** A

4 C **5** C

Exam-style questions

Within lesson

6 D **7** A **8** B **9** D

10 C **11** A **12** C

Multiple lessons

13 B **14** A **15** B

16 A **17** A **18** B

19 **a** [Nucleic acid[1]][and protein.[2]]

✓ ✗ I have identified one of the macromolecules shown.[1]

✓ ✗ I have identified the second macromolecule shown.[2]

b [The monomers of a nucleic acid are nucleotides[1]][and the monomers of a protein are amino acids.[2]]

✓ ✗ I have identified the monomer of the first type of macromolecule.[1]

✓ ✗ I have identified the monomer of the second type of macromolecule.[2]

Key science skills

20 **a** **i** [The primary structure of a protein,[1]][which is the sequence of amino acids in a protein.[2]]

✓ ✗ I have identified the level of protein structure which is informed by protein sequencing.[1]

✓ ✗ I have described this level of protein structure.[2]

ii [The sequence of nucleotides in a gene.[1]]

✓ ✗ I have identified the information obtained from gene sequencing.[1]

b **i** [Bar X represents the nucleotide cytosine[1]][and bar Y represents the nucleotide thymine.[2]]

✓ ✗ I have correctly identified bar X.[1]

✓ ✗ I have correctly identified bar Y.[2]

ii [Scientist B is correct.[1]][Because there are equal numbers of the nucleotides A and T and the nucleotides C and G this is likely double stranded DNA.[2]][If the sample were single stranded DNA, it would be highly unlikely that there are equal number of complementary nucleotides.[3]]

✓ ✗ I have stated which scientist is correct.[1]

✓ ✗ I have explained why this is likely a sample of double stranded DNA.[2]

✓ ✗ I have explained why this is unlikely to be a sample of single stranded DNA.[3]

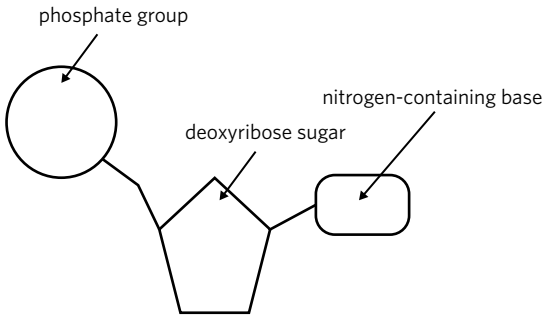
✓ ✗ I have used appropriate biological terminology such as: nucleotide, complementary.

iii [230 base pairs.[1]]

✓ ✗ I have correctly calculated the length of the DNA sample.[1]

✓ ✗ I have recognised that this is a sample of double stranded DNA, so the length must be half the total number of nucleotides.[2]

iv



✓ ✗ I have correctly drawn a nucleotide, the monomer of DNA.

✓ ✗ I have labelled the diagram.

✓ ✗ I have used appropriate biological terminology such as: nitrogen-containing base, deoxyribose sugar, phosphate group.

4C From DNA to protein

Theory review questions

1 **a** Gene **b** Template strand **c** Codon **d** Genetic code **e** Uracil (U) **f** 5′ methyl cap **g** RNA polymerase **h** Coding strand **i** Translation **j** pre-mRNA **k** Transfer RNA (tRNA) **l** Stop codon **m** Triplet **n** Transcription **o** Ribosome **p** Termination sequence **q** poly-A tail **r** Exons **s** Introns **t** Peptide bond **u** Nucleus

2 B **3** C **4** B **5** D **6** D

Exam-style questions

Within lesson

7 D **8** D **9** A **10** B **11** A

Multiple lessons

12 D

13 **a** [Six.[1]]

✓ ✗ I have identified how many amino acids would be present.[1]

✓ ✗ I have not included the stop codon or introns in my count.

b **i** [5′ AUG UGG CGA AUA AAA GUA GAA AGA CGU AUC CUA UAG 3′.[1]]

✓ ✗ I have written a complementary chain of RNA nucleotides.[1]

✓ ✗ I have identified the direction using 5′ and 3′.

ii [5′ AUG UGG CGA GUA AGA CUA UAG 3′.[1]]

✓ ✗ I have written a complementary chain of RNA nucleotides without introns.[1]

✓ ✗ I have identified the direction using 5′ and 3′.

✓ ✗ I have included the stop codon in the mRNA strand.

iii [Met-Trp-Arg-Val-Arg-Leu.[1]]

✓ ✗ I have stated the order of the amino acids in the polypeptide.[1]

14 **a** **i** [Translation.[1]]

✓ ✗ I have stated which process Molecule Z is involved in.[1]

ii [The tRNA anticodon is complementary to the mRNA codon being read by the ribosome.[1]] [The anticodon attaches to the mRNA codon, which then allows for the corresponding amino acids to be joined to the growing polypeptide chain.[2]]

✓ ✗ I have stated how the anticodon is related to mRNA.[1]

✓ ✗ I have outlined what this allows for.[2]

✓ ✗ I have used appropriate biological terminology such as: tRNA, complementary, mRNA, codon, amino acids, polypeptide chain.

b **i** [Primary structure.[1]]

✓ ✗ I have identified which level of structure preproinsulin is.[1]

ii [Preproinsulin coils and folds into structures such as alpha helices and beta-pleated sheets.[1]] [The polypeptide chain then arranges into a 3D-shape,[2]] [and then combines with another polypeptide chain to form the A and B chain of insulin.[3]]

✓ ✗ I have described what occurs at the secondary structure level.[1]

✓ ✗ I have stated that the tertiary structure level is formed.[2]

✓ ✗ I have described how the quaternary structure of insulin is formed.[3]

15 **a** [mRNA.[1]]

✓ ✗ I have identified the molecule.[1]

b [RNA polymerase attaches to the promoter region of a gene.[1]] [The DNA helix unwinds, and one strand is used as the template strand.[2]] [RNA polymerase then reads the template strand, and adds complementary RNA nucleotides to a growing mRNA strand, replacing thymine with uracil.[3]] [The pre-mRNA molecule then undergoes post-transcriptional modifications to become mRNA.[4]]

✓ ✗ I have stated how transcription begins.[1]

✓ ✗ I have stated that DNA is unwound.[2]

✓ ✗ I have described how mRNA is elongated.[3]

✓ ✗ I have identified that post-transcriptional modifications occur.[4]

✓ ✗ I have used appropriate biological terminology such as: RNA polymerase, promoter, gene, DNA helix, unwinds, template strand, nucleotides, complementary, pre-mRNA, post-transcriptional modifications, mRNA.

c [A protein.[1]]

Other acceptable responses include:

- A polypeptide.

✓ ✗ I have identified the molecule type.[1]

d [The ribosome binds and reads the mRNA code,[1]][and tRNA molecules bring specific amino acids to the ribosome.[2]][The tRNA anticodon binds to the complementary mRNA codon,[3]][allowing for amino acids to be joined by condensation polymerisation, forming the polypeptide polymer.[4]]

- I have identified the role of the ribosome in translation.[1]
- I have stated that tRNA delivers amino acids.[2]
- I have identified how tRNA interacts with mRNA.[3]
- I have described how the polymer is formed.[4]
- I have used appropriate biological terminology such as: ribosome, mRNA, tRNA, amino acids, anticodon, complementary, condensation polymerisation, polypeptide.

16

A	**DNA**
B	**pre-mRNA**
C	**mRNA**
D	**ribosome**
E	**tRNA**
F	**polypeptide**
G	**anticodon**
Stage Y	**transcription**
Stage Z	**translation**

Key science skills

17 a [The independent variable is the sequence of amino acids within the polypeptide and the dependent variable is the accumulation in the nucleus.[1]]

- I have identified the dependent and independent variables.[1]

b [Polypeptides N and E were easily able to cross the nuclear membrane,[1]][as they were able to accumulate in the nucleus.[2]]

- I have identified which polypeptides were able to cross the nuclear membrane.[1]
- I have stated why this is known.[2]

c [Polypeptide E* contains an Asp amino acid in the same position that polypeptide E contains a Gly. This change may affect the ability of the polypeptide to accumulate in the nucleus.[1]]

- I have stated why polypeptide E* could not accumulate like polypeptide E.[1]

d [The scientists could repeat their experiment to ensure the same results occur.[1]][Repeating the experiment would determine if the results are similar to what is true, and reduce the chances of impact from outliers.[2]]

- I have identified a way the scientists could increase their experiment's precision.[1]
- I have described why this change would increase precision.[2]

4D Gene regulation

Theory review questions

1 a Regulatory gene **b** Repressor protein
c *Lac* operon **d** Structural gene

2 C **3** A

4 D

Exam-style questions

Within lesson

5 B **6** C

Multiple lessons

7 B

8 a [Stage 1 is transcription.[1]][The purpose is to create a mature mRNA strand from the code on the DNA template strand.[2]][Stage 2 is translation.[3]][Its purpose is to convert the mature mRNA strand into a polypeptide chain by joining amino acids together.[4]]

- I have correctly named stage 1.[1]
- I have explained the purpose of stage 1.[2]
- I have correctly named stage 2.[3]
- I have explained the purpose of stage 2.[4]
- I have used appropriate biological terminology such as: transcription, template strand, DNA, mRNA, translation, polypeptide chain.

b [The introns are removed from the pre-mRNA strand[1]][and exons are joined together to make an mRNA strand which only contains coding fragments.[2]][A poly-A tail is also added to the 3′ end of the mRNA molecule and a methyl cap is added to the 5′ end.[3]]

- I have explained that introns are removed.[1]
- I have explained that exons are joined together.[2]
- I have explained what is added to each end of DNA.[3]
- I have used appropriate biological terminology such as: introns, exons, poly-A tail, methyl cap.

c [Structure P contains structural and regulatory genes.[1]][Structural genes encode for proteins that become part of the structure or function of an organism and do not regulate the expression of another gene[2]][and regulatory genes encode proteins that influence the expression of another gene.[3]]

- I have identified the two components of structure P.[1]
- I have defined structural genes.[2]
- I have defined regulatory genes.[3]
- I have used appropriate biological terminology such as: structural genes, regulatory genes.

9 a [*lacZ*.[1]]

Other acceptable responses include:

- *lacY*.
- *lacA*.

✓ ✗ I have identified a structural gene of the *lac* operon.[1]

b [The repressor protein binds to the operator sequence[1]][and prevents RNA polymerase from transcribing the *lac* operon.[2]] [When allolactose is present, it binds to the repressor protein, changing its structure and releasing it from the operator region,[3]] [allowing transcription to occur.[4]]

✓ ✗ I have stated where the repressor protein binds.[1]

✓ ✗ I have outlined the role of the repressor protein.[2]

✓ ✗ I have explained the effect of allolactose binding to the repressor protein.[3]

✓ ✗ I have explained the effect on transcription of the *lac* operon.[4]

✓ ✗ I have used appropriate biological terminology such as: repressor protein, operator, RNA polymerase.

c [The promoter region is the site where RNA polymerase binds to transcribe DNA.[1]]

✓ ✗ I have described the role of the promoter region.[1]

d [In the presence of allolactose, the repressor molecule will release from the operator region,[1]][allowing RNA polymerase to begin transcription of the *lacZ* gene.[2]][Once pre-mRNA is formed from transcription, post-transcriptional modifications take place to splice out introns and add a 5′ methyl cap and poly-A tail.[3]][The mature mRNA then moves out of the nucleus into the ribosomes[4]][and can commence the process of translation to produce the β-galactosidase enzyme.[5]]

✓ ✗ I have described what happens in the presence of allolactose.[1]

✓ ✗ I have explained the effect on transcription.[2]

✓ ✗ I have outlined the post-transcriptional modifications.[3]

✓ ✗ I have described where the mRNA moves to.[4]

✓ ✗ I have outlined how the enzyme is formed.[5]

✓ ✗ I have used appropriate biological terminology such as: repressor, operator, RNA polymerase, transcription, splice, 5′ methyl cap, poly-A tail, translation.

e [*E. coli* must conserve energy to survival.[1]][Transcription and translation both require a large input of energy.[2]][Therefore, by preventing the transcription of the *lac* operon, transcription and translation will only progress when required, lowering the total energy expenditure of the bacterium.[3]]

Other acceptable responses include:

- There is a selective advantage to regulate the *lac* operon.
- *E. coli* may only require the proteins made from *lacY*, *lacZ*, and *lacA* at particular times during the bacterium's life cycle.

✓ ✗ I have explained the importance of energy conservation.[1]

✓ ✗ I have described the amount of energy required for transcription and translation.[2]

✓ ✗ I have explained the importance of repressing the *lac* operon.[3]

Key science skills

10 a [An experimental control is an experimental procedure in which the experimental group does not receive the treatment or experience the influence of the independent variable.[1]][This serves to highlight any effects of confounding variables on the dependent variable.[2]] [Therefore, sample 1 is the experimental control.[3]]

✓ ✗ I have defined an experimental control.[1]

✓ ✗ I have explained the purpose of an experimental control.[2]

✓ ✗ I have identified the experimental control in the experiment.[3]

b [When working with *E. coli*, the experiment should take place in an aseptic environment.[1]]

Other acceptable responses include:

- Wearing gloves.
- Incubating *E. coli* at a temperature that prevents excessive growth.
- Washing hands after the experiment.
- Wearing lab coats.
- Following standard procedures for cleaning spills.

✓ ✗ I have identified a reasonable safety consideration.[1]

c [It is expected that for an increase in allolactose concentration, there will be an increase in the concentration of β-galactoside transacetylase.[1]]

✓ ✗ I have stated a suitable hypothesis.[1]

✓ ✗ I have included the relationship between the independent variable and dependent variable in my response.

d i [Personal error.[1]]

✓ ✗ I have identified the type of error.[1]

ii [It can be expected that sample K represents sample 2, sample L represents sample 4, sample M represents sample 1, and sample N represents sample 3.[1]][This can be determined as a greater amount of allolactose causes a greater rate of transcription of β-galactoside transacetylase.[2]]

✓ ✗ I have identified which results match which samples.[1]

✓ ✗ I have briefly explained my response.[2]

Chapter 4 Review

SECTION A

1	A	**2**	B	**3**	C	**4**	A
5	C	**6**	C	**7**	D	**8**	B
9	B	**10**	D	**11**	B	**12**	D
13	A	**14**	C	**15**	A	**16**	D

SECTION B

17 a [W is quaternary level structure, X is secondary structure, Y is primary structure, and Z is tertiary structure.[1]]

- I have identified the correct level of protein structure represented by each diagram.[1]

b [Diagram Z, the tertiary structure.[1]]

- I have identified which diagram gains its structure from R-group interactions.[1]

c [The primary structure of proteins, diagram Y, obtains its structure from peptide bonds between amino acids in the sequence.[1]][The secondary level of structure seen in diagram X involves folding and coiling which is determined by hydrogen bonding between amino acids.[2]]

- I have described the type of bonding involved in the primary level of protein structure.[1]
- I have described the type of bonding involved in the secondary level of protein structure.[2]
- I have used appropriate biological terminology such as: peptide bonds, folding and coiling, hydrogen bonding, amino acids.

18 a [Molecule X is mRNA.[1]][The mRNA molecule carries genetic information to the ribosome by specifying the ordering of amino acids in the polypeptide chain.[2]]

- I have correctly identified Molecule X.[1]
- I have described its function.[2]
- I have used appropriate biological terminology such as: mRNA, genetic information, ribosome, ordering of amino acids, polypeptide chain.

b [Translation.[1]]

- I have identified which process is being stopped.[1]

c [By stopping the movement of the ribosome along the mRNA, ricin inhibits the translation process in mammals.[1]][Inhibiting the translation process means that the mammals are unable to produce the proteins that are required to function and are essential for living.[2]]

- I have described what ricin poisoning is inhibiting.[1]
- I have explained how this inhibition can lead to death.[2]
- I have used appropriate biological terminology such as: ribosome, mRNA, inhibits, translation, proteins.

19 a [Amino acids.[1]]

- I have stated the monomer of insulin.[1]

b [Amino acids contain amine and carboxyl functional groups as well as a variable R-group which differs between different amino acids.[1]][On the other hand, nucleotides[2]][contain a phosphate group, a sugar, and a nitrogen-containing base which differs between different nucleotides.[3]]

- I have identified the three main parts of amino acids.[1]
- I have identified the monomer of DNA.[2]
- I have identified the three main parts of DNA monomers.[3]
- I have used appropriate biological terminology such as: amine, carboxyl, functioning groups, R-groups, nucleotides, phosphate, sugar, nitrogen-containing base.
- I have used comparative language such as: on the other hand.

c [In amino acids, amine, and carboxyl functional groups form a peptide bond, continuing on to produce a primary polypeptide sequence.[1]][In DNA, nucleotides form a phosphodiester bond between phosphate and sugar, which produces a single-stranded DNA molecule.[2]][For both macromolecule groups, water is a byproduct of the condensation reaction.[3]]

- I have described the joining of amino acids and named the bond type.[1]
- I have described the joining of nucleotides and named the bond type.[2]
- I have explained the role of water in condensation reactions.[3]
- I have used appropriate biological terminology such as: amine, carboxyl, functional groups, peptide bond, polypeptide sequence, nucleotides, phosphodiester bond, phosphate, sugar, single-stranded DNA.

d i [The sheep form of insulin is least similar,[1]][as it has the most differences in amino acids in both the alpha and beta chain when compared to humans.[2]]

- I have stated which animal's form of insulin is least similar.[1]
- I have referred to differences in amino acids as evidence for differences in insulin.[2]

ii [It is not known if all three have an identical nucleotide sequence even though they all have an alanine amino acid.[1]][This is because the genetic code is redundant, and multiple sequences of nucleotides can code for the same amino acid.[2]]

- I have stated that it is unknown if they contain an identical nucleotide sequence.[1]

- ✓ ✗ I have justified my response by referring to the redundancy of the genetic code.[2]
- ✓ ✗ I have used appropriate biological terminology such as: nucleotide sequence, alanine, genetic code, redundant, code, amino acids.

20 a [Gene X represents the regulatory gene (*lacI*)[1]][and Gene Y represents the operator gene.[2]]

- ✓ ✗ I have stated what Gene X represents.[1]
- ✓ ✗ I have stated what Gene Y represents.[2]

b [The promoter gene is the binding site of RNA polymerase.[1]]

- ✓ ✗ I have identified which gene RNA polymerase binds to.[1]

c [The *lac* repressor binds to the operator gene, stopping transcription.[1]]

- ✓ ✗ I have identified which gene the *lac* repressor binds to.[1]

d [Lactose inhibits the action of the *lac* repressor which changes its shape and removes it from the operator region,[1]][allowing RNA polymerase to bind to the promoter and transcription to occur.[2]] [This allows β-galactosidase to be produced,[3]][which breaks down lactose into glucose and galactose.[4]]

- ✓ ✗ I have identified that lactose inhibits the *lac* repressor.[1]
- ✓ ✗ I have identified that transcription occurs.[2]
- ✓ ✗ I have stated that β-galactosidase is produced.[3]
- ✓ ✗ I have explained the function of β-galactosidase.[4]
- ✓ ✗ I have used appropriate biological terminology such as: RNA polymerase, transcription, β-galactosidase.

5A Introducing enzymes!

Theory review questions

1 **a** Substrate **b** Catalyse
c Activation energy **d** Active site
e Product **f** Induced-fit model
g Enzyme

2 C **3** B

4 C **5** C

Exam-style questions

Within lesson

6 C **7** C **8** D **9** A

10 A **11** D **12** C **13** A

14 D **15** C **16** A

Multiple lessons

17 **a** [Condensation reaction.[1]]

✓ ✗ I have identified the kind of reaction.[1]

b [Peptide bond.[1]]

✓ ✗ I have identified what bond is formed.[1]

c [High pH value.[1]]

Other acceptable responses include:

- Low pH value
- High temperature

✓ ✗ I have stated a condition that can denature enzymes.[1]

d **i** [Primary structure.[1]]

✓ ✗ I have identified what level of protein structure is represented.[1]

ii [The primary structure of a protein refers to the sequence of amino acids in a polypeptide chain.[1]][The secondary structure is determined by hydrogen bonds, and is the folding and coiling of a section of the polypeptide chain. Secondary structures include alpha helices and beta-pleated sheets.[2]][When the protein takes on a three-dimensional globular shape it is said to have tertiary structure.[3]][Quaternary structure is achieved when multiple polypeptide chains or prosthetic groups combine to form a fully functional protein.[4]]

✓ ✗ I have described the primary level of protein structure.[1]

✓ ✗ I have described the secondary level of protein structure.[2]

✓ ✗ I have described the tertiary level of protein structure.[3]

✓ ✗ I have described the quaternary level of protein structure.[4]

✓ ✗ I have used appropriate biological terminology such as: polypeptide, hydrogen bonds, folding, coiling, alpha helices, beta-pleated sheets, globular, prosthetic groups.

18 **a** [pre-mRNA molecule.[1]]

✓ ✗ I have stated what type of molecule Molecule Z is.[1]

b [After RNA polymerase initiates transcription by attaching to the promoter region, DNA is unwound and the template strand of the AMY1 gene is exposed.[1]][RNA polymerase then reads the template and joins complementary RNA nucleotides,[2]][elongating the mRNA molecule.[3]][Transcription is ended when RNA polymerase reaches a termination sequence.[4]]

✓ ✗ I have described the initiation step of transcription.[1]

✓ ✗ I have described the elongation step of transcription.[2]

✓ ✗ I have stated what kind of molecule is being produced.[3]

✓ ✗ I have described the termination step of transcription.[4]

✓ ✗ I have used appropriate biological terminology such as: RNA polymerase, promoter, DNA, AMY1 gene, template, nucleotides, complementary, mRNA, transcription.

c [The mRNA Molecule Z binds to a ribosome in the cytoplasm. The start codon on the mRNA molecule initiates translation.[1]][tRNA with anticodons complementary to mRNA delivers specific amino acids to the ribosome, and amino acids bind together with peptide bonds to form the polypeptide chain.[2]][Translation terminates once the stop codon is reached.[3]][The polypeptide is then released and undergoes protein folding to form amylase.[4]]

✓ ✗ I have described the initiation step of translation.[1]

✓ ✗ I have described the elongation step of translation.[2]

✓ ✗ I have described the termination step of translation.[3]

✓ ✗ I have related this to amylase.[4]

✓ ✗ I have used appropriate biological terminology such as: mRNA, ribosome, start codon, tRNA, amino acids, anticodon, polypeptide chain, translation, stop codon.

Key science skills

19 **a** [Water and oxygen.[1]]

✓ ✗ I have stated the products of the reaction.[1]

b [The shape of the active site of catalase is complementary to hydrogen peroxide.[1]][This allows for catalase to catalyse the breakdown of hydrogen peroxide into water and oxygen.[2]]

✓ ✗ I have stated that their shapes are complementary.[1]

✓ ✗ I have stated the significance of their structures.[2]

✓ ✗ I have used appropriate biological terminology such as: active site, complementary, catalyse, breakdown.

c i [You would expect the shape of the graph for the carrot catalase to be the same, or similar to that of human catalase,[1]][and the optimal temperature to be close to 16°C.[2]]

I have described the graph's expected shape.[1]

I have described where the graph would be expected to sit.[2]

ii [Testing 25 pieces compared to 5 would likely increase the accuracy of the experiment.[1]][This is because increasing the sample size would make the results closer to the true value and reduce the margin of error, or the effect of outliers.[2]]

I have stated how the accuracy of the experiment would change.[1]

I have explained why this change would occur.[2]

5B Inhibiting enzymes

Theory review questions

1 a Non-competitive (or allosteric) inhibition
b Irreversible inhibition
c Enzyme inhibitor
d Competitive inhibition
e Reversible inhibition
f Allosteric site

2 B
3 D
4 A
5 B

Exam-style questions

Within lesson

6 C **7** C **8** D **9** A
10 C **11** C **12** B

Multiple lessons

13 a [Enzymes catalyse biochemical reactions by lowering the activation energy of reactions.[1]]

I have identified the mode of action of enzymes.[1]

I have used appropriate biological terminology such as: catalyse, activation energy.

b [The enzyme-substrate complex refers to the complex formed when an enzyme and substrate are bound.[1]][The substrate binds to the enzyme at the active site.[2]]

I have defined the enzyme-substrate complex.[1]

I have identified where binding occurs.[2]

c [The drug competitively occupies the enzyme's active site, allowing no substrate to bind.[1]][The drug's structure would have to be complementary to the enzyme's active site,[2]][and similar to the substrate's structure.[3]]

I have identified that competitive inhibition occurs at the active site.[1]

I have stated how the drug's structure relates to the enzyme.[2]

I have stated how the drug's structure relates to the substrate.[3]

I have used appropriate biological terminology such as: active site, complementary.

14 a [They would be lower than healthy individuals.[1]]

I have stated that they would be lower.[1]

b [Hex A.[1]]

I have identified the inhibited enzyme.[1]

c [The presence of compound R leads to the breakdown of compound Q, lowering the concentration.[1]]

I have described the relationship in the pathway.[1]

d [Increasing the concentration of transferase would not help with TSD symptoms.[1]][Transferase is responsible for converting compound P to glycolipid.[2]][However, the faulty Hex A enzyme would still be preventing glycolipid from progressing down the metabolic pathway, as increasing substrate does not reduce the impacts of allosteric inhibition.[3]]

I have stated whether it would help with TSD symptoms.[1]

I have explained the role of transferase in the pathway.[2]

I have related transferase's role to the allosteric inhibition of Hex A.[3]

15 a [The production is decreased.[1]]

I have identified what happens to tryptophan production.[1]

b [When pathway Y is activated, enzyme 1 is inhibited by tryptophan and compound 1 is not produced,[1]][whereas when pathway X is activated, the transcription of all genes is stopped or suppressed.[2]]

I have described what occurs when pathway Y is activated.[1]

I have described what occurs when pathway X is activated.[2]

I have used comparative language such as: whereas.

I have used appropriate biological terminology such as: inhibited, transcription, stopped or suppressed.

c [If enzyme 4 was unable to function, tryptophan would not be produced and would be unable to regulate the system.[1]][Compound 3 would also buildup as it is unable to be broken down.[2]]

I have explained what this would mean for tryptophan levels.[1]

I have explained what this would mean for compound 3 levels.[2]

Key science skills

16 a [The graphs display blood testosterone before and after the ACTH test in normal individuals and those with CAH.[1]] [Individuals with CAH had a slightly higher resting level of testosterone before the test.[2]] [Following the ACTH test, CAH individuals had an increase in blood testosterone levels whereas normal individuals levels stayed the same.[3]]

- I have described what the graph displays.[1]
- I have compared the results of the two groups before the test.[2]
- I have compared the results of the two groups after the test.[3]
- I have used comparative language such as: whereas.

b [The injection of ACTH in the test stimulates the biochemical pathway.[1]] [In normal individuals, ACTH stimulation leads to the production of cortisol which causes inhibition, leading to the regulation of ACTH and testosterone levels.[2]] [In CAH individuals the pathway is stimulated, however, the inhibited enzyme does not produce cortisol and no inhibition occurs, leading to continued ACTH production and a testosterone buildup.[3]]

- I have identified what the test does.[1]
- I have explained the reasoning for the normal group's results.[2]
- I have explained the reasoning for the CAH group's results.[3]

c [The inhibitor is irreversible and competitive.[1]] [With a similar structure to the substrate it is likely the inhibitor is competing for the active site.[2]] [As excess substrate does not increase the amount of product when a competitive inhibitor is present then it must be irreversibly binding to the enzymes.[3]]

- I have identified the type of inhibitor.[1]
- I have explained the competitiveness of the inhibitor.[2]
- I have explained the reversibility of the inhibitor.[3]

5C Coenzymes

Theory review questions

1 a Loaded **b** ATP
c Coenzyme **d** Unloaded
e NADPH **f** NADH

2 A **3** D
4 B **5** D

Exam-style questions

Within lesson

6 D **7** A **8** D **9** B

Multiple lessons

10 A **11** C

12 a [The substrate is glucose,[1]] [the enzyme hexokinase,[2]] [and the coenzyme is ATP.[3]]

- I have correctly identified the substrate.[1]
- I have correctly identified the enzyme.[2]
- I have correctly identified the coenzyme.[3]

b [The active site of hexokinase has a complementary structure to glucose.[1]]

- I have stated how the two structures are related.[1]
- I have used appropriate biological terminology such as: active site, complementary.

c [ATP is the coenzyme[1]] [which is used to provide the energy for the enzyme-catalysed reaction converting glucose into glucose 6-phosphate.[2]] [This energy comes from the donation of the energy-rich phosphate group on the ATP molecule, converting ATP into ADP.[3]]

- I have stated ATP is a coenzyme.[1]
- I have described the role of the coenzyme in this reaction.[2]
- I have stated what happens to ATP in the reaction.[3]
- I have used appropriate biological terminology such as: coenzyme, enzyme-catalysed, phosphate group, ADP.

d i [The third phosphate group forms part of the product, glucose 6-phosphate.[1]]

- I have identified the location of the third phosphate group.[1]

ii [After being unloaded in this reaction, ADP is cycled back to its loaded form ATP,[1]] [where it is then free to facilitate more enzyme-catalysed reactions.[2]]

- I have stated that ADP is cycled.[1]
- I have explained that ATP can facilitate more reactions.[2]
- I have used appropriate biological terminology such as: unloaded, cycled, loaded, ATP, enzyme-catalysed.

Key science skills

13 a [Coenzyme Y is altered as it is converted to its unloaded form.[1]]

- I have stated what change occurs to Coenzyme Y.[1]

b [The concentrations of molecules A and B would decrease, the concentration of molecule C would increase[1]][as the enzyme X-catalysed reaction will still occur.[2]][As for molecule D, concentration may increase slightly, but at a much slower rate.[3]] [This is because enzyme Y will not be able to catalyse the reaction from C to D without the loaded coenzyme Y, so this reaction may still occur at a very slow rate. However, the Enzyme X catalysed reaction would still occur quickly.[4]]

- I have described the concentrations of each of the molecules A, B, and C.[1]
- I have justified why this concentration is predicted for molecule A, B, and C.[2]
- I have described the concentration of molecule D.[3]
- I have justified why this concentration is predicted for molecule D.[4]

c [Enzyme X is likely a better fit to Molecules A and B,[1]][as Enzyme Y requires a coenzyme to bind with Molecule C.[2]]

- I have stated which enzyme is likely more complementary.[1]
- I have described why the other enzyme is less complementary.[2]

d i [When the concentration of Molecule D is lowest.[1]]

- I have identified when the consumption of Molecules A and B is greatest.[1]

ii [Molecule D inhibits the function of Enzyme X[1]][as the production of Molecule C is lowered as the concentration of Molecule D increases.[2]][This means that as the concentration of Molecule D increases, the inhibition of Enzyme X increases, and the total rate of reaction of the overall pathway decreases.[3]]

- I have stated which enzyme is inhibited.[1]
- I have outlined the evidence for inhibition.[2]
- I have described the effect on the rate of reaction of the pathway.[3]

iii [Molecule D is likely acting as an allosteric (non-competitive) inhibitor of Enzyme X.[1]][If it was a competitive inhibitor, it would block the active site of Enzyme X and be similar in structure to the substrates, Molecules A and B.[2]] [However, we are told Molecule D is not similar in shape, so it is likely acting allosterically.[3]]

- I have correctly identified what type of inhibitor Molecule D is acting as.[1]
- I have explained why it is likely not a form of inhibition.[2]
- I have referred to the information given in my response.[3]
- I have used appropriate biological terminology such as: allosteric, competitive, active site, substrates.
- I have signposted steps in my response using terms such as: however.

Chapter 5 Review

SECTION A

1	A	**2**	A	**3**	C	**4**	D
5	B	**6**	A	**7**	B	**8**	D
9	A	**10**	B	**11**	B	**12**	A
13	C	**14**	C	**15**	D		

SECTION B

16 a [Independent variable: pH of buffer.[1]][Dependent variable: % of oxygen in conical flask.[2]]

- I have identified the independent variable.[1]
- I have identified the dependent variable.[2]

b [The results do not support the students' hypothesis.[1]][The enzymes in flask 2 (high pH buffer) produced a flask filled with approximately 50% oxygen after five minutes. However the enzymes in flask 1 (neutral pH buffer) produced a flask filled with almost 75% oxygen after five minutes, disproving the students' hypothesis.[2]]

- I have stated if the results support the hypothesis.[1]
- I have justified my answer.[2]
- I have used data from the experiment in my response.

c [A flask could be set up that contained only 50 mL of 3% hydrogen peroxide solution and 52 mL of distilled water.[1]][This control would determine the percentage of oxygen produced without the enzyme present.[2]][This would enable the students to determine the extent of oxygen production that is due to the enzyme's activity and not due to confounding factors.[3]]

Other acceptable responses include:

- A flask containing 50 mL of 3% hydrogen peroxide solution and 50 mL of distilled water (the 52 mL of distilled water is used to account for the 2 mL of enzyme solution used ensuring there is the same amount of room in the flask for oxygen. However, 50 mL would still produce a result of similar accuracy).

- I have included only the necessary components for the control.[1]
- I have stated what this flask would show.[2]
- I have explained the function of this control flask.[3]
- I have used the correct experimental and biological terminology such as: oxygen percentage, hydrogen peroxide, enzyme, confounding factors.

d [The students' hypothesis was disproved as the highest oxygen production was seen in the neutral pH buffer.[1]][The students found that a neutral pH buffer solution resulted in a flask filled with 75% oxygen over 5 minutes due to the enzyme-catalyzed breakdown of hydrogen peroxide. The high pH buffer solution produced a 50% oxygen filled flask, while the low pH flask produced no oxygen over 5 minutes.[2]][This suggests that the enzyme's optimal pH is closest to the neutral pH, and low pH values can denature the enzyme.[3]]

- ✓ ✗ I have stated if the hypothesis was accurate.[1]
- ✓ ✗ I have stated how the enzyme performed in each flask, with reference to the variables identified in part a.[2]
- ✓ ✗ I have drawn a conclusion about the enzyme's activity.[3]
- ✓ ✗ I have used data in my response.
- ✓ ✗ I have used the correct experimental and biological terminology such as: oxygen filled flask, enzyme-catalysed, breakdown, hydrogen peroxide, enzyme, pH, denature.

17 a [In PKU unaffected individuals, if PAH were to increase, fumarate and acetoacetate would also increase.[1]][This is because PAH catalyses the production of tyrosine, which is the substrate for the next reaction in a cascade of reactions, eventually leading to the production of fumarate and acetoacetate in the final reaction step.[2]]

- ✓ ✗ I have stated how the concentrations of PAH and fumarate and acetoacetate are linked.[1]
- ✓ ✗ I have explained how the production of PAH leads to the production of fumarate and acetoacetate.[2]
- ✓ ✗ I have used appropriate biological terminology such as: PAH, fumarate, acetoacetate, catalyses, cascade.

b [Irreversible inhibitors typically form strong bonds with an enzyme and alter the enzymes active site. These inhibitors bind permanently to the enzyme, preventing the enzyme-catalysed reaction.[1]][On the other hand, reversible inhibitors form bonds with enzymes and can alter the enzymes active site to an extent, but these bonds can be broken, allowing the enzyme-catalysed reactions to continue.[2]]

- ✓ ✗ I have explained what irreversible inhibitors are.[1]
- ✓ ✗ I have explained what reversible inhibitors are.[2]
- ✓ ✗ I have used comparative language such as: on the other hand.

c [The presence of a PAH inhibitor would mean the baby is more likely to suffer from the symptoms of PKU.[1]][If PAH were to be impacted by a competitive inhibitor, there would be lowered or no conversion of phenylalanine to tyrosine, resulting in a buildup of phenylalanine and a greater risk of PKU symptoms.[2]]

- ✓ ✗ I have stated whether they would be more or less likely to suffer from PKU symptoms.[1]
- ✓ ✗ I have stated how the inhibitor impacting PAH relates to the chance of suffering from PKU symptoms.[2]
- ✓ ✗ I have used appropriate biological terminology such as: PAH, PKU, inhibitor, phenylalanine.

18 a [The results show that Test 2 had an increased rate of oxygen production and finished with an overall higher oxygen volume when compared to Test 1.[1]][Tests 1 and 2 produced 0.5 cm^3 and 1.0 cm^3 of oxygen gas over 5 minutes, respectively, and both tests were still producing oxygen at the end of the 5 minute period.[2]]

- ✓ ✗ I have stated which test had greater oxygen production.[1]
- ✓ ✗ I have explained the trends of the results.[2]
- ✓ ✗ I have used data in my response.
- ✓ ✗ I have used appropriate biological terminology such as: oxygen, production.

b [The results support Student B's statement more than Student A's statement.[1]][This is because we know that the optimum pH of catalase is 7, which is the pH that both tests were conducted at. This means that if the buffer's pH was changed and every other factor was identical, we would never see greater activity of the enzyme like we do in Test 2 on the graph.[2]][The optimum temperature of catalase is unknown, but it is likely closer to the body temperature of humans than it is to 20 °C, meaning the results of Test 2 could be from an increase in temperature.[3]]

- ✓ ✗ I have stated which students statements could be supported by the results.[1]
- ✓ ✗ I have explained why one student's statements could not cause these results.[2]
- ✓ ✗ I have explained how one student's statements could cause these results.[3]
- ✓ ✗ I have used appropriate biological terminology such as: optimum, pH, catalase, temperature.

c i [Approximately 37 °C[1]]

Other acceptable responses include:

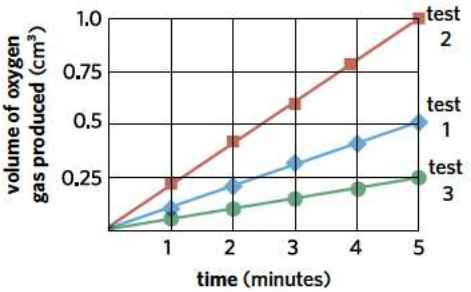
- Human body temperature

- ✓ ✗ I have stated what the optimum temperature of catalase would be.[1]

ii [At catalase's optimum temperature, molecules move faster, increasing the number of collisions between molecules to form the enzyme-substrate complex.[1]][However, it is not hot enough to denature the enzyme.[2]]

- ✓ ✗ I have explained how temperature affects the number of enzymatic reactions.[1]
- ✓ ✗ I have accounted for the effects of denaturation.[2]
- ✓ ✗ I have used appropriate biological terminology such as: optimum, catalyse, catalase, collisions, denature.

d [Test 3 would lie below Tests 1 and 2 on the graph, in both the steepness of the slope and final value after 5 minutes.[1]][This is because the 20°C experimental temperature of Tests 1 and 2 is much closer to catalases optimal temperature of 37°C than the 5 °C temperature Test 3 was conducted at. Consequently, the lowest enzyme activity and line on the graph would correspond to Test 3.[2]]



- ✓ ✗ I have described the line's slope and end point.[1]
- ✓ ✗ I have justified why the line would be here.[2]
- ✓ ✗ I have used data in my response.

e [The greatest activity of catalase and breakdown of hydrogen peroxide was seen at a pH of 7 and a temperature greater than 20 °C.[1]][This temperature is likely close to the human body temperature of 37 °C.[2]][Student B's hypothesis that a change in temperature resulted in the difference between Tests 1 and 2 was more likely to be correct, whilst Student A's hypothesis was inaccurate.[3]]

- ✓ ✗ I have stated the key finding relating catalase activity to temperature and pH.[1]
- ✓ ✗ I have explained that this is indicative of the human body temperature.[2]
- ✓ ✗ I have stated whether the results support or contradict Student A and Student B's hypotheses.[3]

6A Overview of photosynthesis

Theory review questions

1 **a** Granum **b** Chloroplast
c Endosymbiosis theory **d** Glucose
e Water **f** Stroma
g Thylakoids **h** Chlorophyll

2 A **3** A
4 D **5** A
6 C

Exam-style questions

Within lesson

7 B **8** A **9** A
10 D **11** D **12** B

13 **a** [Glucose.[1]]

I have identified the product of photosynthesis that is an energy-rich molecule.[1]

b Carbon dioxide + Water → (sunlight, chlorophyll) Glucose + Oxygen

I have written the simplified equation, not including water as an output.

I have written all inputs and outputs in worded form.

I have written 'sunlight' above the arrow and 'chlorophyll' below the arrow.

c **i** [Chloroplasts.[1]]

I have identified the organelle in slugs.[1]

ii [Chloroplasts and bacteria both contain free floating ribosomes.[1]]

Other acceptable responses include:

- Chloroplasts contain their own circular DNA.
- Chloroplasts divide by binary fission.
- Chloroplasts have a double membrane.

I have outlined a piece of evidence that supports the scientists' theory.[1]

d [*E. chlorotica* eats less than the black sea slug[1]][as they are able to undergo photosynthesis to produce their own food source. Therefore, they are less dependent upon eating other organisms to produce energy.[2]]

I have stated which organism would eat more.[1]

I have linked the ability of *E. chlorotica* to undergo photosynthesis with why they do not require as much food.[2]

Multiple lessons

14 **a** [Transfer RNA.[1]]

I have identified Molecule X.[1]

b [They are responsible for transporting amino acids from the stroma to ribosomes in the chloroplast.[1]][tRNA molecules carry a specific amino acid to the ribosome.[2]][The anticodon of the tRNA will then attach to the complementary mRNA codon,[3]][releasing the amino acid which starts building the polypeptide chain.[4]]

I have specified that tRNA carries amino acids from the stroma to the ribosomes.[1]

I have specified that tRNA is specific to one specific amino acid.[2]

I have explained that the tRNA anticodon will attach to the mRNA codon.[3]

I have addressed that the amino acids will be released and form a polypeptide chain.[4]

I have used appropriate biological terminology such as: stroma, ribosomes, anticodon, polypeptide chain.

c [Molecule W is mRNA.[1]][Firstly, RNA polymerase binds to the promoter region of the DNA as the DNA unwinds.[2]][Next, RNA polymerase catalyses transcription[3]][by reading the template strand of DNA and adding complementary RNA bases to synthesise the mRNA strand.[4]][As it is RNA, Molecule W pairs uracil, as opposed to thymine, with adenine.[5]]

I have identified molecule W.[1]

I have specified that RNA polymerase binds to the promoter region.[2]

I have specified that RNA polymerase catalyses transcription.[3]

I have identified that Molecule W is the product of RNA polymerase transcribing the template strand.[4]

I have explained the differences between RNA and DNA.[5]

I have included process words such as: firstly, next, then.

I have used appropriate biological terminology such as: unwinds, promoter region, catalyses, complementary strand, template strand.

d [Chloroplasts are encircled by a double membrane[1]][which supports the theory that they were engulfed by another cell.[2]][In addition, they contain their own ribosomes[3]][which means they can produce their own proteins, allowing them to live in isolation.[4]]

Other acceptable responses include:

- Chloroplasts contain their own circular DNA.
- Chloroplasts divide by binary fission.

I have identified a piece of evidence that supports the theory of endosymbiosis.[1]

I have linked the piece of evidence to how it supports the theory.[2]

✓ ✗ I have identified another piece of evidence that supports the theory of endosymbiosis.[3]

✓ ✗ I have linked the piece of evidence to how it supports the theory.[4]

✓ ✗ I have used appropriate biological terminology such as: double membrane, ribosomes, engulf.

Key science skills

15 a [The independent variable is exposure to light[1]][and the dependent variable is the amount of growth in cm of the plant.[2]]

✓ ✗ I have identified the independent variable.[1]

✓ ✗ I have identified the dependent variable.[2]

b [If the growth of a plant depends upon its exposure to light, then there would be a larger growth in Plant A when compared to Plant B.[1]]

✓ ✗ I have stated a suitable hypothesis.[1]

✓ ✗ I have included the independent variable and dependent variable in my hypothesis.

c [To increase reliability, Timmy should include more plant replicates in each group. This will mean that a more accurate average of each group can be estimated.[1]][Therefore, the impact of random errors or outliers in the data can be minimised.[2]]

Other acceptable responses include:

- Running the experiment for a longer time to eliminate other growth factors.
- Repeating the experiment.
- Keeping both plants in the same room to replicate conditions.

✓ ✗ I have identified a factor that will increase reliability.[1]

✓ ✗ I have explained how that factor increases reliability.[2]

✓ ✗ I have referred to the scenario in my response.

✓ ✗ I have used appropriate biological terminology such as: random error, reliability, accurate.

d [To increase precision, Timmy should use the same ruler[1]][to eliminate the impacts of any calibration errors of the ruler.[2]]

Other acceptable responses include:

- Using a digital ruler or caliper.

✓ ✗ I have identified a factor that will increase precision.[1]

✓ ✗ I have explained how that factor increases precision.[2]

✓ ✗ I have ensured I discussed a factor increasing precision and not accuracy.

✓ ✗ I have used appropriate biological terminology such as: calibration errors.

e [To disprove Timmy's hypothesis, the results would have to show a growth rate that does not differ between two plants,[1]][which would suggest that light is not necessary for plant growth.[2]]

Other acceptable responses include:

- The plant in the dark room grows more.

✓ ✗ I have referred to what the results would show.[1]

✓ ✗ I have outlined that growth in Plant B would suggest light is not required for growth.[2]

✓ ✗ I have used appropriate biological terminology such as: growth rate.

6B How photosynthesis works

Theory review questions

1 a Glucose
b Calvin cycle or dark stage
c NADPH
d Light-independent stage
e CO_2
f Thylakoid membranes
2 C
3 B
4 D
5 B
6 D
7 A

Exam-style questions

Within lesson

8 D
9 C

10 a [Light is required for the *Elodea* to photosynthesise.[1]][This light is used to energise the light-dependent reactions of photosynthesis.[2]]

✓ ✗ I have stated that photosynthesis is dependent on light.[1]

✓ ✗ I have outlined the role of light in photosynthesis.[2]

b [The two stages of photosynthesis are the light-dependent stage and the light-independent stage.[1]]

✓ ✗ I have stated both stages of photosynthesis.[1]

c [The light-dependent reaction produces oxygen which form bubbles in the water.[1]]

✓ ✗ I have identified how the bubbles are formed.[1]

11 a i [H_2O.[1]]

✓ ✗ I have identified input X.[1]

ii [CO_2.[1]]

✓ ✗ I have identified input Y.[1]

iii [All the carbon atoms from carbon dioxide are used to make glucose.[1]][Some of the oxygen atoms of carbon dioxide are also used to make glucose, while the remainder pair up with extra hydrogen ions unloaded by NADPH to form water.[2]]

✓ ✗ I have described what happens to the carbon atoms of carbon dioxide.[1]

✓ ✗ I have described what happens to the oxygen atoms of carbon dioxide.[2]

b [The oxygen in the carbon dioxide (input Y) was radioactively labelled.[1]][Glucose is built from the carbon and oxygen from carbon dioxide and the hydrogen collected by NADPH during the light-dependent stage.[2]][The oxygen from water (input X) cannot be the radioactively labelled sample as it is released at the end of the light-dependent stage as oxygen gas.[3]]

✓ ✗ I have stated which input is radioactively labelled.[1]

✓ ✗ I have explained the source of the carbon and oxygen in the formation of glucose.[2]

✓ ✗ I have explained why it cannot be from the other input.[3]

12

Name of the stage of photosynthesis that occurs at the stroma	**Light-independent stage**
Two input molecules that are required for reactions at the stroma	**Any two of the following:** • **Carbon dioxide (CO_2)** • **ATP** • **NADPH**
Two output molecules from the reactions at the stroma	**Any two of the following:** • **Glucose ($C_6H_{12}O_6$)** • **ADP + P_i** • **$NADP^+$** • **Water (H_2O)**

Other acceptable responses include:

Name of the stage of photosynthesis that occurs at the grana	**Light-dependent stage**
Two input molecules that are required for reactions at the grana	**Any two of the following:** • **Water (H_2O)** • **$NADP^+$** • **ADP + P_i**
Two output molecules from the reactions at the grana	**Any two of the following:** • **Oxygen (O_2)** • **NADPH** • **ATP**

✓ ✗ I have stated the name of each stage at the correct location.

✓ ✗ I have identified two inputs of each stage.

✓ ✗ I have identified two outputs of each stage.

Multiple lessons

13 B **14** D

Key science skills

15 a [The independent variable in this experiment is the concentration of $NADP^+$ available.[1]][The dependent variable is the concentration of oxygen gas.[2]]

✓ ✗ I have stated the independent variable.[1]

✓ ✗ I have stated the dependent variable.[2]

b [Students must ensure that the amount of light that each thylakoid is exposed to is consistent in all trials of the experiment.[1]]

Other acceptable responses include:

- Temperature.
- pH of solution.
- Amount of grana/thylakoids.
- Time exposed to the independent variable.

✓ ✗ I have stated a variable that must be controlled.[1]

c [The results could differ if Student A had not properly sealed the sample.[1]][This would mean oxygen could escape into the environment and the detected concentration was inaccurate.[2]]

Other acceptable responses include:

- Student A may have performed the experiment later than Student B, meaning that thylakoid membranes in their sample had become inactive, resulting in a lower reaction rate compared to the fresher samples used by Student B.

✓ ✗ I have identified why the students' results are different.[1]

✓ ✗ I have explained how this may have impacted their results.[2]

6C Increasing and decreasing photosynthesis

Theory review questions

1 a Stomata **b** Chloroplast
c Optimal **d** Denature

2 C **3** B

4 A **5** B

Exam-style questions

Within lesson

6 A **7** D **8** C

9 D **10** C

Multiple lessons

11 a [The rate of photosynthesis increases as temperature increases due to more enzyme-substrate collisions, until the optimal temperature of the enzymes within the cells is reached.[1]][Above this temperature, the rate begins to drop as the enzymes start to denature from the high temperatures.[2]]

✓ ✗ I have explained the initial increase in photosynthesis rate.[1]

✓ ✗ I have outlined why the reaction rate decreases.[2]

b i [Enzymes are biological catalysts that speed up reactions that would normally take much longer to occur by lowering the activation energy.[1]]

✓ ✗ I have identified the function of enzymes.[1]

ii [ATP and NADPH.[1]]

- ✓ ✗ I have named two loaded enzymes.[1]
- ✓ ✗ I have not listed ADP or $NADP^+$.

12 a i [Granum.[1]]

Other acceptable responses include:

- Thylakoid.

- ✓ ✗ I have identified structure X.[1]

ii [Light-dependent stage.[1]]

- ✓ ✗ I have identified the correct stage of photosynthesis.[1]

b i [$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$.[1]]

- ✓ ✗ I have identified the balanced and simplified chemical equation of photosynthesis.[1]
- ✓ ✗ I have not included H_2O on the products side of the equation.

ii [Plants use photosynthesis to convert light energy into chemical energy in the form of glucose.[1]]

- ✓ ✗ I have described why plants photosynthesise.[1]

c [Increasing the light intensity increases photosynthesis rate, until the enzyme-catalysed reactions cannot operate quicker and the maximum photosynthesis rate is reached.[1]][An increase in CO_2 concentration also increases the reaction rate until the maximum rate is reached.[2]][When temperature increases, the photosynthesis rate increases until the optimal temperature is reached, then the rate begins to rapidly decline[3]][as the enzymes within the cells begin to denature.[4]]

- ✓ ✗ I have described how light influences photosynthetic rate.[1]
- ✓ ✗ I have described how CO_2 influences photosynthetic rate.[2]
- ✓ ✗ I have described how increasing temperature increases the rate before the optimal and decreases after.[3]
- ✓ ✗ I have outlined why this decrease occurs.[4]
- ✓ ✗ I have used appropriate biological terminology such as: maximum, rate, optimal, enzymes, denature.

Key science skills

13 a [The oxygen meter records the oxygen produced by the plant, which corresponds to the rate of photosynthesis because oxygen is a product.[1]]

- ✓ ✗ I have identified that the meter shows photosynthesis rate.[1]

b [Flask 1 acted as a control, the absence of light shows that no photosynthesis occurs when there is no light present.[1]]

- ✓ ✗ I have stated the purpose of Flask 1.[1]

c [To ensure that minimal oxygen was released into the atmosphere, or introduced from the atmosphere, so that the meter recorded only the total amount of dissolved oxygen produced by photosynthesis.[1]]

- ✓ ✗ I have identified why the flasks were sealed.[1]

d [It is expected that Flask 4 would have the fastest photosynthesis rate,[1]][as light is required for photosynthesis and the light intensity on Flask 4 is the greatest.[2]]

- ✓ ✗ I have identified which flask is predicted to show the fastest rate.[1]
- ✓ ✗ I have explained that this is due to the high light intensity.[2]

e [The temperature of the flasks, the length of time that the oxygen levels were measured, and the size of the plants.[1]]

Other acceptable responses include:

- The health of plants, background light intensity, the time the plants spend in the flasks, CO_2 levels in flasks at the beginning.

- ✓ ✗ I have identified three variables that need to be controlled.[1]

f [Davis is most likely correct.[1]][The greater amount of light intensity will result in a faster photosynthesis rate.[2]][The greatest light intensity was on Flask 4 which results in the fastest rate, and the least light on Flask 1 results in the slowest rate.[3]]

- ✓ ✗ I have identified which student is correct.[1]
- ✓ ✗ I have described how light affects photosynthesis rate.[2]
- ✓ ✗ I have related this to the graphs.[3]

Chapter 6 Review

SECTION A

1	D	**2**	B	**3**	A	**4**	B
5	C	**6**	A	**7**	B	**8**	C
9	C	**10**	A	**11**	B	**12**	B
13	B						

SECTION B

14 a [Carbon dioxide is part of the light-independent reaction[1]][which occurs in the stroma.[2]]

- ✓ ✗ I have identified the stage of photosynthesis where carbon dioxide is an input.[1]
- ✓ ✗ I have identified the location of this stage.[2]

b [By inhibiting photosynthesis, a plant will be unable to produce glucose.[1]][This prevents the plant from producing ATP through cellular respiration, because glucose is a key input for respiration.[2]][Without ATP, vital metabolic processes will cease and the plant will ultimately die.[3]]

- ✓ ✗ I have explained the effect of inhibiting photosynthesis.[1]
- ✓ ✗ I have stated the primary use of glucose for a plant.[2]
- ✓ ✗ I have stated that without glucose the plant will die.[3]

c [This inhibitor would bind to the allosteric site of an enzyme[1]][as it is a non-competitive inhibitor.[2]][This causes the enzyme's active site to change shape, preventing any substrate from binding to the active site, ceasing the reaction.[3]]

- I have stated that the inhibitor would bind to the allosteric site of the enzyme.[1]
- I have mentioned that the inhibitor is non-competitive.[2]
- I have explained that the enzyme's active site will change shape which prevents substrate from binding to it.[3]
- I have used appropriate biological terminology such as: allosteric, non-competitive, substrate, and active site.

15 a [Glucose.[1]]

- I have identified the primary output of photosynthesis.[1]

b i [NADPH.[1]]

- I have identified the loaded form of the proton carrier in photosynthesis.[1]

ii [The net production of NADPH is 0[1]][as all NADPH is reconverted to $NADP^+$ in the light-independent reaction.[2]]

- I have stated the net production of NADPH.[1]
- I have justified my answer.[2]
- I have used appropriate biological terminology such as: NADPH, $NADP^+$, light-independent reaction.

16 a [Structure Z is the stroma[1]][and is the location of the light-independent stage.[2]]

- I have named structure Z.[1]
- I have identified the stage that occurs at structure Z.[2]

b [Plant A is from a roadside habitat[1]][as it has fewer thylakoid membranes, indicating that there is a large amount of light available,[2]][unlike the shaded rainforest habitat which is exposed to limited light and requires many thylakoids to meet photosynthetic needs.[3]]

- I have identified the plant from the roadside habitat.[1]
- I have explained why this plant has fewer thylakoid membranes.[2]
- I have compared this to the other environment.[3]
- I have used appropriate biological terminology such as: thylakoids.

c [The concentration of carbon dioxide available affects the rate of photosynthesis.[1]][As the concentration of carbon dioxide increases, the rate of photosynthesis increases until it plateaus due to other limiting factors such as light.[2]]

Other acceptable responses include:

- Temperature affects the rate of photosynthesis. As temperature increases or decreases from the optimum, the rate of photosynthesis decreases.

- I have stated a factor.[1]
- I have explained the relationship between the factor and the rate of photosynthesis.[2]
- I have not discussed light as a factor.

d i [Chloroplasts produce RNA through transcription, and this is a process that is evidence for endosymbiosis as it indicates that they survived independently once.[1]][Prokaryotes also undergo transcription to produce their own mRNA.[2]]

Other acceptable responses include:

- Chloroplasts can translate proteins with their ribosomes from mRNA produced in transcription.
- Chloroplasts divide independently from the rest of the cell by binary fission.
- Chloroplasts replicate their circular DNA independently from the rest of the cell.

- I have stated a process that supports the endosymbiosis theory.[1]
- I have stated that prokaryotes share this process.[2]
- I have used appropriate biological terminology such as: transcription, translation.

ii [Chloroplasts contain their own circular DNA molecule. This is a structural feature that supports the endosymbiosis theory,[1]][as prokaryotes also have a circular DNA molecule for the production of proteins[2]][which suggests that chloroplasts could survive independently.[3]]

Other acceptable responses include:

- Chloroplasts are bound by a double membrane. This is consistent with the theory that prokaryotes were engulfed by ancestral eukaryotic cells. The inner membrane is from the original prokaryote. The outer membrane is derived from the vesicular membrane, formed from the ancestral eukaryote.
- Chloroplasts have their own ribosomes, which are a similar size to bacterial ribosomes.

- I have stated a structural feature that supports the endosymbiosis theory.[1]
- I have explained why this supports the endosymbiosis theory.[2]
- I have explained that this suggests chloroplasts could survive independently.[3]
- I have used appropriate biological terminology such as: circular DNA.

17 a [Two inputs include carbon dioxide and water.[1]][Two outputs include glucose and oxygen.[2]]

Other acceptable responses include:

- Input: $NADP^+$, ADP + P_i.
- Output: water, NADPH, ATP.

- I have stated two inputs of photosynthesis.[1]
- I have stated two outputs of photosynthesis.[2]

b [Oxygen gas.[1]]

✓ ✗ I have stated what forms the bubbles.[1]

c [Grana.[1]]

Other acceptable responses include:

- Thylakoid membrane.

✓ ✗ I have stated where oxygen is produced.[1]

d [Chlorophyll.[1]]

✓ ✗ I have identified the chemical that captures sunlight.[1]

e [If the light source is removed, then the rate of the light-dependent reaction will decrease[1]][as light is required to split water molecules.[2]][Therefore, the overall rate of photosynthesis will decrease.[3]]

✓ ✗ I have stated that removing the light will decrease the rate of light-dependent reaction.[1]

✓ ✗ I have outlined the role of light in photosynthesis.[2]

✓ ✗ I have stated the effect on the entire photosynthesis process.[3]

✓ ✗ I have used appropriate biological terminology such as: light-dependent reaction.

f [If the light source increases water temperature too much, the rate of photosynthesis will decrease.[1]][This is because the temperature could shift above optimal, causing enzymes involved in photosynthesis to denature.[2]]

✓ ✗ I have stated that the rate of photosynthesis will decrease.[1]

✓ ✗ I have explained why the rate decreases.[2]

7A Cellular respiration and mitochondria

Theory review questions

1 **a** Glucose
b Mitochondrial matrix
c Aerobic cellular respiration
d Cristae
e ATP
f Anaerobic cellular respiration
g Endosymbiosis

2 C
3 B
4 B
5 A
6 D

Exam-style questions

Within lesson

7 D
8 D

Multiple lessons

9 B
10 B
11 A

12 **a** [Lactic acid and ATP.[1]]

I have stated the outputs of anaerobic respiration in animals.[1]

b [$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + 36 - 38\ ATP$[1]]

I have stated the chemical equation for aerobic respiration.[1]

c **i** [Carbon dioxide + water $\xrightarrow[\text{chlorophyll}]{\text{sunlight}}$ glucose + oxygen[1]]

[$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$[2]]

I have stated the word equation for photosynthesis.[1]

I have stated the balanced chemical equation for photosynthesis.[2]

ii [The presence of circular DNA[1]] [and replication by binary fission.[2]]

Other acceptable responses include:

- The presence of ribosomes.
- The ability to produce proteins independently from the cell.
- Presence of a double membrane.

I have identified a similarity between chloroplasts, mitochondria, and prokaryotes.[1]

I have identified a second similarity between chloroplasts, mitochondria, and prokaryotes.[2]

d **i** [Anaerobic cellular respiration. [1]]

I have identified which cellular respiration type occurs.[1]

ii [Oxygen is needed in aerobic respiration but not in anaerobic,[1]] [and aerobic respiration occurs in the mitochondria, whereas anaerobic does not.[2]]

Other acceptable responses include:

- Aerobic respiration produces carbon dioxide and water, rather than lactic acid.
- Aerobic respiration produces more ATP per glucose molecule.

I have stated a difference between aerobic and anaerobic respiration in animals.[1]

I have stated a second difference between aerobic and anaerobic respiration in animals.[2]

I have used comparative language such as: whereas.

13 **a** [The first technique transfers DNA from the mother's egg to a donor egg before fertilisation from the father's sperm occurs.[1]] [In contrast to this late fertilisation, the second technique involves fertilisation from the father's sperm first, followed by the transfer of fertilised egg material into a donor egg.[2]]

I have explained when fertilisation occurs in the first technique.[1]

I have explained when fertilisation occurs in the second technique.[2]

I have used comparative language such as: in contrast to.

b **i** [Parents may be able to conceive a child that will not inherit mitochondrial diseases when they were previously unable to.[1]]

Other acceptable responses include:

- The research may lead to scientific breakthroughs that reduce the chances of other heritable diseases.
- Parents will spend less on medical costs if their child does not have a mitochondrial disease.

I have identified a potential benefit of using donor mitochondrial DNA for parents.[1]

ii [The price of undertaking the techniques may be too expensive, so there will be unequal access to the treatment.[1]]

Other acceptable responses include:

- The new techniques may have unforeseen side effects on the conceived baby.
- The new techniques may not reduce the chance of the baby obtaining mitochondrial diseases later in life.
- Because it is a new technique, doctors may be unable to obtain perfect results every time.

I have identified a potential concern parents may have about using donor mitochondrial DNA.[1]

c [They are said to have three parents as the DNA of three people is passed onto one child, the mother's egg, the father's sperm and the donor's mitochondrial DNA.[1]]

I have explained why they are said to have three parents.[1]

Key science skills

14 **a** [Sugar is an input in cellular respiration and required for the yeast cells to produce ATP.[1]]

✓ ✗ I have explained why the sugar solution was added.[1]

b [To ensure there was no exchange of gas with the environment.[1]] [Interactions with the environment would impact the oxygen and carbon dioxide measurements.[2]]

✓ ✗ I have explained why the container was sealed.[1]

✓ ✗ I have explained why this is important for the experiment's results.[2]

c i [Oxygen is an input of aerobic cellular respiration in yeast,[1]] [so the oxygen concentration in the container was reduced by 4% as it was used up.[2]]

✓ ✗ I have identified how oxygen is related to aerobic respiration.[1]

✓ ✗ I have explained the decrease in oxygen concentration.[2]

ii [Carbon dioxide is an output of the aerobic cellular respiration pathway in yeast[1]] [and so aerobic respiration causes an increase of carbon dioxide concentration by 6% as it is produced.[2]]

✓ ✗ I have identified how carbon dioxide is related to aerobic respiration.[1]

✓ ✗ I have explained the increase in carbon dioxide concentration.[2]

d i [Replication reduces the effect of outliers and random errors, which has the potential to increase the precision of results[1]] [however, the accuracy will likely be unchanged as replication does not reduce the impact of systematic errors.[2]]

✓ ✗ I have described how replication impacts the precision of the experiment.[1]

✓ ✗ I have described how replication impacts the accuracy of the experiment.[2]

✓ ✗ I have used appropriate biological terminology such as: outliers, random errors, systematic errors.

✓ ✗ I have used comparative language such as: however.

ii [Using more sophisticated measuring instruments increases the accuracy of the experiment by reducing systematic errors.[1]] [The precision would also increase as better equipment reduces the chance of random errors.[2]]

✓ ✗ I have described how using better measurement equipment impacts the accuracy of the experiment.[1]

✓ ✗ I have described how using better measurement equipment impacts the precision of the experiment.[2]

✓ ✗ I have used appropriate biological terminology such as: systematic errors, random errors.

7B Aerobic cellular respiration

Theory review questions

1 a Pyruvate **b** NAD^+
c Cytosol or cytoplasm **d** Glycolysis
e Mitochondrial matrix **f** Acetyl CoA
g $FADH_2$ **h** Cristae
i ATP

2 D **3** C
4 A **5** D

Exam-style questions

Within lesson

6 D **7** C **8** A **9** D

Multiple lessons

10 C **11** A **12** B **13** D

14 a [Output X is carbon dioxide[1]] [and molecule Y oxygen.[2]]

✓ ✗ I have identified output X.[1]

✓ ✗ I have identified molecule Y.[2]

b

Process	Name of process(es)	Site of process
M	Light-dependent reactions	**grana of chloroplast**
O	**Glycolysis**	cytoplasm
P	Krebs cycle and electron transport chain	**mitochondria**

✓ ✗ I have identified the site of the light-dependent reactions.

✓ ✗ I have identified the process O.

✓ ✗ I have identified the site of the Krebs cycle and ETC.

15 a [Structure Y is the mitchondria.[1]] [It is the site of aerobic cellular respiration which produces the majority of energy/ATP for the cell.[2]]

✓ ✗ I have named structure Y.[1]

✓ ✗ I have described the role of structure Y.[2]

✓ ✗ I have not described mitochondria as the powerhouse of the cell.

b [An oxygen molecule crosses the plasma membrane (structure X)[1]] [by simple diffusion[2]] [down a concentration gradient[3]] [as it is a small, hydrophobic molecule.[4]]

✓ ✗ I have identified structure X.[1]

✓ ✗ I have stated the process to cross the membrane.[2]

✓ ✗ I have identified the direction of movement.[3]

✓ ✗ I have justified my answer by referring to the chemical nature of oxygen.[4]

c [The heart requires a large supply of ATP from mitochondria for contraction.[1]][Therefore, the heart requires a large number of mitochondria to function efficiently.[2]]

- I have stated why the heart needs a large amount of energy.[1]
- I have explained how this affects the number of structure Y.[2]

16 a [Cellular respiration.[1]]

- I have identified the metabolic process that produces energy.[1]

b [Glucose + Oxygen → Carbon dioxide + Water + Energy[1]]

- I have written the correct equation.[1]
- I have not written the equation for photosynthesis.
- I have not written chemical formulas.

c i [Glycolysis,[1]][which occurs in the cytosol of the cell.[2]]

- I have stated the process.[1]
- I have stated the correct location in the cell.[2]

ii [Electron transport chain,[1]][which occurs on the cristae of the mitochondria.[2]]

- I have stated the process.[1]
- I have stated the correct location in the cell.[2]

d i [The O_2 produced is equal to the O_2 used[1]][as the rate of photosynthesis is equal to the rate of aerobic cellular respiration.[2]]

- I have explained how overall oxygen produced can equal zero.[1]
- I have explained how this occurs with reference to metabolic processes.[2]

ii [At point N, O_2 produced is greater than O_2 used[1]][which means more photosynthesis is occurring than aerobic respiration,[2]][as oxygen is an output for photosynthesis, but an input for aerobic cellular respiration.[3]]

- I have compared O_2 used to O_2 produced at point N.[1]
- I have stated which metabolic process is occurring to a greater extent.[2]
- I have described the relevance of O_2 with reference to the appropriate metabolic processes.[3]

iii [At point M, the graph plateaus because factors such as carbon dioxide availability become limiting factors.[1]]

- I have explained why the graph plateaus.[1]
- I have used appropriate biological terminology such as: limiting factor.

Key science skills

17 a [The independent variable is temperature[1]][and the dependent variables are oxygen and carbon dioxide levels.[2]]

- I have identified the independent variable.[1]
- I have identified the dependent variables.[2]

b [In aerobic cellular respiration, oxygen is an input of the electron transport stage,[1]][whereas carbon dioxide is an output of the Krebs cycle.[2]][Therefore, the experimental design should measure levels of both oxygen and carbon dioxide[3]][to determine if temperature affects certain stages of aerobic cellular respiration.[4]]

- I have stated that oxygen is an input of the electron transport chain.[1]
- I have stated that carbon dioxide is an output of the Krebs cycle.[2]
- I have explained how the experimental design should factor this in.[3]
- I have explained what the results can prove from the experimental design.[4]

c [A systematic error.[1]]

- I have identified the type of error.[1]

7C Anaerobic cellular respiration

Theory review questions

1 a Ethanol **b** Yeast
c Lactic acid or Lactate **d** Anaerobic cellular respiration
e Lactic acid fermentation

2 A **3** C

4 D

Exam-style questions

Within lesson

5 A **6** C **7** A
8 C **9** D **10** A

Multiple lessons

11 C **12** C **13** B

14 a [Anaerobic cellular respiration,[1]][which produces two ATP per glucose molecule.[2]][Glucose is broken down into pyruvate which then reacts further to form lactic acid in animals or ethanol and carbon dioxide in yeast, bacteria, and plants.[3]]

- I have named the process that produces ATP in the absence of oxygen.[1]
- I have described the process with reference to ATP yield.[2]
- I have described the process with reference to the product/s.[3]

b i [Carbon monoxide is a competitive inhibitor.[1]] [As oxygen concentration increases, carbon monoxide is displaced from haemoglobin.[2]] [This means that it must bind to the same site as oxygen[3]] [and therefore, it must be a competitive inhibitor.[4]]

- I have stated carbon dioxide's mode of inhibition.[1]
- I have identified a relationship between oxygen concentration and carbon monoxide binding.[2]
- I have stated where oxygen and carbon monoxide bind to haemoglobin.[3]
- I have used this information to support my conclusion.[4]

ii [Glycolysis (occurs in the cytosol) involves glucose being broken down into two pyruvate molecules, producing two ATP in the process.[1]] [The Krebs cycle (occurs in the mitochondrial matrix) involves pyruvate being successively broken down into carbon dioxide, producing NADH, $FADH_2$, and two ATP in the process.[2]] [The electron transport chain (on the mitochondrial cristae) involves NADH and $FADH_2$ being unloaded. Oxygen is the final electron acceptor and binds with hydrogen ions to produce water and 32-34 ATP.[3]]

- I have named and described the first stage of aerobic respiration.[1]
- I have named and described the second stage of aerobic respiration.[2]
- I have named and described the third stage of aerobic respiration.[3]
- I have used appropriate biological terminology such as: glycolysis, the Krebs cycle, the electron transport chain, NADH, $FADH_2$, ATP, pyruvate, carbon dioxide.

Key science skills

15 a [Ethanol, carbon dioxide, and ATP.[1]]

- I have identified all of the products of anaerobic cellular respiration in yeast.[1]
- I have not given lactic acid as a product.

b [Fermentation enables yeast cells to rapidly produce ATP in the absence of oxygen.[1]]

- I have explained the importance of fermentation in yeast cells.[1]

c [Both aerobic and anaerobic cellular respiration involve glycolysis.[1]] [Anaerobic cellular respiration only produces two ATP per glucose molecule, whereas aerobic respiration produces 36-38 ATP per glucose molecule.[2]]

Other acceptable similarities include:

- Both involve reactions that occur in the cytosol.
- Both use glucose as an input.
- Both use NAD^+ as an electron and proton carrier.

Other acceptable differences include:

- Anaerobic cellular respiration produces ATP faster than aerobic respiration.
- Anaerobic cellular respiration cannot be sustained indefinitely due to a build-up of toxins (such as lactic acid), whereas aerobic respiration can be sustained indefinitely.
- Anaerobic cellular respiration produces lactic acid whilst aerobic respiration produces carbon dioxide and water.

- I have stated a similarity between aerobic and anaerobic cellular respiration.[1]
- I have stated a difference between aerobic and anaerobic cellular respiration.[2]
- I have used comparative language such as: whereas, both.

d i [The independent variable is the concentration of oxygen.[1]] [The dependent variable is the amount of *K. xylinus* survival.[2]]

- I have identified the independent variable.[1]
- I have identified the dependent variable.[2]

ii [An environment with no oxygen available.[1]]

- I have described an anaerobic environment.[1]

iii [Personal error.[1]]

- I have identified the type of error.[1]

iv [There would be no growth of *K. xylinus* in the oxygenated group whilst there would be lots of growth of *K. xylinus* in the deoxygenated group.[1]]

- I have stated results that would support the hypothesis that *K. xylinus* are obligate anaerobes.[1]

7D Increasing and decreasing cellular respiration

Theory review questions

1 a Optimal temperature **b** ATP
c Denaturation **d** Electron transport chain (ETC)

2 A **3** C

4 D **5** A

Exam-style questions

Within lesson

6 B **7** D **8** D **9** A

Multiple lessons

10 D **11** A **12** C

13 a [Danny is incorrect.[1]] [When there is no environmental O_2, there is no oxygen for aerobic respiration to occur.[2]] [The CO_2 is produced from anaerobic respiration.[3]]

- I have evaluated Danny's statement.[1]
- I have explained the significance of no environmental O_2.[2]
- I have explained where CO_2 is produced.[3]

b [Deprivation of O_2 means the root cells will undergo only anaerobic respiration to produce energy, which produces less ATP for growth or metabolism.[1]][Only respiring anaerobically results in a large amount of ethanol being produced,[2]][which in large amounts can be toxic and result in death of the root cells.[3]]

- I have described the consequence for the plant root cells.[1]
- I have outlined what is produced when this happens.[2]
- I have explained why this can lead to plant death.[3]

c i [The rate of aerobic respiration has reached its maximum due to the enzyme-catalysed systems working at full capacity, and no further intake of O_2 can increase the rate.[1]]

- I have explained why the graph plateaus.[1]

ii [Altering the glucose (or sucrose) availability could result in a higher plateau on the graph.[1]][If more glucose is present, more reactant is available to undergo the reaction and be turned into CO_2, raising the graph.[2]]

- I have stated the variable that could raise the graph's plateau.[1]
- I have described how this change could change the graph.[2]

Key science skills

14 a [The independent variable is the species of yeast in container[1]][and the dependent variables are percentages of oxygen and ethanol at the start and end of the experiment.[2]]

- I have identified the independent variable.[1]
- I have identified the dependent variables.[2]

b i [Aerobic cellular respiration.[1]]

- I have identified which type of respiration can be measured using O_2 levels.[1]

ii [This process is anaerobic cellular respiration.[1]][Without the use of oxygen, yeast cells anaerobically turn glucose into ethanol and carbon dioxide in a reaction that produces two ATP.[2]]

- I have identified anaerobic respiration.[1]
- I have described anaerobic respiration in yeast.[2]
- I have used appropriate biological terminology such as: anaerobic, oxygen, ethanol, ATP.

c [It is expected that the ethanol levels will be lower,[1]][as the high temperature is likely to denature the yeast enzymes responsible for both aerobic and anaerobic respiration, resulting in decreased ethanol production.[2]]

- I have identified the expected change in ethanol levels.[1]
- I have described why this change is expected.[2]
- I have used appropriate biological terminology such as: dentaure, enzyme.

d i [Personal error.[1]]

- I have identified the error type.[1]

ii [The error lowers the class mean of percentage of oxygen at the start of the experiment.[1]]

- I have identified which class mean has been impacted.[1]

iii [Besides sucrose availability, changing the temperature of each container could lower the rate of both respiration types.[1]][If the temperature is changed to be further away from the optimal of the enzyme within the yeast it will lower the rate of both reactions.[2]]

Other acceptable responses include:

- Increasing or decreasing the pH levels away from the optimal pH for the enzymes involved in respiration will decrease enzyme efficiency and therefore will decrease the overall respiration rate within yeast.

- I have identified a factor other than sucrose that could lower respiration rates.[1]
- I have explained why changing this factor could lower respiration rates.[2]
- I have used appropriate biological terminology such as: optimal, enzyme.

Chapter 7 Review

SECTION A

1	D	**2**	A	**3**	A	**4**	C
5	C	**6**	C	**7**	B	**8**	B
9	B	**10**	C	**11**	C	**12**	C
13	C	**14**	C	**15**	D		

SECTION B

16 a [Aerobic cellular respiration.[1]]

- I have correctly identified the metabolic process.[1]
- I have not just stated cellular respiration.
- I have used appropriate biological terminology such as: aerobic.

b [As there is a lack of oxygen, cells will rely more on anaerobic respiration[1]][which produces ATP and lactic acid.[2]][As lactic acid is an acid, it will decrease the overall pH within cells.[3]]

- I have explained that there is a greater reliance on the anaerobic process.[1]
- I have stated the products of anaerobic respiration.[2]
- I have explained the effect on pH of cells.[3]

c [At high altitudes and low oxygen concentrations, the tree relies more on anaerobic respiration, which is known as fermentation.[1]]

[This process produces ethanol and carbon dioxide as products which cannot be metabolised.[2]][Ethanol is toxic and eventually accumulates enough to kill the organism.[3]]

- I have explained that there is a greater reliance on fermentation.[1]
- I have stated the products of fermentation.[2]
- I have stated that ethanol is toxic for the plant.[3]
- I have used appropriate biological terminology such as: fermentation, ethanol, metabolised, toxic.

17 a [Anaerobic respiration allows a cell to produce ATP very quickly in the absence of oxygen.[1]][This is useful from a survival perspective as a mammal may need to produce ATP after using up all available oxygen in muscles, such as when rapidly escaping danger.[2]]

- I have described a useful characteristic of anaerobic respiration.[1]
- I have explained how this characteristic might benefit a mammal.[2]

b [Lactic acid, ATP.[1]]

- I have identified all products of anaerobic respiration in mammal cells.[1]
- I have not stated: carbon dioxide, water, ethanol.

c [The rate of cellular respiration increases when the temperature increases, and is greatest at the optimal temperature of the enzymes involved in cellular respiration, but above this optimal the rate decreases.[1]][At temperatures lower than optimal, enzymes have less kinetic energy and move slower, resulting in a lower respiration rate.[2]][At temperatures higher than optimal, enzymes can denature, also lowering respiration rate.[3]]

- I have described the relationship between temperature and respiration rate.[1]
- I have explained the effect of lower temperatures on enzyme activity.[2]
- I have explained the effect of higher temperatures on enzyme activity.[3]

d [Anaerobic respiration and aerobic respiration both involve glycolysis.[1]][Anaerobic respiration only produces 2 ATP per glucose molecule, whereas aerobic respiration produces 36-38 ATP per glucose molecule.[2]]

Other acceptable similarities include:

- Both involve reactions that occur in the cytosol.
- Both use glucose as an input.
- Both use NAD^+ as an electron and proton carrier.

Other acceptable differences include:

- Anaerobic respiration produces ATP faster than aerobic respiration.
- Anaerobic respiration cannot be sustained indefinitely due to a build-up of toxins, whereas aerobic respiration can be sustained.
- Anaerobic respiration produces lactic acid whilst aerobic respiration produces carbon dioxide and water.

- I have stated a similarity between anaerobic respiration and aerobic respiration.[1]
- I have stated a difference between anaerobic respiration and aerobic respiration.[2]
- I have used comparative language such as: whereas, both.

18 a

Stage	Location	Inputs	Outputs
Glycolysis	**Cytosol**	ADP + P_i **Glucose** $NAD^+ + H^+$	2 ATP Pyruvate NADH
The Krebs cycle	Matrix	ADP + P_i $NAD^+ + H^+$ Acetyl CO-A FAD + 2 H^+	2 ATP NADH **CO_2** $FADH_2$
Electron transport chain	Cristae	$FADH_2$ 32-34 ADP + P_i NADH **Oxygen**	FAD + 2 H^+ 32-34 ATP $NAD^+ + H^+$ **Water**

- I have correctly identified each of the blanks in the table.

b i [As hydrogen cyanide is a non-competitive inhibitor, it binds to an allosteric site on the enzyme[1]][and alters the structure of the active site.[2]][Consequently, the substrate can no longer bind to the active site.[3]]

- I have stated that hydrogen cyanide does not bind to the active site.[1]
- I have explained that this alters the structure of the active site.[2]
- I have stated that this prevents substrate from binding to the active site.[3]
- I have used appropriate biological terminology such as: allosteric site, active site, substrate, enzyme.
- I have referred to the scenario in my response.

ii [Hydrogen cyanide prevents the electron transport chain from operating[1]][which stops aerobic cellular respiration.[2]][Aerobic cellular respiration is required to produce sufficient ATP to sustain life.[3]][Therefore, inhibition by hydrogen cyanide is lethal.[4]]

- I have explained that hydrogen cyanide stops the electron transport chain.[1]
- I have explained the effect on aerobic cellular respiration.[2]
- I have described the importance of aerobic cellular respiration.[3]
- I have linked the lack of ATP produced with the survival of the cell.[4]
- I have referred to the scenario in my response.

19 a [The cytosol.[1]]

I have identified where ethanol would be produced in a yeast cell.[1]

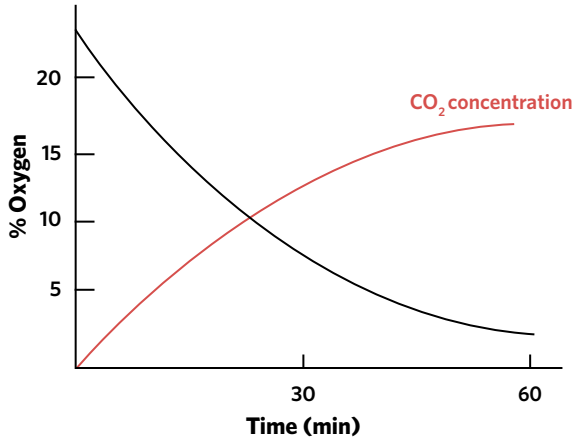
b [Ethanol concentration would stay the same.[1]][Ethanol is only produced in anaerobic respiration,[2]][and as there is oxygen present in the container, aerobic respiration would occur rather than anaerobic respiration.[3]]

I have correctly identified whether ethanol concentration would increase, stay the same, or decrease.[1]

I have explained when ethanol is produced.[2]

I have explained my prediction.[3]

c



I have identified that the concentration of carbon dioxide increases.

I have identified that the carbon dioxide concentration rate of increase is similar (but opposite) to the rate of change in oxygen concentration.

I have started my graph from a concentration of 0.

d [Krebs Cycle,[1]][mitochondrial matrix.[2]]

I have identified the stage of cellular respiration.[1]

I have identified the location of this stage.[2]

8A The stimulus-response model

Theory review questions

1 **a** Signalling molecule **b** Stimulus
c Response **d** Receptor
e Reception **f** Signal transduction

2 B **3** D

4 A

Exam-style questions

Within lesson

5 D **6** C **7** A

8 A **9** A

Multiple lessons

10 B

11 **a** [Light is a stimulus because it is an external change[1]][that is detected by rhodopsin and causes a response in the cell.[2]]

- ✓ ✗ I have identified that light is an external variable.[1]
- ✓ ✗ I have identified that light triggers a cellular response.[2]

b [Moving his arms to catch the ball.[1]]

- ✓ ✗ I have correctly identified the response.[1]

c **i** [As the bacterially-produced molecule competitively inhibits the enzyme phosphodiesterase, it must bind to the active site of phosphodiesterase.[1]][This prevents the c-GMP molecule from binding to the active site of phosphodiesterase[2]][and the normal hydrolysis of the c-GMP molecule cannot occur.[3]]

- ✓ ✗ I have described the binding site of the bacterially-produced molecule.[1]
- ✓ ✗ I have explained the effect this would have on the interaction between phosphodiesterase and c-GMP.[2]
- ✓ ✗ I have explained the effect on the normal function of the phosphodiesterase enzyme.[3]

ii Because the enzyme phosphodiesterase cannot function as intended, the inhibition of electrical impulses in Jordan's rod cells would not occur.[1]

- ✓ ✗ I have correctly explained the effect on electrical impulses in the rod cell.[1]

12 **a** [When the environmental concentration of glucose is low[1]][and the environmental concentration of lactose is high.[2]]

- ✓ ✗ I have described the glucose concentration.[1]
- ✓ ✗ I have described the lactose concentration.[2]

b [The mRNA molecule encoding for the *lac* repressor protein travels and binds to a ribosome,[1]][which then reads the mRNA molecule and initiates translation.[2]][The amino acid corresponding to each codon on the mRNA strand is retrieved by tRNA molecules that contain a complementary anticodon.[3]]

[The specific amino acid is then added onto the growing polypeptide by condensation polymerisation.[4]][Once the STOP codon is reached, translation halts and the *lac* repressor polypeptide is formed.[5]]

- ✓ ✗ I have stated that an mRNA molecule interacts with a ribosome.[1]
- ✓ ✗ I have stated the ribosome reads the mRNA molecule.[2]
- ✓ ✗ I have explained that complementary tRNA anticodons and specific amino acids are retrieved.[3]
- ✓ ✗ I have explained that amino acids are added by condensation polymerisation.[4]
- ✓ ✗ I have stated that translation halts once the STOP codon is reached.[5]
- ✓ ✗ I have referred to the scenario in my response.
- ✓ ✗ I have not referred to the transcription of the *lac* operon in my response.
- ✓ ✗ I have used appropriate biological terminology such as: mRNA, *lac* repressor protein, ribosome, tRNA, amino acid, codon, anticodon, condensation polymerisation.

c [Allolactose binds to and changes the structure of the *lac* repressor protein.[1]][The change in structure causes the *lac* repressor protein to detach from the *lac* operon, and the transcription of the *lac* genes can occur.[2]]

- ✓ ✗ I have stated that allolactose changes the shape of the *lac* repressor protein.[1]
- ✓ ✗ I have explained how the function of the *lac* repressor protein is altered.[2]

d [The *lac* repressor protein binds to the operator region of the *lac* operon.[1]][This operator region is a sequence of DNA located downstream of the promoter of the *lac* operon but upstream of the three genes *lacZ*, *lacY*, and *lacA*.[2]]

- ✓ ✗ I have correctly named this as the operator region of the *lac* operon.[1]
- ✓ ✗ I have described the specific location of this region in relation to the operon.[2]

e [These three regions are structural genes,[1]][as they encode for proteins that do not control the activity of other genes.[2]]

- ✓ ✗ I have stated that the three regions are structural genes.[1]
- ✓ ✗ I have explained why these regions are considered structural genes.[2]

f [Stimulus: the environmental concentration of glucose and lactose.[1]]
[Response: using lactose as a source of energy for cellular function.[2]]

- ✓ ✗ I have correctly identified the stimulus.[1]
- ✓ ✗ I have correctly identified the response.[2]

Key science skills

13 **a** **i** [Independent variables: amino acid concentration, and temperature.[1]][Dependent variable: *GCN4* gene expression.[2]]

✓ ✗ I have correctly identified the two independent variables.[1]

✓ ✗ I have correctly identified the dependent variable.[2]

ii [Stimuli: amino acid concentration and temperature.[1]][Response: *GCN4* gene expression.[2]]

✓ ✗ I have correctly classified the stimuli.[1]

✓ ✗ I have correctly classified the response.[2]

b i [When the concentration of amino acids are high, *GCN4* gene expression decreases. However, expression does not sink below 5 AU. When the concentration of amino acids are low, *GCN4* gene expression increases up to 10 AU when amino acid concentration is 0 mg/L.[1]]

✓ ✗ I have described the relationship between *GCN4* gene expression and amino acid concentration.[1]

✓ ✗ I have used data in my response.

ii [This relationship suggests that low amino acid concentrations stimulate the expression of the *GCN4* gene.[1]]

✓ ✗ I have suggested a plausible mechanism to describe the relationship between amino acid concentration and *GCN4* gene expression.[1]

c [*GCN4* is a regulatory gene,[1]][as its expression can influence the expression of other genes.[2]]

✓ ✗ I have identified that *GCN4* gene is a regulatory gene.[1]

✓ ✗ I have justified my answer with reference to the definition of a regulatory gene.[2]

d [The scientists could have included a control where they measured the *GCN4* gene expression under standard environmental conditions.[1]]

Other acceptable responses include:

- Increased the sample size of the experiment.
- Replicating the treatments.

✓ ✗ I have suggested a suitable method for increasing the reliability of the results.[1]

e [A shortage of amino acids would prevent the production of proteins.[1]] [A lack of these proteins could harm certain cellular functions.[2]]

✓ ✗ I have explained that a lack of amino acids would affect the production of proteins.[1]

✓ ✗ I have explained that a lack of these proteins would harm cellular function.[2]

8B Living things communicate using chemicals

Theory review questions

1 a Pheromones **b** Signalling molecule
c Cytokines **d** Hormones
e Neurotransmitters, or neurohormones

2 A **3** C
4 C **5** D

Exam-style questions

Within lesson

6 A **7** C **8** B **9** D
10 B **11** C **12** B **13** D
14 D **15** B

Multiple lessons

16 a [Auxin.[1]]

✓ ✗ I have identified the plant hormone responsible for phototropism.[1]

b [Gibberellins,[1]][which act as a growth accelerator in plants.[2]]

Other acceptable responses include:

- Cytokinins, which control cell division and the growth of lateral branches.
- Abscisic acid, which controls seed and bud dormancy and helps overcome stresses such as droughts.
- Ethylene, which regulates the ripening of fruits, and when fruits and leaves drop.

✓ ✗ I have identified a hormone in plants other than auxin.[1]

✓ ✗ I have briefly described its function.[2]

c [$6\,CO_2 + 6\,H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6\,O_2$.[1]]

✓ ✗ I have stated the balanced and simplified chemical equation for photosynthesis.[1]

✓ ✗ I have not included H_2O on the products side of the equation.

d i [The endocrine system.[1]]

Other acceptable responses include:

- The endocrine glands of the body.

✓ ✗ I have stated where human hormones are produced.[1]

ii [In humans, hormones are secreted by endocrine glands into the bloodstream and transported around the body,[1]][before exiting the blood and binding to a target cell, causing a response.[2]]

✓ ✗ I have described how hormones are transported away from the point of secretion.[1]

✓ ✗ I have stated how hormones then impact target cells.[2]

I have used appropriate biological terminology such as: endocrine, bloodstream, target cell.

17 a [Neurotransmitters.[1]]

I have identified the type of signalling molecule released by neurons.[1]

b [The reception of neurotransmitters from a neighbouring neuron.[1]]

I have identified the stimulus that leads to a response in a neuron.[1]

c [Label C.[1]]

I have identified which label represents the synaptic gap.[1]

d [Neurotransmitters are released via exocytosis from neuron cells at point A.[1]][They then diffuse across the synaptic gap represented by label C,[2]][before reaching specific receptors on a target cell at point B,[3]][where they initiate a response in the target cell.[4]]

I have stated that label A represents where neurotransmitters are released.[1]

I have stated that neurotransmitters cross the synaptic gap at label C.[2]

I have described what happens when neurotransmitters reach label B.[3]

I have stated that a response is initiated in the target cell.[4]

I have used appropriate biological terminology such as: neurotransmitters, synaptic gap, receptors, target cell, response.

e [Target cell 3,[1]][as it can be stimulated by either neuron 1 or 2, whereas the other cells only undergo a response when stimulated by neuron 1.[2]]

I have stated which target cell undergoes more frequent responses.[1]

I have explained that the more frequent responses are due to more frequent neurotransmitter reception.[2]

Key science skills

18 a [That auxin in the apical tips inhibits the growth of lateral branches in pea plants.[1]]

I have stated the hypothesis.[1]

b [To remove the auxin-rich apical tips of the plants, allowing for different auxin treatments.[1]]

I have identified why the plants were decapitated.[1]

c [Treatment C was used as a control[1]][to confirm that the lateral growth of the pea plants was due to the auxin within the gel, not the gel alone.[2]]

I have identified Treatment C as a control.[1]

I have explained why a second control was needed in the experiment.[2]

d [The results support the hypothesis,[1]][as lateral branches were produced in treatments A and C but not in B. This suggests that auxin inhibits lateral branch growth.[2]]

I have stated that the hypothesis was supported.[1]

I have explained why the results support the hypothesis.[2]

8C Signal transduction

Theory review questions

1 a Hydrophilic
b Second/secondary messengers
c Signal amplification
d Transmembrane protein
e Hydrophobic
f Signal transduction

2 A
3 B
4 D
5 B

Exam-style questions

Within lesson

6 C
7 A
8 B
9 A
10 A

11

Name of pain receptor	Chemical nature of signalling molecule	Receptor location	Justification
GPLR4-2	Protein-based, hydrophilic	Plasma membrane/ transmembrane	Hydrophilic signalling molecules cannot cross the plasma membrane, meaning they must bind to receptors on the plasma membrane
X9	Lipid-based, hydrophobic	Inside the cell/ intracellular	Hydrophobic signalling molecules can cross the plasma membrane, meaning their receptors can be within the cell
K2P4	Both protein-based hydrophilic molecules AND lipid-based hydrophobic molecules	Plasma membrane/ transmembrane	As the receptor can interact with hydrophilic signalling molecules, the receptor must be on the plasma membrane as that is the only area both signalling molecules can occupy

Multiple lessons

12 C **13** A **14** D **15** C

16 a [Hormone.[1]]

✓ ✗ I have identified what type of signalling molecule insulin is.[1]

b [It is hydrophilic.[1]]

Other acceptable responses include:

- Lipophobic.
- Polar.
- Protein-based.

✓ ✗ I have stated a key aspect of the nature of insulin.[1]

c i [Because glucose is a large, polar molecule.[1]]

Other acceptable responses include:

- Hydrophilic.
- Lipophobic.

✓ ✗ I have stated why glucose can't freely cross the plasma membrane.[1]

ii [Facilitated diffusion[1]][is a passive form of transport that does not require an energy input.[2]]

✓ ✗ I have identified the mode of transport for insulin in this scenario.[1]

✓ ✗ I have stated whether energy is required in this mode of transport.[2]

iii [Movement occurs down the concentration gradient.[1]]

✓ ✗ I have identified which direction movement occurs.[1]

d [The hormone insulin is secreted by the pancreas into the bloodstream,[1]][where it then travels to the muscle cells, exits the stream, and binds to specific receptors on target cells.[2]]

✓ ✗ I have stated that insulin enters the bloodstream.[1]

✓ ✗ I have described that it can travel to target cells.[2]

Key science skills

17 a [Cell Y.[1]]

✓ ✗ I have identified the cell/s where second messengers are present.[1]

b [Cell Y,[1]][as the one signalling molecule, molecule B, has lead to multiple second messengers transducing a signal within the cell.[2]]

✓ ✗ I have identified the cell/s where signal amplification occurs.[1]

✓ ✗ I have explained what signal amplification means.[2]

✓ ✗ I have referred to the scenario in my response.

c [The hydrophilic signalling molecule arrives at a transmembrane receptor, where it binds and causes a change in the receptor.[1]][The change activates a second messenger within the cell, which carries the signal to proteins and other second messengers in a cascade.[2]]

[The signal undergoes amplification to increase the number of second messengers,[3]][before arriving at enzymes where responses are initiated.[4]]

✓ ✗ I have described how signal transduction begins in Cell Y.[1]

✓ ✗ I have explained how a cascade of second messengers occurs.[2]

✓ ✗ I have identified that signal amplification occurs.[3]

✓ ✗ I have stated that the process ends with a cellular response.[4]

✓ ✗ I have used appropriate biological terminology such as: hydrophilic, signalling molecule, transmembrane receptor, second messenger, amplification, enzymes.

d [Akmed is correct,[1]][as nonpolar substances can easily cross the plasma membrane whereas polar ones cannot.[2]][This is due to the majority of the plasma membrane being made of nonpolar fatty acid tails.[3]][Although Ling is correct that water can cross the membrane, it is an exception as it is a small polar molecule and other, larger polar molecules cannot cross.[4]]

✓ ✗ I have identified which student is correct.[1]

✓ ✗ I have stated which molecules can diffuse across the plasma membrane.[2]

✓ ✗ I have explained the polarity of the plasma membrane.[3]

✓ ✗ I have explained why the other student is incorrect.[4]

8D Apoptosis

Theory review questions

1 a Cancer **b** Blebbing

c T cytotoxic cell **d** Mitochondrial pathway or intrinsic pathway

e Apoptosis **f** Apoptotic bodies

2 A **3** D

4 C **5** A

Exam-style questions

Within lesson

6 B **7** B **8** D **9** C

10 D **11** B **12** B **13** A

14 a [No,[1]][apoptosis in this cell is caused by internal DNA damage and would be initiated via the mitochondrial pathway.[2]]

✓ ✗ I have stated if apoptosis is initiated via the death receptor pathway.[1]

✓ ✗ I have justified my response.[2]

✓ ✗ I have used appropriate biological terminology such as: mitochondrial pathway.

b [During apoptosis, phagocytes receive external signals and move to the dying cell.[1]]

Other acceptable responses include:

- Apoptotic bodies form.
- Phagocytosis of apoptotic bodies.

✓ ✗ I have correctly identified a change that is external to the cell during apoptosis.[1]

c [Phagocytes engulf and digest apoptotic bodies after a cell has broken up.[1]]

✓ ✗ I have identified the role of phagocytes during apoptosis.[1]

✓ ✗ I have used appropriate biological terminology such as: apoptotic bodies.

Multiple lessons

15 D

16 a i [Misfolding changes the shape of the binding site of the receptor protein,[1]][and the receptor may not be able to recognise death signalling molecules.[2]]

✓ ✗ I have recognised that misfolding changes the shape of the receptor binding site.[1]

✓ ✗ I have explained the effect this would have on death receptor function.[2]

ii [As the receptor cannot recognise death signalling molecules,[1]][it cannot generate a response as part of the death signalling pathway of apoptosis.[2]][This would decrease the rate of apoptosis in the affected cells, increasing the chances of cancerous cells surviving.[3]]

✓ ✗ I have stated that the receptor cannot recognise death signalling molecules.[1]

✓ ✗ I have explained the effect this would have on the apoptosis pathway.[2]

✓ ✗ I have explained how this increases the chances of developing thyroid lymphoma.[3]

b [Cancerous cells have mechanisms which reduce their total rate of apoptosis when compared to healthy cells.[1]][As the BCL-2 proteins repress apoptosis,[2]][they would be much more active in cancerous cells when compared to healthy cells.[3]]

✓ ✗ I have compared the rate of apoptosis in cancerous to healthy cells.[1]

✓ ✗ I have stated the effect of the BCL-2 protein.[2]

✓ ✗ I have related these two pieces of information to the activity of BCL-2 proteins in cancerous cells compared to healthy cells.[3]

Key science skills

17 a [By blocking expression of membrane death receptor proteins[1]][or by increasing the expression of apoptosis-inhibiting proteins.[2]]

Other acceptable responses include:

- Expressing malfunctioning death receptor proteins.
- Expressing malfunctioning apoptosome proteins.
- Increased resistance to internal cell damage.
- Blocking the expression of apoptosome proteins.

✓ ✗ I have identified one plausible mechanism of 'apoptosis resistance'.[1]

✓ ✗ I have identified a second plausible mechanism of 'apoptosis resistance'.[2]

b [Yes.[1]][Chemotherapy drugs damage DNA in the cell which initiates apoptosis[2]][and senolytic drugs cause the release of cytochrome c.[3]][Both of these actions are part of the mitochondrial pathway of apoptosis.[4]]

✓ ✗ I have correctly stated if the two drugs act on the same pathway of apoptosis.[1]

✓ ✗ I have described the effects of chemotherapy drugs on the cell.[2]

✓ ✗ I have described the effects of senolytic drugs on the cell.[3]

✓ ✗ I have correctly identified the pathway(s) of apoptosis.[4]

c [Chemotherapy drugs are likely to have more severe side effects.[1]][This is because chemotherapy drugs 'cause apoptosis in a wide range of cell types' whereas senolytic drugs 'selectively initiate apoptosis' only in senescent cells.[2]]

Other acceptable responses include:

- Senolytic drugs could be more damaging as they have not been tested in humans and may have unintended side effects.

✓ ✗ I have stated which drug type is likely to have more severe side effects.[1]

✓ ✗ I have justified my response by referring to the specificity of each drug type.[2]

Chapter 8 review

SECTION A

1	A	**2**	C	**3**	B	**4**	D
5	C	**6**	C	**7**	C	**8**	B
9	B	**10**	A	**11**	D	**12**	C
13	C	**14**	C	**15**	A		

SECTION B

16 a [Signal transduction.[1]]

✓ ✗ I have recognised this is an example of signal transduction.[1]

b [The cellular receptors are proteins.[1]]

✓ ✗ I have stated which group of biomacromolecules the cellular receptors belong to.[1]

c [This suggests that thyroid hormones are hydrophobic.[1]]

Other acceptable responses include:

- Steroid based.

- Non-polar.
- Lipid/fatty acid based.
- Lipophilic/lipid soluble.

✓ ✗ I have recognised what this suggests about the nature of thyroid hormones.[1]

d [Each cell type may contain different receptor proteins, causing different cellular responses.[1]]

Other acceptable responses include:

- Each cell type may produce different secondary messenger molecules.

✓ ✗ I have suggested what may cause the different cellular responses observed.[1]

17 a [A reduction in the rate of apoptosis could result in the presence of skin cells between mice digits, causing webbed paws.[1]]

Other acceptable responses include:

- The formation of tumours within mouse paws.

✓ ✗ I have identified a potential consequence of reduced apoptosis in mouse paws.[1]

b [Apoptosis assists in the removal of virally infected cells[1]][and removes damaged or non-functioning cells.[2]]

Other acceptable responses include:

- Removal of unnecessary cells.
- Prevent the formation of tumours within mice.
- Apoptosis ensures that the total number of cells in an organism remains constant.

✓ ✗ I have stated a benefit of apoptosis in mice.[1]

✓ ✗ I have stated a second benefit of apoptosis in mice.[2]

✓ ✗ I have not stated that apoptosis assists in paw formation.

✓ ✗ I have not just stated that apoptosis removes infected cells or pathogens.

✓ ✗ I have used appropriate biological terminology such as: virally infected cells, non-functioning cells.

c [Internal cellular damage[1]][can trigger the mitochondria to release cytochrome-c.[2]][Cytochrome-c is recognised by internal receptors, activating caspase enzymes[3]][and the process of apoptosis.[4]]

✓ ✗ I have explained that intrinsic signalling pathway is initiated by internal cellular damage.[1]

✓ ✗ I have stated that mitochondria release cytochrome-c.[2]

✓ ✗ I have explained that cytochrome-c activates caspases.[3]

✓ ✗ I have stated that this triggers the process of apoptosis.[4]

✓ ✗ I have used appropriate biological terminology such as: cellular damage, mitochondria, cytochrome-c, caspase enzymes.

d [Caspases cleave specific proteins in the cell as part of a cascade of reactions.[1]]

✓ ✗ I have stated the role of caspases in apoptosis.[1]

18 a [It detects contact with T-cells.[1]]

✓ ✗ I have explained why the macrophage is regarded as the receptor.[1]

b i [This suggests that α-TNF is a hydrophilic molecule.[1]]

Other acceptable responses include:

- Protein-based.
- Polar.
- Lipophobic.
- Water soluble.

✓ ✗ I have described the nature of the α-TNF molecule.[1]

ii [The binding of the signalling molecule to a receptor alters the protein structure, triggering a response within the cell.[1]][This intracellular response can result in the production of secondary messenger molecules[2]][and a cascade of events to occur, eventually leading to a cellular response (such as apoptosis).[3]]

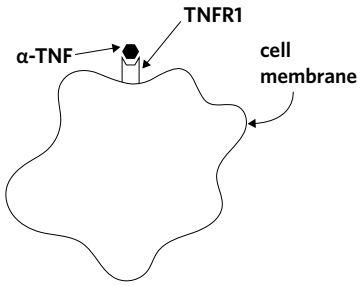
✓ ✗ I have explained how the signalling molecule triggers an intracellular response.[1]

✓ ✗ I have explained this can trigger the production of secondary messenger molecules.[2]

✓ ✗ I have explained this would be followed by a cascade of events culminating in a cellular response.[3]

✓ ✗ I have used appropriate biological terminology such as: binding, signalling molecule, receptor, secondary messenger molecules, cascade of events.

c



✓ ✗ I have included the TNFR1 death signalling receptor.

✓ ✗ I have included the cell membrane.

✓ ✗ I have included the α-TNF death signalling molecule in my diagram.

d [Specific enzymes, such as caspases, are activated within the cell.[1]][These enzymes cleave specific proteins which leads to intracellular content digestion[2]][causing the cell to shrink and bleb.[3]][After blebbing, the cell breaks up[4]][into apoptotic bodies[5]][which are then recognised and are digested by phagocytes.[6]]

✓ ✗ I have stated that enzymes are activated within the cell.[1]

✓ ✗ I have explained that intercellular materials are digested.[2]

I have stated that the cell will shrink and bleb.[3]

I have stated that the cell will break up.[4]

I have explained that the cell breaks up into apoptotic bodies.[5]

I have explained the role of phagocytes in apoptosis.[6]

I have used appropriate biological terminology such as: caspases, cleave, blebbing, digest, phagocytes.

e [Increased rates of apoptosis could result in excessive cell death and damaged tissues which affect the organism.[1]]

I have stated a consequence of excessive cell death.[1]

19 a [Reception stage.[1]]

I have correctly identified the region X in the cell signalling pathway.[1]

b [These molecules would bind to the GC receptor[1]][preventing glucocorticoid (GC) hormone from binding to the GC receptor due to competitive inhibition[2]][which prevents the formation of the GCR-complex[3]][and reduces binding to the GRE region of DNA and hence, GH gene expression.[4]]

I have stated that the molecules would bind to the GC receptor.[1]

I have explained that glucocorticoid cannot bind to the GC receptor.[2]

I have explained that the GCR-complex cannot be formed.[3]

I have explained how this affects GH gene expression in rats.[4]

c [Translation.[1]]

I have correctly identified the process that occurs at the ribosome.[1]

d [The structure of growth hormone (GH) would not differ between cell types.[1]]

I have stated whether there is difference in growth hormone (GC) structure between cell types.[1]

9A Introducing antigens and pathogens!

Theory review questions

1 **a** Cellular pathogen **b** Antigen
c Major histocompatibility complex (MHC) proteins **d** Bacteria
e Viruses **f** Prions
g Parasites

2 B **3** C
4 A **5** B

Exam-style questions

Within lesson

6 A **7** C **8** B **9** B
10 B **11** C **12** A

13 **a** [The rhesus protein is the antigen[1]][because it is a molecule that is recognised as non-self by the mother's immune system and initiates a response.[2]]

I have stated the role of the rhesus protein as an antigen.[1]

I have explained my response.[2]

b [No,[1]][because the fetal blood cells aren't causing disease in the mother.[2]]

I have stated whether fetal blood cells are pathogens.[1]

I have explained my response.[2]

Multiple lessons

14 D **15** A **16** C **17** A

Key science skills

18 **a** [Bacteria.[1]]

Other acceptable responses include:

- Fungi.

I have correctly stated the type of pathogen that is present.[1]

b [No.[1]][A control would have been an agar plate with pathogen broth present but no medication applied to it.[2]]

I have correctly stated whether a control was used.[1]

I have stated what a control would be in this experiment.[2]

c [A control group would have allowed Sharon to determine the extent to which the medication was influencing the bacterial growth by allowing her to compare how much the bacteria grew without the medication present to how much they grew with the different concentrations of the medication.[1]]

I have explained why a control would have been important in this experiment.[1]

I have referred to the scenario in my response.

d [Personal error.[1]]

I have correctly identified the type of error that has taken place.[1]

9B The first line of defence

Theory review questions

1 **a** Stomata **b** Chemical barriers
c Cuticle **d** Lysozyme
e Physical barriers

2 A **3** D
4 C **5** A

Exam-style questions

Within lesson

6 C **7** B **8** B **9** B
10 C **11** B **12** D

Multiple lessons

13 A

14 **a** [Mucus traps inhaled bacteria[1]][and cilia beat the trapped bacteria up from the airways into the throat, where they are swallowed and destroyed by the gastrointestinal tract.[2]]

I have explained how mucus traps bacteria.[1]

I have explained the role of cilia in preventing infection.[2]

b [Presence of non-pathogenic bacteria in the gut[1]][and bacteria on the surface of the skin.[2]]

Other acceptable responses include:

- Non-pathogenic organisms in the vagina.

I have identified one microbiological barrier and its location in humans.[1]

I have identified a second microbiological barrier and its location in humans.[2]

15 **a** [Gut flora compete with pathogenic bacteria for space and resources, potentially challenging their survival and preventing them from thriving and causing infection.[1]]

I have explained how normal gut flora can prevent infection.[1]

b [Digestive enzymes in saliva[1]][and stomach acid.[2]]

Other acceptable responses include:

- Acidic sweat.
- Antibacterial earwax.
- Antimicrobial proteins in semen.
- Protective enzymes in eyes.
- Low pH in the vagina.

I have identified one chemical barrier in animals.[1]

I have identified a second chemical barrier in animals.[2]

c i [The acid contained in the stomach.[1]]

✓ ✗ I have identified the chemical barrier in the stomach.[1]

ii [The low pH in the stomach environment is outside of the optimal pH range for *Salmonella* ATPase.[1]][Denaturation of ATPase occurs outside of its optimal pH, and the shape of the active site changes.[2]][ATPase can no longer bind to ADP and Pi, and its reaction into ATP is no longer catalysed.[3]][Consequently, there is insufficient ATP for *Salmonella* metabolic reactions, resulting in death of the bacteria.[4]]

✓ ✗ I have compared stomach pH to the optimal pH of ATPase.[1]

✓ ✗ I have stated the effect of pH on the structure of ATPase.[2]

✓ ✗ I have stated the changes to the function of ATPase.[3]

✓ ✗ I have stated the consequence for *Salmonella* bacteria.[4]

Key science skills

16 a [Chemical barrier.[1]]

✓ ✗ I have identified the correct type of barrier.[1]

b [This information suggests that jasmonic acid is hydrophilic and soluble in water.[1]]

✓ ✗ I have stated the chemical nature of jasmonic acid.[1]

c i [Have two large groups of plants (e.g. 50) that do not produce jasmonic acid naturally.[1]][The plants are of the same species, age, size, health, and are given the same amount of water, nutrients, and sunlight.[2]][Both groups are infested with the same number of caterpillars and the pathogen that infects them, and placed in separate enclosures.[3]][The experimental group gets sprayed with jasmonic acid;[4]][the control group is not exposed to jasmonic acid.[5]][After a week, count the number of caterpillars infected with the pathogen.[6]]

Other acceptable responses include:

- Other controlled variables include the health status of the caterpillars, the amount of spray used, the duration of the groups' exposure to the spray.

✓ ✗ I have specified two groups of specimens and stated that they must be large in number.[1]

✓ ✗ I have identified at least three controlled variables.[2]

✓ ✗ I have outlined the experimental procedure.[3]

✓ ✗ I have described the experimental group.[4]

✓ ✗ I have described the control group.[5]

✓ ✗ I have stated how results are collected.[6]

ii [The experimental plant group with jasmonic acid will have a larger number of infected and/or dead caterpillars compared to the control group.[1]]

✓ ✗ I have described results that support the hypothesis.[1]

✓ ✗ I have used comparative language such as: compared to.

iii [The experiment may cause caterpillars to become infected with a pathogen and die.[1]]

Other acceptable responses include:

- The experimental caterpillars may develop resistance to jasmonic acid, providing them with an unnatural selective advantage.
- The caterpillar pathogen may mutate and become more virulent.

✓ ✗ I have identified an ethical issue present in the experiment.[1]

9C The second line of defence

Theory review questions

1 a Histamine **b** Antigen-presenting cells
c Natural killer cells **d** Complement
e Interferon

2 B **3** A
4 A **5** B
6 C

Exam-style questions

Within lesson

7 C **8** B **9** C **10** C
11 C **12** C **13** A **14** C

15 a [An increase in mast cell activation would result in the release of histamine.[1]][This causes blood vessels to dilate allowing more blood into the affected area.[2]][Migration of phagocytes to the area will destroy the pathogen.[3]]

Other acceptable responses include:

- Blood vessels become more 'leaky', allowing more leukocytes to enter the site of infection.
- Swelling.
- Increased clotting factors such as platelets.
- Release of cytokines by dead cells.

✓ ✗ I have stated one component of the inflammatory response and a consequence of it.[1]

✓ ✗ I have stated a second component of the inflammatory response and a consequence of it.[2]

✓ ✗ I have stated a third component of the inflammatory response and a consequence of it.[3]

b i [Dendritic cells and macrophages.[1]]

✓ ✗ I have identified two innate types of antigen-presenting cells.[1]

✓ ✗ I have not stated neutrophils.

ii [Antigen-presenting cells phagocytose pathogens/foreign material[1]][and present antigens on their surface[2]][to specific cells of the adaptive immune system.[3]]

✓ ✗ I have stated that antigen-presenting cells phagocytose.[1]

✓ ✗ I have stated that antigen-presenting cells present antigens on their surface.[2]

✓ ✗ I have stated that antigen-presenting cells interact with cells of the adaptive immune system.[3]

✓ ✗ I have used appropriate biological terminology such as: phagocytose, pathogens, antigen, adaptive immune system.

Multiple lessons

16 C **17** A

18 a [Lysozymes, complement proteins, and cytokines.[1]]

Other acceptable responses include:

- Venom inhibitors.
- Interferons.

✓ ✗ I have identified three chemicals from the innate immune system.[1]

b [They are non-specific and respond to all pathogens in the same manner.[1]]

Other acceptable responses include:

- They respond immediately/rapidly to pathogens.

✓ ✗ I have stated a defining property of the innate immune system.[1]

Key science skills

19 a [That different concentrations of pathogenic bacteria would cause different levels of neutrophils and histamines in the skin.[1]]

✓ ✗ I have stated the hypothesis of the scientists.[1]

b [A control group was used in this experiment.[1]][The mouse that wasn't infected with pathogenic bacteria served as the control.[2]]

✓ ✗ I have stated that a control group was used.[1]

✓ ✗ I have stated which mouse served as the control.[2]

c [No.[1]][In order to make a sound conclusion about this, the scientists would have to conduct their experiment on a larger population of mice.[2]]

Other acceptable responses include:

- The scientists would have had to replicate their experiment multiple times.
- More leukocytes and molecules of the innate immune system need to be measured.

✓ ✗ I have stated whether the experiment would have allowed scientists to make a sound scientific conclusion.[1]

✓ ✗ I have explained my response.[2]

d [Neutrophils would phagocytose and destroy the pathogenic bacteria.[1]][Histamine would cause vasodilation, allowing more blood and leukocytes to reach the site of infection.[2]]

✓ ✗ I have explained the role of neutrophils.[1]

✓ ✗ I have explained the role of histamine.[2]

✓ ✗ I have used appropriate biological terminology such as: phagocytose, vasodilation.

9D The third line of defence

Theory review questions

1 a Plasma cell **b** Immunological memory
c T cytotoxic cell **d** Antibody
e Cytokines **f** Variable region
g T helper cell

2 C **3** A

4 B

Exam-style questions

Within lesson

5 B **6** A **7** C **8** B

9 a [Activated T helper cells release cytokines to stimulate selected B cells.[1]][Selected B cells would then differentiate to produce plasma cells[2]][and secrete antibodies into the bloodstream.[3]][B cells would also differentiate into memory cells,[4]][allowing for long-lasting immunity in the affected individual.[5]]

✓ ✗ I have stated that T helper cells would release cytokines.[1]

✓ ✗ I have stated B cells would differentiate into plasma cells.[2]

✓ ✗ I have described the role of plasma cells.[3]

✓ ✗ I have stated B cells would differentiate into memory cells.[4]

✓ ✗ I have described the role of B memory cells.[5]

b [Activated T helper cells release cytokines to stimulate selected T cells.[1]][Selected T cells would then differentiate to produce cytotoxic T cells[2]][and memory T cells.[3]][Cytotoxic T cells then go on to kill infected or abnormal cells via the release of chemicals that induce apoptosis.[4]][T memory cells reside in the body for a long time and allow the individual to mount a faster response upon re-exposure to the same pathogen.[5]]

I have stated T helper cells would release cytokines.[1]

I have stated that T cells would differentiate into cytotoxic T cells.[2]

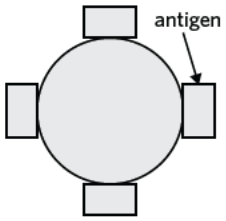
I have stated that T cells would differentiate into memory T cells.[3]

I have described the function of cytotoxic T cells.[4]

I have described the function of T memory cells.[5]

Multiple lessons

10 a i



I have correctly drawn a pathogen with surface antigens that are complementary to the antigen-binding sites of the antibody.

I have correctly labelled an antigen.

ii [Antibodies can neutralise pathogens, agglutinate pathogens, and allow phagocytes to engulf pathogens more easily.[1]]

Other acceptable responses include:

- Antibodies can opsonise pathogens.
- Antibodies can activate complement proteins.
- Antibodies can immobilise pathogens.

I have stated three of the ways antigen-antibody complexes aid in combatting pathogens.[1]

b [Tertiary structure is the overall 3D shape of a protein.[1]][It is determined by the arrangement and interactions (hydrogen bonds and disulphide bridges) between the components of the secondary structure such as alpha helices and beta-pleated sheets.[2]]

I have stated that the tertiary structure is the overall 3D shape of a protein.[1]

I have explained what causes tertiary protein structure.[2]

c [Condensation reaction.[1]]

I have stated the correct reaction.[1]

11 a [This cell is an antigen-presenting cell.[1]][MHC II allows the cell to present digested foreign antigens on its surface and interact with T and B cells to stimulate the adaptive immune response.[2]]

Other acceptable responses include:

- Dendritic cell.
- Macrophage.

I have correctly identified the type of cell described.[1]

I have explained the role of MHC II.[2]

b [Neutrophils are a phagocytic cell but aren't part of the adaptive immune response[1]][because they express MHC I on their surface. This means that they do not present foreign antigens to T and B cells, and are therefore not involved in stimulating the adaptive immune response.[2]]

I have identified the correct cell type.[1]

I have explained why neutrophils are not a cell of the adaptive immune system.[2]

Key science skills

12 a [That antibodies taken from infected mice will be able to recognise influenza *in vitro* and prevent red blood cells from clumping.[1]]

I have identified a reasonable hypothesis of the experiment.[1]

b [Well A is a control[1]][since it has no independent variable applied to it meaning it shows what happens to red blood cells that are unaffected by influenza.[2]]

Other acceptable responses include:

- Well B is a positive control since it shows what happens to red blood cells that are affected by influenza (and without antibodies present).
- Well A is a negative control since it has no independent variable applied and shows what happens to red blood cells that are unaffected by influenza or antibodies.

I have identified one of the control groups.[1]

I have explained my reasoning.[2]

c [The independent variable is the source of the antibodies used.[1]] [The dependent variable is the clumping of red blood cells.[2]]

I have identified the independent variable.[1]

I have identified the dependent variable.[2]

d [The antibodies form antigen-antibody complexes, immobilising the virus particles.[1]]

Other acceptable responses include:

- Antibodies block viral interaction with the host cell, preventing viral attachment and entry into the cell.

I have identified a method by which antibodies combat viruses.[1]

9E The lymphatic system

Theory review questions

1 a Lymphatic capillaries **b** Secondary lymphoid tissue
c Thymus **d** Lymph
e Primary lymphoid tissue

2 C **3** A

4 D

Exam-style questions

Within lesson

5 B **6** A **7** C

8 a [Bone marrow and the thymus.[1]][Bone marrow produces immature B and T cells, and is responsible for the maturation of B cells.[2]][The thymus is the site of the maturation of immature T cells.[3]]

- I have stated the two primary lymphoid organs.[1]
- I have explained the role of bone marrow in the lymphatic system.[2]
- I have explained the role of the thymus in the lymphatic system.[3]

b [Secondary lymphatic organs contain mature lymphocytes[1]][and are responsible for the initiation of the adaptive immune response via clonal selection and lymphocyte differentiation.[2]]

- I have stated mature lymphocytes are present in secondary lymphoid organs.[1]
- I have stated that secondary lymphoid organs initiate the adaptive immune response.[2]

c i [Afferent lymphatic vessels carry lymph fluid to the lymph node.[1]]

- I have explained the role of afferent lymphatic vessels.[1]

ii [Helper T cell.[1]][This cell then goes on to drive the processes of B cell and T cell cloning and differentiation in the adaptive immune response.[2]]

Other acceptable responses include:

- Immature T cell. This cell then goes on to be selected and differentiate into memory T cells and cytotoxic T cells.

- I have stated the correct cell type.[1]
- I have explained the role of this cell.[2]

Multiple lessons

9 D **10** A

11 a [Macrophages are antigen-presenting cells.[1]][This means that after they engulf and destroy a pathogen they display antigens on their surface and present these antigens on MHC II to T cells in the lymph nodes.[2]]

- I have stated that macrophages are antigen-presenting cells.[1]
- I have stated the role of antigen-presenting cells.[2]

b i [Patient's with ALL are unable to form mature T cells.[1]][T cells would normally be selected for and undergo clonal differentiation into cytotoxic T cells that would kill infected cells,[2]][however because there are no mature T cells to be selected this would not occur.[3]]

Other acceptable responses include:

- Patients will ALL are unable to form mature B cells, which means that B cell clonal selection and differentiation into antibody-producing plasma cells does not occur and therefore antibodies against the virus are not able to be produced in significant numbers.

- I have stated that the patients would not have mature lymphocytes.[1]
- I have stated what normally occurs in the adaptive response.[2]
- I have explained that this would not occur in an ALL patient.[3]

ii [Patients with ALL are unable to produce mature B cells[1]][and therefore the process of B clonal selection and differentiation would not occur in the lymph node.[2]][These patients therefore would be unable to mount an effective humoral response against the pathogen.[3]]

- I have stated that ALL patients do not produce B cells.[1]
- I have explained that B cell clonal selection and differentiation would not occur.[2]
- I have stated the consequence of this for the patient.[3]
- I have not suggested that T cell differentiation would not occur, because the pathogen is not intracellular.

Key science skills

12 a [Dendritic cells and macrophages.[1]]

- I have named the two types of antigen-presenting cells.[1]

b i [The independent variable is the application of *S. epidermidis* to the skin.[1]][The dependent variables are the levels of APCs, levels of T_c cells, and the growth of the pathogenic fungus.[2]]

- I have correctly identified the independent variable.[1]
- I have correctly identified the dependent variables.[2]

ii [Firstly, the lymphatic system in this experiment would serve as the means of transport for the pathogen and antigen-presenting cells to the lymph nodes.[1]][Secondly, once they arrive at the lymph node, the lymphatic system would be the site of selection, cloning, and differentiation.[2]]

Other acceptable responses include:

- The lymphatic system would drain fluid from the tissues of the mice.

- I have stated one function of the lymphatic system.[1]
- I have stated a second function of the lymphatic system.[2]
- I have signposted my response using terms such as: firstly, secondly.

iii [Personal error.[1]]

✓ ✗ I have correctly stated the type of error that has occurred.[1]

Chapter 9 Review

SECTION A

1	C	**2**	D	**3**	C	**4**	B
5	B	**6**	C	**7**	B	**8**	D
9	A	**10**	D	**11**	D	**12**	D
13	D						

SECTION B

14 a [A causative agent of disease.[1]]

✓ ✗ I have correctly defined the term 'pathogen.'[1]

✓ ✗ I have not made reference to pathogens being cellular or organisms causing disease.

b [Non-cellular[1]][because viruses aren't made of cells.[2]]

Other acceptable responses include:

- Does not undergo cellular processes.
- Only reproduces in a host cell.

✓ ✗ I have stated viruses are non-cellular pathogens.[1]

✓ ✗ I have stated one reason justifying my answer.[2]

c [T helper cells stimulate specific B cells to undergo clonal expansion[1]][and release cytokines that activate cytotoxic T cells.[2]] [HIV destroys T helper cells[3]][causing a person infected with HIV to have fewer B cells undergoing clonal expansion[4]][and a lower number of activated cytotoxic T cells.[5]]

Other acceptable responses include:

- T helper cells secrete cytokines that stimulate macrophages/phagocytes.
- T helper cells secrete cytokines that recruit macrophages/phagocytes.
- T helper cells promote inflammation.

✓ ✗ I have stated one function of T helper cells.[1]

✓ ✗ I have stated a second function of T helper cells.[2]

✓ ✗ I have stated the effect of HIV on T helper cells.[3]

✓ ✗ I have stated one consequence of HIV in relation to T helper cells.[4]

✓ ✗ I have stated a second consequence of HIV in relation to T helper cells.[5]

15 a [One example of a plant's physical defence is the presence of waxy cuticles that create barriers to pathogens.[1]][A second physical defence is the formation of galls that limit the spread of pathogens beyond infected tissue.[2]]

Other acceptable responses include:

- The presence of thick bark that creates a barrier to pathogens.
- The closing of stomata in response to pathogens to prevent further infection.
- Presence of thorns and trichomes (plant hair) to deter insects.

✓ ✗ I have identified one physical defence method.[1]

✓ ✗ I have identified a second physical defence method.[2]

✓ ✗ I have signposted my response using terms such as: one example, a second physical defence.

b [Firstly, plants can secrete toxins such as antimicrobials that are harmful to pathogens, potentially killing them.[1]][Secondly, plants can produce enzymes that affect the functioning of pathogens and/or that inhibit their development.[2]]

Other acceptable responses include:

- Plants can produce chemicals that repel insects.

✓ ✗ I have stated one way chemical barriers help plants fight pathogens.[1]

✓ ✗ I have stated a second way chemical barriers help plants fight pathogens.[2]

✓ ✗ I have signposted my response using terms such as: firstly, secondly.

c [Plants do not have an adaptive immune system.[1]][Therefore, their innate immune system is important because it is the only protection they have against pathogens.[2]]

✓ ✗ I have stated that plants do not have an adaptive immune system.[1]

✓ ✗ I have related this back to the importance of the innate immune system in plants.[2]

16 a [The innate immune system.[1]]

Other acceptable responses include:

- The nonspecific immune system.
- The second line of defence.

✓ ✗ I have stated the correct part of the immune system.[1]

b [Firstly, there is increased blood vessel dilation and permeability which allows for more immune cells to reach the site of injury.[1]] [Secondly, phagocytes migrate to the injured site and consume pathogens that may be present.[2]][Thirdly, the presence of clotting factors increases which helps to prevent bleeding.[3]]

Other acceptable responses include:

- Increased activation of mast cells.
- Increased histamine release.
- Increased swelling.
- Recruitment of healthy T helper cells.
- Release of cytokines.

✓ ✗ I have stated one inflammatory response and explained its function.[1]

✓ ✗ I have stated another inflammatory response and explained its function.[2]

✓ ✗ I have stated a third inflammatory response and explained its function.[3]

✓ ✗ I have signposted my response using terms such as: firstly, secondly, thirdly.

17 a [Cytotoxic T cells recognise and kill abnormal/infected cells[1]] [via cytotoxic chemicals such as perforins.[2]]

✓ ✗ I have stated that cytotoxic T cells recognise and kill abnormal cells.[1]

✓ ✗ I have stated how cytotoxic T cells kill abnormal cells.[2]

b [Antibodies bind to bacteria causing agglutination, making it easier for them to be phagocytosed.[1]] [Macrophages consume and kill pathogens.[2]]

Other acceptable responses include:

- Macrophages present antigens on their surface to stimulate the adaptive immune system.

✓ ✗ I have stated how antibodies inhibit the spread of bacteria.[1]

✓ ✗ I have stated how macrophages inhibit the spread of bacteria.[2]

c [Group 1.[1]]

✓ ✗ I have correctly identified the experimental group.[1]

d [The independent variable was the presence of *S. epidermidis* on the skin.[1]] [The dependent variable was the levels of APCs and T_c cells in the skin of the mice, and the rate of pathogenic growth.[2]]

✓ ✗ I have identified the independent variable.[1]

✓ ✗ I have identified the dependent variable.[2]

e [Personal error.[1]]

✓ ✗ I have correctly identified the type of error.[1]

18 a [Afferent lymphatic vessels.[1]] [These carry lymph into the lymph node.[2]]

✓ ✗ I have named the structure.[1]

✓ ✗ I have stated the role of the structure.[2]

b [B lymphocytes are present[1]] [and undergo differentiation if presented with a specific antigen.[2]]

Other acceptable responses include:

- T helper cells are presented with antigens from antigen-presenting cells and stimulate other cells of the adaptive immune system.
- Cytotoxic T cells proliferate and travel to the site they're needed at when stimulated by T helper cells.

✓ ✗ I have stated one cell type present.[1]

✓ ✗ I have described the role of this cell type.[2]

10A How to become immune

Theory review questions

1 **a** Artificial active immunity
b Herd immunity
c Artificial passive immunity
d Natural active immunity
e Vaccine
f Natural passive immunity
g Booster shot

2 A
3 C
4 A
5 C

Exam-style questions

Within lesson

6 B
7 A
8 B

9 **a** [Artificial, active immunity.[1]] [This immunity is artificial because the vaccine injection is a medical intervention[2]] [and active as the vaccination contains antigens to the *Bordetella pertussis* bacteria which stimulates an adaptive immune response.[3]]

- ✓ ✗ I have identified the correct type of immunity.[1]
- ✓ ✗ I have explained why this immunity is artificial.[2]
- ✓ ✗ I have explained why this immunity is active.[3]

b **i** [Booster vaccine.[1]] [Booster vaccines work by producing more memory B cells[2]] [and are necessary because B memory cells die over time. As they die, a person's immunity to a disease decreases.[3]]

- ✓ ✗ I have stated the correct type of vaccine.[1]
- ✓ ✗ I have stated how booster vaccines work.[2]
- ✓ ✗ I have explained why booster vaccines are necessary.[3]
- ✓ ✗ I have used appropriate biological terminology such as: memory B cell.

ii [Herd immunity,[1]] [which aims to protect unvaccinated individuals by having a high rate of vaccination within a population.[2]] [By doing so, the number of people who become ill with pertussis and could infect the unvaccinated population is low, meaning it is unlikely the disease will spread to babies who have not been vaccinated.[3]]

- ✓ ✗ I have stated the correct type of immunity.[1]
- ✓ ✗ I have explained what herd immunity aims to achieve.[2]
- ✓ ✗ I have explained the benefit of herd immunity.[3]
- ✓ ✗ I have referred to the scenario in my response.

Multiple lessons

10 D

11 **a** [Artificial, active immunity.[1]]

- ✓ ✗ I have identified the correct type of immunity.[1]

b [Secondary lymphoid tissues.[1]]

Other acceptable responses include:

- Lymph node.
- Spleen.

- ✓ ✗ I have identified the correct location.[1]

c [Antibodies could neutralise the toxin by blocking its active site[1]] [or could opsonise the toxin, making it easier for phagocytosis to occur.[2]]

Other acceptable responses include:

- Antibodies could immobilize the toxin.
- Antibodies could agglutinate the toxin.

- ✓ ✗ I have described one way in which antibodies prevent toxins from harming the body.[1]
- ✓ ✗ I have described a second way in which antibodies prevent toxins from harming the body.[2]

12 **a** [If a child does not receive a full vaccination schedule their immune system will not be stimulated to produce enough memory cells and antibodies to confer immunity.[1]] [They will, therefore, be susceptible to infection by the pathogen.[2]]

- ✓ ✗ I have stated the impact of not completing a vaccination schedule on a person's immune system.[1]
- ✓ ✗ I have stated they will still be susceptible to disease.[2]

b [Access and acceptance.[1]]

- ✓ ✗ I have stated the two factors provided by the article.[1]

c [Parents who refuse to get their children vaccinated are overrepresented in the media.[1]]

- ✓ ✗ I have stated the reason provided by the article.[1]

d [The parents who are supportive of vaccination but fear potential negative outcomes and therefore do not vaccinate their children fully.[1]] [This group should be targeted because they make up 6% of parents in Australia, as opposed to parents who completely reject vaccines who only comprise 2% of the population.[2]]

- ✓ ✗ I have chosen the correct group of parents.[1]
- ✓ ✗ I have explained why this group should be targeted.[2]
- ✓ ✗ I have used evidence from the article in my response.

e [Improving access to vaccines,[1]] [addressing concerns of hesitant parents,[2]] [and educating anti-vaccination parents about the benefits of vaccination.[3]]

Other acceptable responses include:

- Decrease the media exposure given to non-vaccinating parents.

- ✓ ✗ I have stated one possible strategy.[1]
- ✓ ✗ I have stated a second possible strategy.[2]
- ✓ ✗ I have stated a third possible strategy.[3]

Key science skills

13 a [A vaccine is an altered form of a pathogen that is used to trigger an immune response.[1]][Antigen-presenting cells present antigens of the inactivated pathogen to T and B cells, selecting those which have complementary receptors to the antigen.[2]][These lymphocytes then undergo clonal selection and differentiation, resulting in the formation of B and T memory cells.[3]][These reside in the body for extended periods of time, and will enable the body to mount a larger, faster response to the pathogen if it is re-encountered.[4]]

- I have stated the definition of a vaccine.[1]
- I have described the initiation of the adaptive immune system.[2]
- I have described the process of clonal selection and differentiation.[3]
- I have explained how immunological memory results in lifelong immunity.[4]
- I have used appropriate biological terminology such as: antigen-presenting cell, complementary, lymphocyte, B cell, T cell, memory cell, pathogen.

b i [Intervention A is an injection of VZV antibodies.[1]][This is because the number of antibodies in Patient 1's blood immediately increases on day 1 and then begins to decrease.[2]][Intervention 2 is an injection with the VZV vaccine.[3]][This is because the number of antibodies increases gradually in Patient 2 as their adaptive immune system takes a few days to mount a specific response to the pathogen.[4]]

Other acceptable responses include:

- Intervention A is an injection of antibodies because no lasting immunological memory is formed.
- Intervention B is an injection of the VZV vaccine because immunological memory is formed.

- I have correctly identified intervention A.[1]
- I have referred to the graph of Patient A in my response.[2]
- I have correctly identified intervention B.[3]
- I have referred to the graph of Patient B in my response.[4]

ii [A second injection with the VZV vaccine.[1]][This is needed because typically more than one dose of a vaccine is required to produce enough B memory cells to confer lifelong immunity.[2]]

- I have stated what occurred on day 22.[1]
- I have explained why this is necessary.[2]
- I have not stated that a booster vaccine was given.

iii [Artificial, passive immunity.[1]]

- I have stated the correct type of immunity.[1]

c [A control was not used in this experiment.[1]][A control would have involved not injecting a person with anything.[2]]

Other acceptable responses include:

- A control could have involved injecting them with a placebo.

- I have stated a control was not used.[1]
- I have explained what a control would have been.[2]

10B When the immune system goes wrong

Theory review questions

1 a Autoantibodies
b Human immunodeficiency virus (HIV)
c IgE
d Autoreactive
e Pollen
f Myelin/myelin sheath
g Immunodeficiency

2 A
3 A
4 D
5 C

Exam-style questions

Within lesson

6 B **7** C **8** D

9 a [Autoreactive T cells are meant to be destroyed during development.[1]][In a person with multiple sclerosis, however, it's likely this process hasn't occurred and they still have autoreactive T cells present in their immune system.[2]][These cells recognise the cells that produce myelin as foreign and cause them to undergo apoptosis.[3]]

Other acceptable responses include:

- Due to an individual's immune system not being stimulated enough during development they may develop autoreactive lymphocytes.
- A person with multiple sclerosis has autoreactive B cells that destroy myelin.

- I have stated that autoreactive T cells are normally destroyed.[1]
- I have stated that MS sufferers have autoreactive T cells.[2]
- I have stated that autoreactive T cells destroy myelin-producing cells.[3]

b [Muscles are controlled by electrical signals through the nervous system.[1]][Since MS damages nerves and affects their ability to transmit electrical impulses, including the nerves responsible for muscle movement,[2]][weakening of muscles would be experienced by a person with MS.[3]]

- I have stated muscles are controlled by electrical signals.[1]
- I have stated that MS disrupts normal electrical transmission.[2]
- I have explained that this would cause muscle weakening.[3]

10 a [Firstly, the airways of the hay fever sufferer would have previously been exposed to pollen,[1]][and their B cells would have inappropriately responded to it by producing large amounts of IgE.[2]][These IgE antibodies would have bound to mast cells.[3]][Later, when

inhaled again, pollen would have reacted with the IgE antibodies on the surface of mast cells, causing them to degranulate and release histamine.[4] [This histamine would cause increased mucus secretion in the sufferer's airways, which would be experienced by them as a runny nose.[5]]

- I have stated that prior exposure to pollen would have taken place.[1]
- I have stated B cells would have produced IgE.[2]
- I have explained that IgE binds to mast cells.[3]
- I have explained that histamine is released upon re-exposure to the allergen.[4]
- I have related the release of histamine to the development of a runny nose.[5]
- I have answered in a logical and sequential manner.
- I have signposted steps in my response by using terms such as: firstly, later.
- I have used appropriate biological terminology such as: B cells, IgE antibodies, mast cells, degranulate, histamine.

b [Capillaries become permeable and leaky,[1]] [causing swelling.[2]] [Vasodilation of the skin blood vessels,[3]] [leading to redness of the skin.[4]]

Other acceptable responses include:

- Constriction of the smooth muscles in airways, causing breathing difficulties.

- I have stated a physiological effect of an allergy.[1]
- I have stated a symptom this causes.[2]
- I have stated another physiological effect of an allergy.[3]
- I have stated a symptom this causes.[4]

Multiple lessons

11 D **12** B

13 **a** [Infection with HIV results in the destruction of helper T cells.[1]] [These play a crucial role in the adaptive immune system, and without them the process of B and T cell differentiation would not occur[2]] [leading to an immunodeficiency.[3]]

Other acceptable responses include:

- There would be fewer cytotoxic T cells to combat infected cells.
- Helper T cells would no longer be present to bind to antigen-presenting cells and trigger the recruitment of lymphocytes.

- I have stated that HIV destroys helper T cells.[1]
- I have explained a function of helper T cells in the adaptive immune response.[2]
- I have stated that an immunodeficiency occurs.[3]

b **i** [Plasma cells.[1]]

- I have identified the correct cell type.[1]

ii [Antibodies block viral interaction with the host cell[1]] [preventing them from attaching to and entering the cell.[2]]

Other acceptable responses include:

- Antibodies form antigen-antibody complexes, immobilising the virus particles.

- I have identified a method by which antibodies combat viruses.[1]
- I have explained how this method prevents infection.[2]

Key science skills

14 **a** [Yes,[1]] [it was the half of the rats that didn't have cream applied to it.[2]]

- I have stated that a control was used.[1]
- I have stated what the control was in the experiment.[2]

b [The scientists could expect to find an increased number of cytotoxic T cells in the hairless skin.[1]]

Other acceptable responses include:

- Increased number of phagocytic cells.
- Increased number of T helper cells.

- I have stated what the scientists could expect to find.[1]

c [The age of participants[1]] [and the gender of participants.[2]]

Other acceptable responses include:

- The health status of participants.
- The degree of hair loss of participants.

- I have stated one variable.[1]
- I have stated a second variable.[2]

10C Antibodies to treat cancer

Theory review questions

1 **a** Myeloma cell **b** Hybridoma
c Monoclonal antibodies **d** Antigens

2 D **3** A

4 B

Exam-style questions

Within lesson

5 C **6** A

Multiple lessons

7 **a** [An autoimmune disorder is when the body's immune system initiates an immune response that targets healthy self cells.[1]]

✓ ✗ I have defined autoimmune disorder.[1]

b [Yes,[1]][as mAbs specifically 'target cancerous cells while avoiding healthy cells',[2]][unlike chemotherapy which has a low cell-specificity and causes unwanted effects.[3]]

✓ ✗ I have stated whether monoclonal antibodies cause fewer side effects than chemotherapy.[1]

✓ ✗ I have explained the extent of damage of monoclonal antibodies.[2]

✓ ✗ I have explained the extent of damage of chemotherapy.[3]

c [Passive artificial immunity.[1]]

✓ ✗ I have identified the type of immunity.[1]

d [mAbs can block signals that initiate cell division in cancerous cells[1]][which prevents the growth of cancer in an organism.[2]]

Other acceptable responses include:

- Signal for immune cells to attack cancerous cells.
- Induces apoptosis.

✓ ✗ I have described a mode of action for mAbs.[1]

✓ ✗ I have explained how this can treat cancer.[2]

e i [The mAbs would be different,[1]][as antibodies have an active site that is highly specific to the targeted antigen.[2]][These treatments would treat different cells in a different way.[3]]

✓ ✗ I have stated whether the mAbs are the same.[1]

✓ ✗ I have stated that antibodies are highly specific.[2]

✓ ✗ I have outlined that different treatments target different cells in different ways.[3]

✓ ✗ I have used appropriate biological terminology such as: mAbs, antibody, active site.

ii [mAbs can deliver a drug directly to the target site[1]][due to the specificity of an antibody's active site,[2]][which can increase the efficiency and efficacy of a drug's mode of action.[3]]

✓ ✗ I have stated the role of mAbs in drug delivery.[1]

✓ ✗ I have discussed how mAbs can do this.[2]

✓ ✗ I have outlined the overall implication of mAbs being used in drug delivery.[3]

✓ ✗ I have used appropriate biological terminology such as: mAbs, target site, specificity, antibody, active site, efficiency, efficacy.

Key science skills

8 a [The amount of sample extracted from each patient would affect the results[1]][as extra sample would accomodate for more antigens to bind to the surface of the tube, which would make the colour darker.[2]]

Other acceptable responses include:

- The amount of antibodies added.
- Human error in detecting the colour as it is an observation and not a quantitative result.
- CA19-9 antigen may not have properly attached to the surface of the container.

✓ ✗ I have identified a factor that may have affected the results.[1]

✓ ✗ I have explained how the factor could affect the results.[2]

b i [Positive control groups are expected to show a result for an experimental design by using a sample known to produce results.[1]][Negative control groups are expected to not show results, and if they do, it highlights the presence of confounding variables.[2]]

✓ ✗ I have defined positive control groups.[1]

✓ ✗ I have defined negative control groups.[2]

✓ ✗ I have used appropriate biological terminology such as: experimental design, confounding variables.

ii [A positive control group would have a large concentration of the CA19-9 antigen[1]][and would produce a brown colour.[2]][A negative control group would contain no CA19-9 antigen[3]][and would produce a transparent/white colour.[4]]

✓ ✗ I have explained the contents of the positive control group.[1]

✓ ✗ I have predicted the colour of the positive control group.[2]

✓ ✗ I have explained the contents of the negative control group.[3]

✓ ✗ I have predicted the colour of the negative control group.[4]

c [mAbs can attach to cancer cell antigens and flag them to be detected by immune cells[1]][and initiate an immune response.[2]]

Other acceptable responses include:

- Block signals that initiate cell division of cancerous cells.
- Prevent the growth of new blood vessels to tumours.
- Deliver drugs to target cells in the body.

✓ ✗ I have described a mode of action for mAbs.[1]

✓ ✗ I have explained how this can treat cancer.[2]

Chapter 10 Review

SECTION A

1	D	**2**	D	**3**	A
4	B	**5**	C	**6**	D
7	B	**8**	B	**9**	C
10	D	**11**	D	**12**	B
13	A	**14**	C	**15**	C

SECTION B

16 a [An inactivated component or weakened form of a pathogen that triggers the production of antibodies and memory cells but does not cause disease.[1]]

✓ ✗ I have correctly described what a vaccine is.[1]

b i [The antibodies would bind to the heavy chain of the tetanospasmin toxin.[1]]

✓ ✗ I have correctly identified where antibodies bind to the tetanospasmin toxin.[1]

ii [The antibodies agglutinate the toxin tetanospasmin,[1]][forming large antibody-toxin complexes.[2]][This effectively deactivates the toxin, preventing it from affecting the organism as it usually would.[3]][Phagocytes can then digest the antibody-toxin complexes.[4]]

✓ ✗ I have stated that the antibodies agglutinate the toxin tetanospasmin.[1]

✓ ✗ I have explained that this alters the overall structure of the toxin.[2]

✓ ✗ I have explained the effect this has on the toxin's toxicity.[3]

✓ ✗ I have explained that phagocytes would digest the antibody-toxin complex.[4]

c i [The full vaccination schedule requires the individual to receive the vaccine six times,[1]][as there are six peaks on the graph.[2]]

✓ ✗ I have stated that the schedule requires six individual doses.[1]

✓ ✗ I have used evidence from the graph to support my answer.[2]

ii [After injecting an inactivated form of tetanospasmin, the body's immune system can mount an immune response[1]][by producing lymphocytes and antibodies specific to the invading toxin.[2]] [After the initial immune response, memory cells specific to the toxin tetanospasmin are produced.[3]][This enables a faster and larger immune response in subsequent encounters with tetanospasmin.[4]][Repeated immunisations increase the total amount of these memory cells and increase the effectiveness of future immune responses.[5]]

✓ ✗ I have stated that injecting the inactivated form of tetanospasmin can initiate an immune response.[1]

✓ ✗ I have explained that the immune response involves synthesising lymphocytes and antibodies specific to the toxin tetanospasmin.[2]

✓ ✗ I have explained that after the immune response memory cells are produced.[3]

✓ ✗ I have explained how these memory cells affect future responses to the toxin tetanospasmin.[4]

✓ ✗ I have explained why repeated immunisations are necessary.[5]

17 a [Autoantibodies recognise and attack self-antigens[1]][which leads to the destruction of the tissue surrounding the joints[2]][as well as the inflammation and degradation of the joints.[3]]

✓ ✗ I have explained that autoantibodies attack self-antigens.[1]

✓ ✗ I have explained this results in the destruction of tissue surrounding the joints.[2]

✓ ✗ I have explained that the destruction of cells can result in inflammation and degradation of joints.[3]

b [The humoral response involves the activation of B cells and the production of antibodies against a specific antigen,[1]][whereas the cell-mediated response involves T_c cells/cytotoxic T cells targeting and killing particular cells.[2]]

✓ ✗ I have described a unique component of the humoral response system.[1]

✓ ✗ I have described a unique component of the cell-mediated response system.[2]

✓ ✗ I have used comparative language such as: whereas.

✓ ✗ I have not discussed T helper cells in my response.

✓ ✗ I have described each difference as belonging to either the humoral or cell-mediated immune systems.

c [Many autoimmune diseases have been linked to genetic factors.[1]] [These disease-causing genes may be switched on at different time periods[2]][and the initial onset of the symptoms of an autoimmune disease may vary between disease types and individuals.[3]]

✓ ✗ I have stated that many autoimmune diseases are genetically linked.[1]

✓ ✗ I have explained that certain genes may be switched on at different times.[2]

✓ ✗ I have explained how this can alter the timing of initial onset of symptoms between diseases.[3]

18 a [Booster immunisation.[1]][This is recommended because memory cells do not survive indefinitely.[2]][Booster immunisations stimulate existing memory cells to mount an immune response and produce more memory cells.[3]][This provides a person with an immunity to whooping cough for longer.[4]]

✓ ✗ I have correctly named the type of immunisation.[1]

✓ ✗ I have stated that memory cells die.[2]

✓ ✗ I have stated that booster immunisations produce more memory.[3]

✓ ✗ I have stated that a booster shot extends the period of immunity.[4]

✓ ✗ I have referred to the scenario in my response.

CHAPTER 10 REVIEW

✓ ✗ I have not referred to immunisation schedules in my response.

b [T memory cells[1]][and B memory cells.[2]]

✓ ✗ I have stated one cell type.[1]

✓ ✗ I have stated a second cell type.[2]

c [Vaccination facilitates the production of memory B and T cells for a particular pathogen, which persist in the body for an extended period of time.[1]][When the immune system later encounters the same pathogen,[2]][memory B and T cells differentiate into antibody producing plasma B cells and antigen recognising T cells, which quickly mount a stronger and faster response[3]][than an unvaccinated person.[4]][The pathogen is eliminated quickly and the person does not display symptoms of the disease.[5]]

✓ ✗ I have stated the effect of a vaccine.[1]

✓ ✗ I have stated that the immune system encounters a pathogen.[2]

✓ ✗ I have stated how the immunised individual responds to a pathogen.[3]

✓ ✗ I have compared this response to a non-vaccinated immune system.[4]

✓ ✗ I have stated that an immunised person has a lower chance of getting sick from the pathogen.[5]

d **i** [This is a passive form of protection[1]][as the mother produces antibodies specific to the *B. pertussis* bacterium,[2]][which are then passed on to the infant by crossing the placental barrier or through breastfeeding, rather than these antibodies being produced by the infant.[3]]

✓ ✗ I have stated that this is a passive form of protection.[1]

✓ ✗ I have explained where the antibodies are produced.[2]

✓ ✗ I have explained how the infant acquires these antibodies.[3]

ii [Herd immunity for whooping cough occurs when the vast majority of a population is vaccinated against whooping cough.[1]][As there are few susceptible hosts, whooping cough cannot spread naturally in the population,[2]][preventing the disease from being passed on to infants.[3]]

✓ ✗ I have explained that herd immunity occurs when the majority of the population is immune.[1]

✓ ✗ I have explained how herd immunity prevents a disease from spreading naturally.[2]

✓ ✗ I have explained that this can protect susceptible infants.[3]

✓ ✗ I have referred to the scenario in my response.

11A Mutations

Theory review questions

1 **a** Point mutation
b Base insertion mutation
c Alleles
d Polyploidy
e Mutagen
f Missense mutation
g Block mutation
h Germline
i Aneuploidy

2 D
3 C
4 C
5 A
6 D
7 B

Exam-style questions

Within lesson

8 C
9 B
10 C

11 **a** [There is an additional chromosome 18.[1]]

✓ ✗ I have identified what is different in the karyotype for Edwards syndrome sufferers.[1]

b [Edwards syndrome is an example of an aneuploidy mutation.[1]] [This most likely occurred due to both copies of chromosome 18 splitting together into one gamete.[2]]

✓ ✗ I have identified the type of mutation is Edwards syndrome.[1]

✓ ✗ I have described how this mutation occurs.[2]

12 **a** [This mutation is a missense point mutation[1]] [that involves the substitution in the DNA from adenine to guanine.[2]] [Thus, this changed the mRNA produced and translated ala instead of val.[3]]

✓ ✗ I have identified this as a missense mutation.[1]

✓ ✗ I have stated the two DNA bases substituted in the mutation.[2]

✓ ✗ I have explained how this affected transcription and translation.[3]

✓ ✗ I have not stated RNA bases in my answer.

b [This causes a frameshift mutation[1]] [as the reading frame is altered.[2]] [Therefore, if it is occurring in lys, all the following codons would be affected as all nucleotides move back one position.[3]] [This results in different amino acids being translated and alters the bonding and structure of the overall polypeptide.[4]]

✓ ✗ I have identified this process to be a frameshift mutation.[1]

✓ ✗ I have identified that the reading frame is altered.[2]

✓ ✗ I have described how this mutation would affect the following codons.[3]

✓ ✗ I have explained the overall effect on the protein.[4]

Multiple lessons

13 A

14 **a** [AGA.[1]]

✓ ✗ I have stated the DNA triplet for this anticodon.[1]

b [This mutation is a missense mutation as it has changed the anticodon to code for a different amino acid.[1]] [This would have occurred in germline cells as it has been passed down to future offspring.[2]]

✓ ✗ I have outlined which point mutation has occurred.[1]

✓ ✗ I have explained where this mutation occurred.[2]

15 **a** 5′ AUG CAU GGC UUU AUG CAA GAA CUG AUA UAG 3′

✓ ✗ I have correctly written the mRNA from 5′ to 3′.

✓ ✗ I have left spaces between each codon.

✓ ✗ I have used U instead of T because it is RNA.

b [Six.[1]]

✓ ✗ I have counted the codons that will be transcribed to become amino acids.[1]

c [To observe this change, the GTT codon must mutate into ATT[1]] [through a nonsense mutation.[2]] [This is because ATT is a STOP triplet, signalling for the ribosome to cease translation.[3]] [Therefore, fewer exons are translated and the mutated polypeptide is shorter than the non-mutated polypeptide.[4]]

✓ ✗ I have identified which triplet will mutate to cause this change.[1]

✓ ✗ I have stated that this is a nonsense mutation.[2]

✓ ✗ I have identified that this will cause a stop codon.[3]

✓ ✗ I have explained the effect of this stop codon.[4]

Key science skills

16 **a** [The independent variable is the strength of UV radiation[1]] [and the dependent variable is the number of mutations in the tumour suppressor gene.[2]]

✓ ✗ I have identified the independent variable.[1]

✓ ✗ I have identified the dependent variable.[2]

b [The number of mutations in the tumour suppressor gene would increase as the strength of UV radiation is increased.[1]]

✓ ✗ I have stated that there should be an increase in mutations if UV strength is increased.[1]

c [Mutagen.[1]]

✓ ✗ I have identified what agent UV light is.[1]

d [Random mutations can uncontrollably occur.[1]][This would affect the reliability of the experiment as you cannot distinguish between mutations caused by UV and random mutations.[2]]

Other acceptable responses could include:

- Skin cell samples should be taken from the same part of the mouse. Some parts of the skin might be more exposed to UV radiation than others which would influence mutation rate in the tumour suppressor gene of those skin cells.
- Radiation time must be the same between each treatment. If this is not kept the same between treatments then the comparisons between strengths cannot be made.
- Genetic variation at the tumour suppressor gene locus may exist within mice cultures. This would lead to measurements of mutations being skewed.

✓ ✗ I have identified an uncontrolled variable.[1]

✓ ✗ I have explained its effect on the results of the experiment.[2]

11B Natural selection

Theory review questions

1 **a** Selection pressure **b** Fitness **c** Phenotype **d** Variation **e** Struggle for survival

2 D **3** B

4 C **5** A

Exam-style questions

Within lesson

6 C **7** A **8** D

9 **a** [Variation in shell thickness existed in the population of blue mussels prior to introduction of the shore crab.[1]][This variation was heritable.[2]][When the shore crab was introduced in the south, mussels with thin shells were preyed upon, while thick-shelled mussels survived and had offspring that also had thick shells.[3]][Thus, thick-shelled mussels became more common in locations where the shore crab existed.[4]]

✓ ✗ I have stated that variation existed in the population.[1]

✓ ✗ I have stated that the variation was heritable.[2]

✓ ✗ I have stated that the selection pressure was shore crab predation and that this gave mussels with thick shells a selective advantage/made them fitter.[3]

✓ ✗ I have explained the consequences of this on the phenotype of the southern population of mussels.[4]

b [The thickness of shells in the northern mussel population would also increase.[1]][This is because they would be exposed to the same selection pressure as mussels in the south, and assuming that the same gene for thick shells exists in the northern population, natural selection favouring thick shells would occur here as well.[2]]

✓ ✗ I have stated what would happen to shell thickness of the northern mussels.[1]

✓ ✗ I have explained why this would occur.[2]

Multiple lessons

10 D

11 **a** [Allele frequency is the proportion of certain alleles in a gene pool.[1]]

✓ ✗ I have defined allele frequencies.[1]

b **i** [The Illinois birds have lower genetic variation than the birds from other states.[1]][This means that Illinois birds are at greater risk of extinction,[2]][because they are less likely to have advantageous phenotypes that may help them survive new selection pressures.[3]]

✓ ✗ I have stated whether Illinois birds have higher or lower genetic variation than birds from other states.[1]

✓ ✗ I have stated what this means for the extinction risk of Illinois birds.[2]

✓ ✗ I have explained why low genetic variation increases the risk of extinction.[3]

ii [First, prairie chickens only roam within a few kilometres of their home range, so the two populations are not actually that close.[1]][In addition, there may be an isolating structure between the Illinois and Minnesotan populations - such as a large river.[2]][This means the populations may not have been connected and interbreeding for many generations,[3]][leading to different mean allele frequencies in each population.[4]]

✓ ✗ I have stated that the two populations are not actually that close.[1]

✓ ✗ I have suggested another isolating structure that could have led to different allele frequencies.[2]

✓ ✗ I have explained that this would have prevented gene flow between the populations.[3]

✓ ✗ I have stated that this would lead to different allele frequencies in each population of prairie chicken.[4]

c **i** [The Illinois prairie chickens have a small population and low genetic variation.[1]][This means that, if new selection pressures arise, the population is unlikely to have a phenotypic variant that will help it survive the change.[2]][Additionally, small populations are at risk of inbreeding, which can lead to disadvantageous phenotypes persisting in the population. The other states have prairie chicken populations that are large and genetically diverse, so do not face these problems.[3]]

✓ ✗ I have stated that the prairie chickens have both a small population and low genetic variation.[1]

✓ ✗ I have explained the consequences of low genetic variation if new selection pressures arise.[2]

✓ ✗ I have explained the risks that small populations face from inbreeding.[3]

ii [Fit individuals from the Minnesotan, Kansas, or Nebraskan populations could be introduced into the Illinois population for interbreeding.[1]]

✓ ✗ I have identified a measure to increase the amount of genetic diversity into Illinois.[1]

d [In the pre-human settlement population of prairie chickens, variation in traits existed.[1]][Upon human settlement, some individuals had traits that were advantageous for survival under the new environmental conditions: for example, human and car avoidance or ability to find and digest different food.[2]][Individuals with these advantageous phenotypes survived and had more offspring who inherited these traits than individuals without these phenotypes.[3]][Over generations, the surviving population of prairie chickens had more of these advantageous alleles than historic populations.[4]]

✓ ✗ I have stated that variation existed in the prairie chicken population.[1]

✓ ✗ I have stated that some of these variations in traits were advantageous for survival and reproduction when humans arrived and changed the environment.[2]

✓ ✗ I have stated that these advantageous traits were heritable.[3]

✓ ✗ I have explained that advantageous traits would have become more common in the population.[4]

Key science skills

12 a [If the percentage of females reproductively active before the age of one is dependent upon the infection status of the population then there will be more Tasmanian devils under 1-year old that are reproductively active in 2006 compared to 1983.[1]]

✓ ✗ I have stated that Menna predicted there would be a difference in Tasmanian devil age at reproduction between the two years.[1]

✓ ✗ I have stated the direction of the difference.

b [That there were 87 male and 61 female Tasmanian devils sampled in the study.[1]]

✓ ✗ I have stated that this refers to the number of males and females in the sample.[1]

c i [The infection status of the population.[1]]

✓ ✗ I have stated that either 'year' or 'infection status of the population' is the independent variable.[1]

✓ ✗ I have referred to the scenario in my response.

ii [The % of females reproductively active before the age of one.[1]]

✓ ✗ I have stated that the percentage of females reproductively active before the age of one is the dependent variable.[1]

✓ ✗ I have referred to the scenario in my response.

d [Menna should have checked that the individuals were collected at the same time of year,[1]][as season can impact fertility.[2]][Second, she should have ensured that they were collected using the same sampling technique,[3]][as individuals can be stressed by sampling and this could alter hormones, physiology, and behaviour that are measured to determine reproductive status.[4]]

Other acceptable responses include:

- Ensure the devils were collected from the same population/ geographic location.
- Ensure the techniques used for aging the Tasmanian devils were the same in both years.
- Ensure that there were no other diseases that the population was infected with.
- Ensure there were no hormone-altering chemicals in the environment.

✓ ✗ I have identified a factor that may have affected Menna's results.[1]

✓ ✗ I have explained how this factor could affect the results.[2]

✓ ✗ I have identified a second factor that may have affected Menna's results.[3]

✓ ✗ I have explained how the second factor could affect the results.[4]

e [Menna can accept her hypothesis,[1]][as she found that more females had offspring before the age of one in 2006 (13.3–83.3 %) compared to 1983 (0–12.5 %).[2]]

✓ ✗ I have stated if Menna accepts or rejects her hypothesis.[1]

✓ ✗ I have stated what her results were.[2]

✓ ✗ I have used data in my response.

11C Gene flow and drift

Theory review questions

1 a Immigration **b** Gene flow
c Bottleneck effect **d** Inbreeding
e Founder effect

2 B **3** D
4 A **5** C

Exam-style questions

Within lesson

6 B **7** D

8 a [Gene flow can increase the genetic diversity of a population through immigration introducing new alleles into a population.[1]][However, through emigration, genetic diversity can decrease as alleles are leaving a population.[2]]

✓ ✗ I have explained how gene flow can increase genetic diversity.[1]

✓ ✗ I have explained how gene flow can decrease genetic diversity.[2]

b [As the distance between two populations increases, gene flow decreases[1]][as individuals are less likely to travel a further distance to migrate to another population.[2]]

- ✓ ✗ I have outlined that gene flow decreases as distance increases.[1]
- ✓ ✗ I have justified by stating that individuals are less likely to travel a further distance to migrate.[2]

Multiple lessons

9 B

10 **a** [The smaller island will have a lower genetic diversity due to the founder effect.[1]][These newly formed smaller populations would not have a gene pool which resembles the diversity of the original population.[2]][Therefore, the descendants of each population would inherit the same alleles and will maintain a low genetic diversity.[3]]

- ✓ ✗ I have stated that founder effect is responsible for the lower genetic diversity.[1]
- ✓ ✗ I have outlined how each smaller population does not resemble the original gene pool.[2]
- ✓ ✗ I have described the consequences to the gene pool for future generations.[3]

b [Low genetic diversity makes a population susceptible to new selection pressures that could wipe out all individuals.[1]][Therefore, a greater variation enables a species to thrive under many different selection pressures.[2]]

- ✓ ✗ I have outlined the dangers of low genetic variation.[1]
- ✓ ✗ I have outlined the benefits of high genetic variation.[2]
- ✓ ✗ I have used appropriate biological terminology such as: selection pressure.

11 **a** [This is an example of genetic drift[1]][as fishing and shipping collisions are catastrophic, random events that could affect any dolphin, and there are no selection pressures favouring certain alleles.[2]][Therefore, a bottleneck effect has taken place dramatically decreasing the population's size and genetic diversity.[3]]

- ✓ ✗ I have stated that this is an example of genetic drift.[1]
- ✓ ✗ I have explained why it is not natural selection.[2]
- ✓ ✗ I have explained which type of genetic drift this displays.[3]

b [Gene flow is unlikely to impact burrunan dolphins[1]][as the two populations are separated by a significant distance and rarely mix with other dolphins, making gene flow unlikely to occur.[2]]

- ✓ ✗ I have stated whether gene flow will impact the dolphin populations.[1]
- ✓ ✗ I have explained the effects of the distance between the two populations.[2]

c [The sample used in the breeding program (four dolphins) is small and would cause the founder effect.[1]][The genetic diversity of the resulting offspring from this breeding program would be as low as the limited diversity in the initial four dolphins.[2]]

[Low genetic diversity is dangerous for a population since there will be a lower chance of advantageous alleles existing in the gene pool which are important for safeguarding against future selection pressures that may threaten the species' survival.[3]]

Other acceptable responses include:

- Furthermore, inbreeding between closely related founder dolphins would increase detrimental alleles in the population. Detrimental alleles reduce the fitness of individuals and causes further reductions in the population size until the species becomes extinct.

- ✓ ✗ I have identified that the founder effect would occur in the breeding population.[1]
- ✓ ✗ I have explained how the resulting population will have a low genetic diversity.[2]
- ✓ ✗ I have outlined how future fitness may be affected by low genetic diversity.[3]

Key science skills

12 **a** [The independent variable is the distance between rock-wallaby colonies[1]][and the dependent variable is the amount of gene flow in a population.[2]]

- ✓ ✗ I have stated the independent variable.[1]
- ✓ ✗ I have stated the dependent variable.[2]

b [Gene flow is the introduction of new alleles into a population through new individuals immigrating into and breeding with a population.[1]][Therefore, genetic diversity can increase through an increase in migration and gene flow.[2]]

- ✓ ✗ I have explained what gene flow is.[1]
- ✓ ✗ I have explained how this increases genetic diversity.[2]

c [Genetic diversity is critical for a population to survive, as variation increases the chance of having an allele that confers survival in the face of new selection pressures.[1]][Populations with low genetic diversity may not have this crucial allele, so are at greater risk of extinction.[2]]

- ✓ ✗ I have outlined the importance of variation.[1]
- ✓ ✗ I have explained the risk of low genetic diversity.[2]

d [Rock-wallabies were not exposed to founder effect as the map shows the current population distribution is completely within the historical population distribution.[1]][Therefore, it is unlikely that the smaller population is a founder population of the large population.[2]]

- ✓ ✗ I have explained that the current population is entirely within the historical population.[1]
- ✓ ✗ I have stated a conclusion.[2]

11D Speciation

Theory review questions

1 **a** Sympatric speciation
b Allopatric speciation
c Viable
d Fertile
e Geographic barrier
f Species

2 C
3 C
4 B
5 D

Exam style questions

Within lesson

6 C
7 B

8 **a** **i** [A geographic barrier.[1]]

✓ ✗ I have stated the feature of an environment required for allopatric speciation.[1]

ii [The geographic barrier prevents two populations from breeding together by preventing gene flow.[1]][Therefore, different selective pressures may act on the populations, resulting in speciation.[2]]

✓ ✗ I have stated that the geographic barrier prevents gene flow.[1]

✓ ✗ I have identified that different selection pressures could lead to speciation.[2]

b [Yes, this would disprove the hypothesis.[1]][Two individuals who breed and produce viable and fertile offspring must belong to the same species.[2]]

✓ ✗ I have stated whether the hypothesis is disproved or not.[1]

✓ ✗ I have defined what determines a species.[2]

9 **a** [Initially, the Galápagos tortoise population became isolated by a geographical barrier.[1]][Over time the isolated populations were exposed to different selection pressures[2]][and accumulated sufficient differences from one another so that they formed new species.[3]]

✓ ✗ I have stated the populations are geographically isolated.[1]

✓ ✗ I have identified the presence of different selection pressures on the populations.[2]

✓ ✗ I have explained how a new species is formed.[3]

b [The scientists could breed an individual from each population with one another.[1]][If they cannot produce offspring or the offspring they produce are infertile, then they are considered separate species.[2]]

✓ ✗ I have designed a method to determine whether or not they are the same species.[1]

✓ ✗ I have stated the results that would support the conclusion.[2]

Multiple lessons

10 C

11 **a** [This is an example of allopatric speciation[1]][because new species have been created with a geographic barrier.[2]]

✓ ✗ I have stated whether or not it is an example of allopatric speciation.[1]

✓ ✗ I have justified my response.[2]

b [Different selection pressures can act upon different populations to cause speciation.[1]][Therefore, variation is necessary for a population to survive under these different selection pressures.[2]]

✓ ✗ I have identified the presence of different selection pressures in different populations.[1]

✓ ✗ I have explained the importance of variation because of this.[2]

c [Mutations and sexual reproduction.[1]]

Other acceptable responses include:

- Independent assortment.
- Change in chromosome number.
- Gene flow.

✓ ✗ I have identified two natural methods that cause genetic variation.[1]

Key science skills

12 **a** [They are not the same species[1]][as they could not produce a viable and fertile offspring.[2]]

✓ ✗ I have stated whether they are the same species.[1]

✓ ✗ I have justified my response with reference to the data.[2]

b [Initially, the Australian population became isolated by a geographical barrier through continental drift.[1]][Over time the isolated Australian population was exposed to different selection pressures[2]][and accumulated sufficient differences to the original Mozambican population to be considered a new species.[3]]

✓ ✗ I have stated the populations are geographically isolated.[1]

✓ ✗ I have identified the presence of different selection pressures on the population.[2]

✓ ✗ I have explained how the new species is formed.[3]

c [The two populations were not exposed to different selection pressures despite their distance.[1]]

Other acceptable responses include:

- Isolation of these two populations may have occurred more recently than with the Australian population meaning that not enough time has passed for them to diverge into separate species.
- The cattle tick may have been introduced from one of these countries to the other via migration or artificial means.

✓ ✗ I have suggested a rational reason as to why the populations are not different species.[1]

11E Artificial selection

Theory review questions

1 **a** Desired trait **b** Selective breeding (artificial selection) **c** Inbreeding **d** Recessive

2 C **3** B

4 B **5** C

Exam style questions

Within lesson

6 B **7** D **8** C **9** A

Multiple lessons

10 A **11** B

12 **a** [Humans have selected for dogs that express desired traits based on the functions they perform (e.g. slender bodies for running, sensitive noses for tracking)[1]][and bred them together. Over generations of selective breeding, humans continue to select for more extreme forms of these traits,[2]][eventually resulting in the array of modern dog breeds observed today.[3]]

- ✓ ✗ I have outlined the selection stage of artificial selection.[1]
- ✓ ✗ I have outlined the breeding stage of the process.[2]
- ✓ ✗ I have referred to the scenario in my response.[3]

b [In natural selection, the selection pressure is determined by the natural environment, whereas in artificial selection humans select for a desired trait, so the selection pressure is deliberately human-imposed.[1]]

- ✓ ✗ I have distinguished between artificial and natural selection.[1]
- ✓ ✗ I have used comparative language such as: whereas.

c [In artificial selection, only a subset of a population is selected for breeding.[1]][This results in reduced genetic variation in the population and an increased risk of inbreeding.[2]][The consequences of this are 1) a lowered adaptive potential to changing environments and 2) increased expression of deleterious recessive alleles due to inbreeding.[3]]

- ✓ ✗ I have stated that artificial selection selects for a subset of the population.[1]
- ✓ ✗ I have stated the impact of a reduced gene pool.[2]
- ✓ ✗ I have identified two unintended consequences of artificial selection.[3]
- ✓ ✗ I have signposted my response using terms such as: 1, 2.
- ✓ ✗ I have used appropriate biological terminology such as: gene pool, adaptability, inbreeding.

13 **a** **i** [Natural selection.[1]]

- ✓ ✗ I have stated the correct form of selection.[1]

ii [While human-induced climate change is altering the environment in which *Cryptasterina* live, there is no specific trait that humans are actively selecting for or removing from the breeding pool.[1]][Therefore, this is an example of natural selection.[2]]

- ✓ ✗ I have stated why climate change is not an example of artificial selection.[1]
- ✓ ✗ I have stated that this is an example of natural selection.[2]

b [*C. hystera* is adapted to the cold water environment. When introduced north of the line, *C. hystera* is exposed to both warmer water and warm-water predators.[1]][As there is assumed genetic variation within the *C. hystera* population, some sea stars will express greater resistance to both the warmer water and predators,[2]][and subsequently reproduce more.[3]][If the population is able to survive despite these new pressures, the population will eventually adapt to the new environment over many generations, altering the gene pool. If the population cannot adapt, the population will go extinct.[4]]

- ✓ ✗ I have explained the difference in selection pressures between the cold and warm water environments.[1]
- ✓ ✗ I have explained the importance of genetic variation in *C. hystera* according to the theory of natural selection.[2]
- ✓ ✗ I have stated that fitter individuals will reproduce more.[3]
- ✓ ✗ I have explained two potential outcomes for the introduced population.[4]

Key science skills

14 **a** [Selection for the desired trait over generations will only occur if that trait is heritable.[1]][As cutting off tails with a knife does not affect the gametes of mice, cutting off a tail is not heritable.[2]]

- ✓ ✗ I have stated that artificially selected traits must be heritable.[1]
- ✓ ✗ I have linked my response to Weismann's experiment.[2]

b **i** [That repeated matings between individuals with stunted or malformed tails will result in a population of mice with stunted or missing tails because these traits are heritable.[1]]

- ✓ ✗ I have stated a hypothesis based on the principles of selective breeding.[1]

ii [Mice in a control group would not have undergone selective breeding.[1]]

- ✓ ✗ I have stated what would have been the experimental conditions for the control group of this experiment.[1]

c [Weismann's removal of mouse tails would have caused unnecessary suffering to the mice in the experiment.[1]][This could have been avoided by testing for the heritability of another acquired trait.[2]]

- ✓ ✗ I have stated an ethical issue present in the experiment.[1]
- ✓ ✗ I have stated how this ethical issue could have been avoided.[2]

Chapter 11 Review

SECTION A

1	C	**2**	A	**3**	A	**4**	A
5	C	**6**	D	**7**	D	**8**	C
9	D	**10**	B	**11**	B	**12**	C

SECTION B

13 a [Without predation, a significant selection pressure for the Kākāpō is removed. This reduces the struggle of the population to survive.[1]]

- ✓ ✗ I have identified a benefit of no predation on a population.[1]
- ✓ ✗ I have referred to selection pressures.

b [The Kākāpō is at risk of extinction because it has a small population that is spread out geographically, which means it has low genetic diversity and poor gene flow between potential mates.[1]] [Low genetic diversity increases the risk of extinction because, if a new selection pressure arises, it is unlikely that any individuals will have a phenotype that will help them survive under the new conditions.[2]][If no individuals have a phenotype that confers survival, offspring will not inherit the beneficial phenotype.[3]][As a result, the population will not be able to adapt to survive in the new conditions.[4]]

- ✓ ✗ I have explained why small populations are at risk of extinction.[1]
- ✓ ✗ I have stated that low genetic diversity reduces the likelihood of a beneficial mutation existing within the population if the environment changes.[2]
- ✓ ✗ I have stated that this means advantageous mutations won't be inherited.[3]
- ✓ ✗ I have stated the consequence of this on the population's survival.[4]

14 a [A possible selection pressure would be the temperature difference between the two locations.[1]]

- ✓ ✗ I have stated a potential selection pressure.[1]

b [The ancestral population would have had variation, with some individuals having phenotypes that conferred a survival advantage in warm waters, while some individuals would have phenotypes that confer a survival advantage in cold waters.[1]][These phenotypes would have been heritable.[2]][Over successive generations, it became more common for individuals in the southern, colder waters to have the cold water phenotype, and more common for individuals in the warmer waters to have the warm water phenotype.[3]] [Eventually, more genetic differences would have arisen between the two populations, making them more adapted to their specific environments, until the two populations would have stopped interbreeding and evolved into independent species.[4]]

- ✓ ✗ I have stated that the ancestral population varied phenotypically.[1]
- ✓ ✗ I have stated that the variations would be heritable.[2]
- ✓ ✗ I have stated what would have happened to the two populations over generations.[3]
- ✓ ✗ I have stated that the two populations would eventually become separate species.[4]

15 a [This describes allopatric speciation[1]][as the population has been divided by a geographic barrier which causes the new populations to be exposed to differing selection pressures.[2]][This causes a change in allele frequencies and the formation of a new species which cannot interbreed with the original population.[3]]

- ✓ ✗ I have identified which process of evolution affects the spider species.[1]
- ✓ ✗ I have described the presence of a geographic barrier.[2]
- ✓ ✗ I have stated that different species cannot interbreed.[3]

b [This would indicate the spiders are the same species,[1]][as members of the same species are able to produce viable and fertile offspring.[2]]

- ✓ ✗ I have stated this will indicate the spiders are the same species.[1]
- ✓ ✗ I have explained the definition of a species.[2]

16 a i [The founder effect occurs when a small number of individuals in a population colonise a new region of land.[1]][This new population is unrepresentative of the original[2]][and has a lower genetic diversity.[3]]

- ✓ ✗ I have outlined that founder effect occurs when a small group colonise a new region of land.[1]
- ✓ ✗ I have stated that the new population is unrepresentative of the original population.[2]
- ✓ ✗ I have stated that the new population has a lower genetic diversity.[3]

ii [In the bristlebird populations, Population B has a small population size and a lower genetic diversity,[1]][indicating that Population B could have been impacted by the founder or bottleneck effects, however more information is required to be sure.[2]]

- ✓ ✗ I have referred to population size and genetic diversity as evidence of founder and bottleneck effects.[1]
- ✓ ✗ I have stated which population could be affected.[2]

b [Gene flow is unlikely to affect the bristlebird population[1]][as they are poor flyers that rarely repopulate areas where they have gone locally extinct. Therefore, bristlebirds are unlikely to migrate 200km and so the populations are effectively isolated.[2]]

✓ ✗ I have stated whether gene flow would affect the bristlebird populations.[1]

✓ ✗ I have explained why the bristlebird populations are unlikely to interbreed.[2]

17 a [Low heterozygosity is a strong indicator of low genetic diversity.[1]] [In addition, small populations are likely to have small gene pools, so individuals may inadvertently breed with close relatives.[2]] [By analysing population size and heterozygosity, scientists can estimate the population's adaptive potential and risk of extinction.[3]] [Populations with a higher genetic diversity are more likely to survive in adverse conditions.[4]]

✓ ✗ I have outlined the purpose of testing the amount of heterozygous individuals in the population.[1]

✓ ✗ I have outlined the purpose of testing the population size.[2]

✓ ✗ I have explained the purpose of combining the data of both these tests.[3]

✓ ✗ I have explained the benefits of high genetic diversity.[4]

b [Scientists could identify whether gene flow occurred by comparing the types of alleles present in each population[1]] [and if there is a high similarity then it is likely that gene flow has occurred.[2]]

✓ ✗ I have explained the significance of comparing allele frequencies between populations.[1]

✓ ✗ I have identified what a high similarity in allele frequencies represents.[2]

c i [The trend for both male and female pygmy-possums appears to be roughly U-shaped.[1]] [The female population started with 79 known alive possums in 1996 and dropped down to 0 in 2001, but increased up to 60 in 2013.[2]] [For the male population, it began at 7 known possums that decreased to 0 in 2001 and increased up to 36 in 2013.[3]] [The overall trend shows that the female population has always been significantly greater than the male population.[4]]

✓ ✗ I have stated that the trend is parabolic/U-shaped.[1]

✓ ✗ I have described the trend in the female pygmy-possum population.[2]

✓ ✗ I have described the trend in the male pygmy-possum population.[3]

✓ ✗ I have explained the overall relationship between the male and female populations.[4]

✓ ✗ I have used data in my response.

ii [2010 and 2011.[1]]

✓ ✗ I have identified two consecutive years where the translocation likely occurred.[1]

iii [Gene flow.[1]]

✓ ✗ I have identified the correct evolutionary process.[1]

iv [The males will introduce new alleles into the population to increase genetic diversity and population size.[1]]

✓ ✗ I have suggested a benefit of the translocation.[1]

12A Timeline of life on Earth

Theory review questions

1 **a** Cambrian **b** Stromatolite
c Prokaryotes **d** Flowering plants
e Protists

2 D **3** B

4 C **5** C

Exam-style questions

Within lesson

6 C **7** C

8 C **9** B

10 D

11 **a** [Trilobites evolved during the Cambrian explosion.[1]][They were arthropods with hard shells and a bilaterally symmetrical body plan.[2]]

Other acceptable responses include:

- *Hallucogenia.*
- Arthropods.
- Molluscs.
- Gastropods.
- Jawless fish/early vertebrates.

✓ ✗ I have suggested that an arthropod, crustacean, fish, or other hard-shelled ancient organism evolved during the Cambrian explosion.[1]

✓ ✗ I have described the body shape of the organism.[2]

b [Stromatolites would have been prokaryotes,[1]][because they existed before eukaryotes evolved.[2]]

✓ ✗ I have stated if stromatolites were prokaryotic or eukaryotic.[1]

✓ ✗ I have explained my reasoning, referring to the age of the fossils.[2]

Multiple lessons

12 C

13 **a** [Increasing the oxygen concentration in the atmosphere means more living things can respire aerobically, which means organisms can make more energy and larger organisms can survive.[1]][In addition, oxygen forms the ozone layer which protects living things from harmful radiation.[2]]

✓ ✗ I have explained how increased oxygen affects respiration.[1]

✓ ✗ I have explained how oxygen in the atmosphere protects living things.[2]

b **i** [Once, an ancestor of mountain ash was a eukaryote that lacked chloroplasts.[1]][This eukaryote engulfed a photosynthetic cyanobacteria-like prokaryote,[2]][then used it to make glucose rather than destroying it. In this way, early chloroplasts were formed inside the first eukaryotes.[3]][This cell replicated and evolved over billions of years, passing on its chloroplasts, until it eventually speciated into mountain ash.[4]]

✓ ✗ I have described the ancestral cell of mountain ash.[1]

✓ ✗ I have described the process of endosymbiosis.[2]

✓ ✗ I have explained the consequence of the endosymbiotic event.[3]

✓ ✗ I have described what happened to the ancestral cell of mountain ash over time.[4]

ii [One similarity is that both cyanobacteria and mountain ash photosynthesise.[1]][One difference is that mountain ashes are eukaryotes, but cyanobacteria are prokaryotes.[2]]

Other acceptable similarities include:

- Both have cell walls.
- Both have cell membranes.
- Both have genetic material in the form of DNA.
- Both have ribosomes.
- Both undergo respiration.

Other acceptable differences include:

- Mountain ashes have differentiated cells with specialised functions, cyanobacteria do not.
- Mountain ashes have membrane-bound organelles, cyanobacteria do not.
- Mountain ashes are multicellular, cyanobacteria are not.
- Mountain ashes have linear DNA in a nucleus, cyanobacteria have circular DNA in a nucleoid region.
- Mountain ashes have cellulose cell walls but cyanobacteria have peptidoglycan cell walls.

✓ ✗ I have identified one similarity.[1]

✓ ✗ I have identified one difference.[2]

Key science skills

14 **a** [The scientists simulated lightning and rain.[1]]

Other acceptable responses include:

- They used inorganic molecules that are likely to have existed on early Earth, such as ammonia, methane, and hydrogen.

✓ ✗ I have identified two ways the scientists attempted to simulate early Earth.[1]

b [By not replicating their experiment, we do not know if Miller and Urey's results are reproducible or if they just happened by chance.[1]][This means their results are not reliable.[2]]

✓ ✗ I have stated what no replication means in terms of reproducibility.[1]

✓ ✗ I have explained how a lack of replication affects the reliability of their results.[2]

c [They should run each replicate experiment for the same amount of time, they should heat the water in the 500 mL flask the same amount, and they should ensure each replicate starts with the same amount of reactants.[1]]

Other acceptable responses include:

- Expose each replicate to the same amount of lightning.
- Ensure that the apparatus is thoroughly cleaned before each replicate.
- Ensure the temperature in the room is constant between replicates.
- Ensure the reactants are pure and don't contain contaminants for each replicate.
- Use the same, sterile techniques for each replicate.

✓ ✗ I have suggested three realistic variables that should be controlled.[1]

12B Fossils

Theory review questions

1 **a** Sedimentary rock **b** Radioisotope
c Impression fossil **d** Fossil
e Trace fossil **f** Mummified organism
g Absolute age **h** Half-life
i Index fossil **j** Radiometric dating
k Permineralised fossil **l** Relative age
m Fossil succession or law of superposition

2 B **3** D

Exam-style questions

Within lesson

4 D **5** A **6** C
7 D **8** B **9** C
10 D **11** B **12** A

Multiple lessons

13 A

14 **a** [The scientists would have used an absolute dating method such as radiometric dating, luminescence, or electron spin resonance to calculate the absolute age of the fossil.[1]][Using radiometric dating,[2]] [the scientists would have measured the amount of a suitable radioisotope relative to its breakdown product[3]][and then calculated the age of the molluscs using the radioisotope's half-life.[4]][Suitable radiometric dating pathways include the potassium-argon and uranium-lead pathways.[5]]

✓ ✗ I have identified the range of techniques which could be used to calculate the absolute age of the molluscs.[1]

✓ ✗ I have identified which of these techniques the scientists would have used.[2]

✓ ✗ I have identified what the scientists would have measured.[3]

✓ ✗ I have identified that the absolute age could be calculated using this information and the half-life of the radioisotope.[4]

✓ ✗ I have given suitable radiometric dating pathway/s.[5]

b [The scientists would have used the absolute age of the mollusc fossils to determine the relative age of the Osteichthyan fossil.[1]] [Using the principle of fossil succession and the stratigraphic location of the Osteichthyan fossil, fossils found in the same layer as the molluscs are approximately the same age, whereas fossils in deeper layers are older, and higher layers are younger.[2]]

✓ ✗ I have stated that the molluscs' absolute age could be used to determine the relative age of the Osteichthyan fossil.[1]

✓ ✗ I have explained how the molluscs' absolute age could be used to determine the relative age of the Osteichthyan fossil.[2]

c [The relative age of the Osteichthyan fossil is greater than 400 million years old.[1]]

✓ ✗ I have stated the relative age of the Osteichthyan fossil.[1]

d [No, as the molluscs may not meet the requirements of an index fossil.[1]][It is not known if the molluscs had a wide, populated distribution and the time period of their survival are not known.[2]]

✓ ✗ I have stated if these molluscs could be used as an index fossil.[1]

✓ ✗ I have supported this statement by referring to the characteristics of an index fossil.[2]

e [The Cambrian explosion (~ 535 mya) describes a period of rapid diversification of multicellular life, characterised by the evolution of hardened body parts such as shells or bones.[1]]

Other acceptable responses include:

- The evolution of multicellularity (~ 900 mya), and subsequent specialisation of tissues and organs.

✓ ✗ I have identified an important step in evolution from ancient unicellular eukaryotes to Osteichthyans.[1]

Key science skills

15 D

16 **a** [Point B corresponds to the given ratio of ^{14}C:^{14}N, as it is equal to half that found in present-day organisms.[1]]

✓ ✗ I have correctly identified that point B corresponds to the ratio of ^{14}C:^{14}N.[1]

b [The absolute age of the fossilised kangaroo skull is 5 730 years old.[1]]

✓ ✗ I have correctly calculated the absolute age of the skull.[1]

17 **a** [The absolute age will accurately describe the fossil's age in years,[1]] [whereas the relative age only indicates the order of formation for each fossil.[2]][Therefore, to accurately describe stickleback evolution, the absolute age should be calculated.[3]]

✓ ✗ I have explained what the absolute age describes.[1]

✓ ✗ I have explained what the relative age describes.[2]

✓ ✗ I have concluded whether the scientists should calculate the relative or absolute age.[3]

b [The absolute age of the top layer fossils: 6 000 years old.[1]]
[The absolute age of the middle layer fossils: 12 000 years old.[2]]
[The absolute age of the lower layer fossils: 24 000 years old.[3]]

✓ ✗ I have calculated the age of the top layer fossils.[1]

✓ ✗ I have calculated the age of the middle layer fossils.[2]

✓ ✗ I have calculated the age of the lower layer fossils.[3]

c [The size of dorsal spines and pelvis in sticklebacks increases in saline or oceanic enivornments.[1]]

✓ ✗ I have stated a hypothesis that could explain the change observed in the stickleback fossils.[1]

d [The question states that sticklebacks with large dorsal spines and pelvic bones are common in the ocean, while sticklebacks with small spines and pelvises are common in freshwater.[1]] [This is probably because large dorsal spines and pelvic bones provide a selective advantage in the ocean (i.e. faster swimming, predator defence) but not in freshwater systems.[2]] [Given that the saltwater variety were common ~12 000 years ago, it is likely that the lake was saltwater, or inundated by the ocean, at this time.[3]] [However, the variety with small dorsal spines and pelvic bones were common ~24 000 years ago, suggesting the lake was once again freshwater at this time.[4]]

✓ ✗ I have identified the habitats of each stickleback phenotype.[1]

✓ ✗ I have explained that the physiological differences between fresh- and saltwater sticklebacks provided selective advantages in each habitat.[2]

✓ ✗ I have used evidence to describe the lake environment 12 000 years ago.[3]

✓ ✗ I have used evidence to describe the lake environment 24 000 years ago.[4]

12C Evidence of ancient life on Earth

Theory review questions

1 **a** embryo
b transitional fossil
c supercontinent
d continental drift
e biogeography
f fossilisation bias
g the fossil record
h developmental biology OR comparative embryology

2 B
3 A
4 C

Exam style questions

Within lesson

5 B
6 D
7 C
8 D
9 D
10 A

11 **a** [Structure B is the dorsal nerve cord.[1]] [Structure C is the pharyngeal arches.[2]]

✓ ✗ I have correctly identified structure B.[1]

✓ ✗ I have correctly identified structure C.[2]

b [These features are only present in chordates, implying that their early development is both similar within the phylum Chordata and different to the early development of other phyla.[1]] [This suggests that all chordates share a common ancestor and have gradually acquired changes since then.[2]]

✓ ✗ I have explained that these features describe similarities within the phylum Chordata.[1]

✓ ✗ I have explained that this suggests all chordates evolved from a common ancestor.[2]

Multiple lessons

12 **a** [The *Archeopteryx* fossil is a transitional fossil between ancient dinosaurs and modern birds.[1]] [This indicates that dinosaurs are the ancestors of modern birds.[2]]

✓ ✗ I have identified that *Archeopteryx* is a transitional fossil.[1]

✓ ✗ I have explained the significance of this when considering the evolutionary origins of birds.[2]

b [A radioisotope within a fossil loses half of its mass at a predictable rate called a half-life.[1]] [By measuring the relative amounts of this material and its breakdown product, and given the half-life of the material, the absolute age of the sample can be calculated.[2]]

✓ ✗ I have explained the concept of a half-life.[1]

✓ ✗ I have explained the radiometric dating process.[2]

Key science skills

13 B

14 **a** [Biogeography.[1]]

✓ ✗ I have correctly named the study of the geographic distribution of plants and animals.[1]

b **i** [Ash is of igneous origin. Therefore, potassium-40 would have been used to calculate the absolute age of the ash.[1]]

✓ ✗ I have identified that potassium-40 would have been used.[1]

ii [As the *Glossopteris* fossil was found within the ash, the relative age of the fossil is the same as the absolute age of the ash.[1]]

✓ ✗ I have explained how the absolute age of the ash can be used to find the relative age of the *Glossopteris* fossil.[1]

c [Fossils of the therapsid species can be found closer to the surface than the ash layer, indicating they were alive less than 251 million years ago.[1]] [However, fossils of the therapsid species can also be found below the ash layer, indicating these fossils are more than 251 million years old.[2]] [This suggests that the therapsid species originated more than 251 million years ago.[3]]

I have explained the significance of the therapsid fossil found above the ash layer.[1]

I have explained the significance of the therapsid fossil found below the ash layer.[2]

I have concluded the relative age of the therapsid species.[3]

15 a [The absolute age of the igneous rock is 260 million years old.[1]]

I have correctly calculated the absolute age of the igneous rock.[1]

b [The *Lystrosaurus* fossil is approximately 260 million years old,[1]] [as the fossil was found in the igneous sedimentary layer.[2]]

I have defined the relative age of the *Lystrosaurus* fossil.[1]

I have explained my reasoning.[2]

c [The bivalve is greater than 260 million years old,[1]] [as the bivalve is in a sedimentary layer below the *Lystrosaurus* fossil.[2]]

I have defined the relative age of the bivalve.[1]

I have explained my reasoning.[2]

d [260 million years ago, the Antarctic, Indian, and South African landmasses were part of the supercontinent known as Pangaea.[1]] [As members of the genus *Lystrosaurus* were terrestrial animals, they would have been able to migrate into these areas, where they became fossilised.[2]]

I have described the landmasses 260 million years ago.[1]

I have discussed how this explains the current dispersal of *Lystrosaurus* fossils.[2]

12D Patterns of biological change

Theory review questions

1 a Adaptive radiation
b Background extinction rate
c Analogous structure
d Convergent evolution
e Divergent evolution
f Vestigial structure
g Homologous structure
h Mass extinction

2 B
3 A
4 B
5 D
6 C

Exam-style questions

Within lesson

7 C
8 A
9 D
10 B
11 B

Multiple lessons

12 D
13 B
14 B
15 C

16 a [Vestigial limbs refer to small limb-like appendages found on many snakes, which appear to serve no purpose.[1]]

I have explained the term vestigial limbs.[1]

I have explained vestigial limbs in reference to snakes rather than vestigial organs in general.

b [Snakes evolved from legged lizards, however fully formed legs were disadvantageous for serpentine movement.[1]] [As such, smaller legged individuals were favoured and repeated selection resulted in the almost complete removal of limbs in modern snakes.[2]] [As these vestigial limbs provide no selective advantage or disadvantage, they remain present throughout subsequent generations.[3]]

I have discussed selection pressures surrounding legs in Serpentes evolution.[1]

I have discussed changes in leg size during Serpentes evolution.[2]

I have discussed the selection pressures on *vestigial limbs* in Serpentes.[3]

c i [As the sedimentary layer is of igneous origin, the scientists could calculate the age via radiometric dating[1]] [using the potassium-40 pathway.[2]] [By measuring the relative amount of potassium-40 and stable products of the radioactive pathway, the absolute age of the rock can be calculated.[3]]

Other acceptable responses include:

- Uranium-235.
- Uranium-238.

I have stated a suitable form of dating.[1]

I have given an example of an isotope that would be used for samples 100 million years old.[2]

I have explained the radiometric dating process.[3]

ii [Carbon-14 has a relatively short half-life,[1]] [and can only accurately date samples less than 50 000 years old. As the rock is 100 million years old, there wouldn't have been enough carbon-14 to accurately date the sample.[2]]

I have attributed this to the short half-life of carbon-14.[1]

I have explained why a short half-life makes the carbon-14 pathway unsuitable for use.[2]

iii [The scientists would have calculated the absolute age of sedimentary igneous rock in which *Tetrapodophis amplectus* was found.[1]] [The scientists could then conclude that, because the fossil is found in the same layer as the rock, it has the same relative age as the rock.[2]]

I have stated that radiometric dating was used to date the sedimentary layer.[1]

I have stated that the age of the fossil is approximately the age of the sedimentary layer.[2]

iv [As *Tetrapodophis amplectus* is a transitional fossil, the most recent common ancestor of lizards and snakes occurred more than 100 mya.[1]]

✓ ✗ I have stated how this information could be used to determine the age of a common ancestor.[1]

17 a [Convergent evolution.[1]]

✓ ✗ I have stated the evolutionary pattern which describes this relationship.[1]

b [These two species do not share a recent common ancestor, as they evolved from completely different lineages.[1]][However, both of these species have adapted to fill similar niches, and experience similar selective pressures.[2]][Gliding between trees is an efficient way of moving between trees, and removes the threat of ground-dwelling predators.[3]][As such, individuals with greater gliding ability are able to reproduce more,[4]][repeated selection over generations has facilitated the independent evolution of the analogous structure of skin extensions.[5]]

✓ ✗ I have discussed the lineages of the two species.[1]

✓ ✗ I have explained the selective pressures of similar niches.[2]

✓ ✗ I have explained the selective advantage of gliding.[3]

✓ ✗ I have explained the reproductive advantage of gliding.[4]

✓ ✗ I have discussed subsequent effects on each species over time.[5]

Key science skills

18 a [The line shows the normal extinction rate (background extinction rate).[1]]

✓ ✗ I have stated the meaning of the dashed line.[1]

b [Yes,[1]][because the extinction rate of each group of vertebrates is significantly higher than the background extinction rate.[2]]

✓ ✗ I have stated whether the graph supports the idea.[1]

✓ ✗ I have justified my response by referring to the graph.[2]

19 a [Adaptive radiation.[1]]

✓ ✗ I have correctly identified the pattern of evolution which commonly follows a mass extinction.[1]

b [Widespread extinctions leave many unoccupied niches.[1]][The remaining species can diverge rapidly via adaptive radiation, filling these niches.[2]]

✓ ✗ I have explained an effect of mass extinctions.[1]

✓ ✗ I have explained how species can take advantage of this.[2]

c [Firstly, the study of 2 415 species showed that mammals are heavily biased towards nocturnality,[1]][indicating a nocturnal ancestor.[2]] [Secondly, diurnal mammals tend to have less colour-sensing photoreceptors and more low light-sensing photoreceptors than other diurnal vertebrates.[3]][Since these mammals are diurnal, this is likely not an adaptation and is more likely to be an ancestral trait from a nocturnal ancestor.[4]]

✓ ✗ I have provided a piece of behavioural evidence.[1]

✓ ✗ I have explained how this behavioural evidence suggests a nocturnal mammalian ancestor.[2]

✓ ✗ I have provided a piece of physical evidence.[3]

✓ ✗ I have explained how this physical evidence suggests a nocturnal mammalian ancestor.[4]

d [No, the predation from diurnal predators would not have caused a genetic bottleneck,[1]][as the predation pressure was not large enough to significantly reduce the genetic diversity.[2]]

✓ ✗ I have stated if predation was likely to cause a genetic bottleneck.[1]

✓ ✗ I have used evidence from the text to support my statement.[2]

e [The fossil record indicates placental mammalian life rapidly diversified shortly after the extinction of the dinosaurs during the K-Pg mass extinction.[1]][This aligns with the explosive model and our classic view of adaptive radiation following a mass extinction.[2]][In contrast, the more recent molecular analysis and long-fuse model suggest this diversification may have begun 20 million years before the K-Pg event, while dinosaurs were still alive.[3]][This indicates mammalian radiation occurred despite niches already being occupied , which contradicts the classic view of adaptive radiation.[4]]

✓ ✗ I have indicated timing supported by the fossil record.[1]

✓ ✗ I have discussed its implications on the classic view of adaptive radiation.[2]

✓ ✗ I have indicated timing supported by the molecular analysis.[3]

✓ ✗ I have discussed its implications on the classic view of adaptive radiation.[4]

✓ ✗ I have used comparative language such as: in contrast.

Chapter 12 review

Section A

1	B	**2**	B	**3**	A
4	D	**5**	C	**6**	D
7	A	**8**	D	**9**	A
10	C	**11**	D	**12**	A
13	C	**14**	B	**15**	B
16	D	**17**	D		

Section B

18 a

Species	Environment	Condition
D. optatum	Near the coast of south-eastern Australia	**Submerged in highly mineralised groundwater**
P. cinereus	Cave in western Queensland	**Lack of light, wind, and water**
A. cignorum	Near the coast of south-eastern Australia	**Rapid burial in sediment**

Other acceptable responses include:

- *D. optatum* – Rapid burial in sediment, lack of oxygen, or lack of decomposers and scavengers.
- *P. cinereus* – Constant cool temperature, constant humidity, lack of decomposers or scavengers.
- *A. cignorum* – Presence of decomposers or scavengers.

b [Structural morphology.[1]]

Other acceptable responses include:

- Comparative anatomy.

✓ ✗ I have correctly named the study in question.[1]

c [Finding homologous structures between the skulls would indicate the two species are related.[1]] [The lower jaw structure appears to be homologous between the two species as it is a similar shape.[2]]

Other acceptable responses include:

- The teeth of the lower jaw.
- The teeth of the upper jaw.
- The molars of the lower and upper jaw.

✓ ✗ I have identified that the presence of homologous structures would indicate the two species are related.[1]

✓ ✗ I have stated a piece of evidence the scientists could have used.[2]

d i [The absolute age of the skull is approximately 2 865 years old.[1]]

✓ ✗ I have correctly calculated the absolute age of the skull.[1]

ii [The scientist dropping the skull is an example of personal error.[1]]

✓ ✗ I have correctly identified the type of error this situation describes.[1]

19 a i [The foot structures are homologous.[1]]

✓ ✗ I have correctly identified the relationship between the foot structures.[1]

ii [As the leg structures are homologous, this is an example of divergent evolution.[1]]

✓ ✗ I have correctly identified the pattern of evolution.[1]

b [You would not find any Equus fossils older than three million years old.[1]] [Because the Equus genus originated in North America, they could only migrate to South America over land and the land bridge only developed three million years ago.[2]]

✓ ✗ I have stated the maximum age of *Equus* fossils in South America.[1]

✓ ✗ I have explained why you would not see *Equus* fossils before this time.[2]

c [In absolute dating the age is calculated very accurately, usually by measuring relative amounts of known materials within the fossils.[1]] [In comparison, relative dating approximates a fossil's age by associating it with another specimen within the same or another sedimentary layer.[2]]

✓ ✗ I have explained absolute dating techniques.[1]

✓ ✗ I have explained relative dating techniques.[2]

✓ ✗ I have used comparative language such as: in comparison.

20 a [Independent variable: exposure to a predator.[1]] [Dependent variable: proportion of single-celled and 'multicellular' bacteria.[2]]

✓ ✗ I have stated the independent variable.[1]

✓ ✗ I have stated the dependent variable.[2]

b [Predators act as a selective pressure that favours the evolution of bacterial aggregates.[1]]

✓ ✗ I have stated the hypothesis being tested by the scientists.[1]

c i [The scientists did use a control.[1]] [The container with both forms of the bacteria and no predators acts as a control.[2]]

✓ ✗ I have stated if the scientists used a control.[1]

✓ ✗ I have described the control used in the experimental design.[2]

ii [The scientists' results are more reliable for using a control.[1]] [This is because they have ensured that the proportion of bacterial forms (the dependent variable) is caused by exposure to a predator (the independent variable), rather than the effects of other variables.[2]]

✓ ✗ I have identified the benefits of using a control.[1]

✓ ✗ I have explained how this would affect the scientists' interpretation of the results.[2]

d [No.[1]][While this bacteria does aggregate into a multicellular form, the lack of membrane-bound organelles indicate this bacteria is still a prokaryote.[2]][Current understandings suggests that eukaryotes evolved membrane-bound organelles ~2 bya, and these eukaryotes then evolved multicellularity ~900 mya.[3]]

✓ ✗ I have stated whether a similar bacterial aggregate could be the ancestor to modern multicellular life.[1]

✓ ✗ I have described what type of life these bacteria represent.[2]

✓ ✗ I have described the ancestors of modern multicellular life according to current understandings.[3]

21 a [The data suggests the average skull size of a tortoise from population B is larger than one from population A, indicating they are not of the same species.[1]][For example, at position 1 the difference in size is 20 mm,[2]][which is larger than the difference in measurements between the three named species.[3]][Such a large physical change indicates significant shifts in individual genomes so that any offspring from interbreeding between populations is unlikely to produce viable offspring.[4]]

✓ ✗ I have described differences in characteristics between the two populations.[1]

✓ ✗ I have used data from the table to support this statement.[2]

✓ ✗ I have compared the difference between the two populations to the differences between the three named species.[3]

✓ ✗ I have determined whether they belong to the same species by referring to the definition of species.[4]

b i [Allopatric speciation.[1]]

✓ ✗ I have stated the type of speciation that has occurred.[1]

ii [As the Galápagos tortoise can't swim, the river acts as a geographical barrier,[1]][preventing gene flow between the two populations.[2]][Over time, due to genetic drift, accumulation of mutations, and exposure to different selection pressures, the gene pool for each population shifts and the populations diverge and become different species.[3]]

✓ ✗ I have stated that the river is a geographical barrier.[1]

✓ ✗ I have stated that separation of the two populations prevents mating.[2]

✓ ✗ I have indicated the evolutionary forces which have caused speciation over time.[3]

iii [Divergent evolution.[1]]

✓ ✗ I have stated the evolutionary pattern which describes this process.[1]

iv [A common ancestor with common homologous or vestigial structures.[1]]

✓ ✗ I have identified a piece of evidence for divergent evolution.[1]

13A Phylogenies

Theory review questions

1 **a** Derived trait **b** Phylogeny
c Phylogenetic tree **d** Ancestral trait
e Lineage **f** Taxon

2 D **3** A
4 C **5** B
6 D

Exam-style questions

Within lesson

7 C **8** D **9** B

10 **a** [In both diagrams, the closest relative of *Ceratophyllum* are the eudicots. In both diagrams, all of the plants share a common ancestor.[1]]

Other acceptable responses include:

- Monocots, Chloranthales, magnoliids, *Ceratophyllum*, and eudicots are all classed as Mesangiospermae.

✓ ✗ I have identified and explained two similarities between the two phylogenetic trees.[1]

b [Nymphaeales is more closely related to *Amborella* in the first tree, whereas Nymphaeales is more closely related to all of the other groups in the second tree. Chloranthales is more closely related to magnoliids in the second tree, whereas Chloranthales is more closely related to monocots, *Ceratophyllum*, and eudicots in the first tree.[1]]

Other acceptable responses include:

- In the first tree, the monocots diverged early from the other Mesangiospermae. In the second tree, the magnoliids and Chloranthales diverged before the monocots.

✓ ✗ I have identified and explained two differences between the two phylogenetic trees.[1]

Multiple lessons

11 A **12** A **13** C
14 B **15** D

16 **a** [By comparing the similarities and differences between homologous structures, scientists can deduce relationships between organisms and construct a phylogenetic tree.[1]]

✓ ✗ I have stated that homologous structures (not analogous) must be compared.[1]

b **i** [Species 3[1]][since it shares a common ancestor with species 11 more recently than species 12.[2]]

✓ ✗ I have identified species 3.[1]

✓ ✗ I have justified my answer by referring to the recent common ancestor.[2]

ii [Claws[1]][would enable lizards to cling to trunks better.[2]]

Other acceptable responses include:

- Brown camouflage would allow lizards to blend into tree trunks.
- Large legs would enable lizards to grasp onto tree trunks better.
- Large size would give lizards better protection from predators.
- Claws would allow lizards to defend themselves from predators.

✓ ✗ I have identified an advantageous physical characteristic.[1]

✓ ✗ I have explained how this characteristic would be advantageous for trunk-ground lizards.[2]

iii [One species in each of the four *Anolis* groups of the phylogenetic tree demonstrate a trunk-ground lifestyle.[1]][It is likely that the ancestor was not a trunk-ground lizard, and this lifestyle evolved independently in the four trunk-ground species.[2]]

✓ ✗ I have referred to the relevant part of the phylogenetic tree in my answer.[1]

✓ ✗ I have explained that the independent evolution of trunk-ground lifestyles in the four species is most likely.[2]

17 **a** [Two strains that have diverged will have homologous structures in common.[1]][We expect these homologous structures to change in each strain after divergence, allowing us to use these structures for identification.[2]]

✓ ✗ I have identified homologous structures.[1]

✓ ✗ I have explained how homologous structures are used to show divergence.[2]

b **i** [Strains 7 and 8[1]][diverged most recently and so would have had the least time to accumulate morphological changes.[2]]

✓ ✗ I have identified the correct strains.[1]

✓ ✗ I have justified my response by referring to evolutionary relatedness.[2]

ii [There are two divergences that occurred close together in time.[1]][Due to insufficient data, it may be difficult to determine which divergence occurred first, and this is indicated using three branches.[2]]

✓ ✗ I have explained the origin of polytomies.[1]

✓ ✗ I have explained how uncertainties in data may create polytomies.[2]

c **i** [Since strains 3 and 4 recently diverged, the transmission to palm civet hosts likely occurred in their recent ancestor.[1]]

✓ ✗ I have identified that a single transmission event to palm civets occurred.[1]

ii [Since strains 5 and 6 are not closely related, the transmission to human hosts must have occurred twice independently.[1]][Since most of the strains of virus are now found in bats, the ancestral host is likely to also have been a bat.[2]]

✓ ✗ I have stated that the two strains in humans likely evolved independently.[1]

✓ ✗ I have identified the host of the ancestral virus.[2]

Key science skills

18 a [The most recent divergence occurred between mammals and reptiles.[1]]

✓ ✗ I have identified the correct divergence event.[1]

b i [*Tiktaalik* would have developed lungs and sturdy bones in its limbs.[1]][Its lungs would allow it to take in gulps of air for oxygen while its sturdy limbs would allow *Tiktaalik* to prop itself up above shallow waters to take in gulps of air.[2]]

Other acceptable responses include:

- *Tiktaalik* may have had eyes on top of its head, allowing it to view above the water easily.

✓ ✗ I have given two examples of structural features that support the transitional fossil hypothesis.[1]

✓ ✗ I have explained the survival advantage on land of each feature.[2]

ii [If *Tiktaalik* were dated to be older than ancestral fish then this would suggest that *Tiktaalik* did not evolve from fish as the hypothesis suggests.[1]]

Other acceptable responses include:

- It has features that are not found in either ancestral fish or tetrapods.

✓ ✗ I have given a reasonable example that refutes the hypothesis.[1]

13B Molecular homology

Theory review questions

1 a Mitochondrial DNA (mtDNA)
b Melting temperature (T_m)
c Mutation rate
d DNA hybridisation
e Maternally inherited
f Molecular clock

2 D
3 B
4 B
5 A
6 C

Exam-style questions

Within lesson

7 B **8** C **9** A **10** B
11 C **12** D **13** B **14** A

Multiple lessons

15 D **16** B **17** B

18 a [Morphological features of closely related species[1]][would have more characteristics in common with each other than with those of more distantly related species.[2]][DNA hybridisation[3]][to determine similarity in DNA sequences, and therefore relatedness.[4]]

Other acceptable responses include:

- Analysing DNA sequences to determine similarity, and therefore relatedness.

✓ ✗ I have named a correct piece of evidence.[1]

✓ ✗ I have briefly explained how this evidence would help determine relatedness.[2]

✓ ✗ I have named a second correct piece of evidence.[3]

✓ ✗ I have briefly explained how this evidence would help determine relatedness.[4]

b [Amino acid sequences from the same protein are compared between two species.[1]][Changes from one amino acid to another in the sequence accumulate over time and so more amino acid changes indicate more distant relatedness.[2]]

✓ ✗ I have stated that the same protein from each species is compared.[1]

✓ ✗ I have stated that more amino acid changes indicate they are more distantly related.[2]

19 a [Mitochondrial DNA has a high mutation rate compared to coding regions of nuclear DNA.[1]][There is also no recombination in mtDNA because it's inherited from the mother.[2]]

✓ ✗ I have stated that mtDNA has a high mutation rate.[1]

✓ ✗ I have explained that mtDNA allows us to trace unbroken lineages due to the lack of recombination.[2]

b i [Individuals 1 and 2.[1]][There is only one nucleotide site that differs between them, which is at site F. This is the fewest number of sequence differences between any of the samples, indicating they are the most closely related.[2]]

✓ ✗ I have stated the correct two individuals.[1]

✓ ✗ I have justified my response by referring to the data.[2]

ii [Point mutations.[1]]

✓ ✗ I have stated the correct type of mutation.[1]

iii [This is a nonsense mutation.[1]][A nonsense mutation in a protein-coding gene would cause translation to stop prematurely to create a short polypetide.[2]][This polypetide would likely not function properly.[3]]

✓ ✗ I have stated the correct type of mutation.[1]

✓ ✗ I have explained the effect of this mutation on translation.[2]

✓ ✗ I have explained the effect of this mutation on protein structure.[3]

Key science skills

20 a [DNA is heated to 95°C to break the hydrogen bonds between strands.[1]][Single strands from both species are mixed together and cooled, allowing the two strands to form hydrogen bonds with each other, creating a double-stranded hybrid DNA.[2]][Hybrid DNA is then reheated and the temperature at which half of the DNA becomes single-stranded is noted. This temperature is known as the melting temperature (T_m).[3]]

- ✓ ✗ I have described the denaturation stage.[1]
- ✓ ✗ I have described the hybridisation stage.[2]
- ✓ ✗ I have described the melting stage.[3]
- ✓ ✗ I have not explained the polymerase chain reaction (lesson 15B) in my response.

b i [The more recent the common ancestor between the two species, the higher the melting temperature will be.[1]]

Other acceptable responses include:

- The older the divergence between the two species, the lower the melting temperature will be.

✓ ✗ I have stated that there should be an increase in melting temperature the more related the two species are.[1]

ii [Mouse.[1]]

✓ ✗ I have identified the correct pet.[1]

iii [Tarantula.[1]]

✓ ✗ I have identified the correct pet.[1]

c [Angus should ensure each DNA sample is heated and cooled for the same amount of time.[1]][This ensures the experiment is conducted exactly the same for each sample, reducing the influence of confounding variables.[2]]

Other acceptable responses include:

- The same device is used to control the temperature.
- The same gene(s) are used from each species.

- ✓ ✗ I have stated a reasonable control.[1]
- ✓ ✗ I have explained how this would reduce the effect of extraneous variables.[2]

13C Master Genes

Theory review questions

1 a bone morphogenetic protein 4 (*BMP4*)
b embryonic development
c master gene
d regulatory gene

2 C
3 B
4 A
5 A

Exam-style questions

Within lesson

6 B **7** C **8** D

9 a [Genes could be expressed for different lengths of time in the embryo.[1]][For example, switching on the gene earlier or switching it off later could result in the longer swimming appendage in *Artemia*.[2]]

Other acceptable responses include:

- Each location in *Artemia* may contain different regulatory sequences that respond differently to the same master gene.

- ✓ ✗ I have described how gene expression can vary during embryonic development.[1]
- ✓ ✗ I have referred specifically to appendages in *Artemia*.[2]

b [A mutation in *Ubx* and *Scr* may result in no functional protein being made.[1]][This could result in a complete absence of feeding or swimming appendages in the developed shrimp.[2]]

Other acceptable responses include:

- Loss of *Ubx* and *Scr* may result in reduced swimming and feeding appendages.
- Altered *Ubx* and *Scr* expression may result in appendages growing in incorrect places (e.g. swimming appendage near mouth).
- Overexpression of *Ubx* and *Scr* may result in appendages growing abnormally or in incorrect places.

- ✓ ✗ I have described the molecular effect of a mutation in the *Hox* genes.[1]
- ✓ ✗ I have described the phenotypic consequence to *Artemia* of the mutation.[2]

c [Mutations in master genes result in large phenotypic changes within a short period of time.[1]][This means that fewer mutations in a master gene are needed to result in enough phenotypic change to create a new species.[2]]

- ✓ ✗ I have stated that mutations in master genes result in large phenotypic changes.[1]
- ✓ ✗ I have explained that fewer mutations in master genes are needed to result in divergence.[2]

Multiple lessons

10 a [The *BMP4* gene encodes a signalling protein that is responsible for beak formation in Galápagos finches.[1]][The longer the gene is expressed in the embryo, the more BMP4 is produced and the larger the beak that develops.[2]]

- ✓ ✗ I have identified BMP4 as a signalling protein.[1]
- ✓ ✗ I have described how BMP4 controls beak formation.[2]

b [A wide deep beak would allow a finch to crack open seeds and nuts.[1]][Prey specialisation means finches won't face as much competition from species that do not have the appropriate beak shape to access that food[2]][and will therefore increase their reproductive success.[3]]

✓ ✗ I have described the function of a wide deep beak.[1]

✓ ✗ I have stated that this adaptation will reduce competition.[2]

✓ ✗ I have stated that the fitness of this finch will be increased.[3]

c [Small beak width and depth.[1]]

✓ ✗ I have identified the correct beak type.[1]

11 a [No,[1]][jaw shape could not be used to determine relatedness between cichlid fish species, as jaw shape is not inherited from a common ancestor.[2]][Rather, the jaw shape in each lake is determined by the selective pressures present in each lake.[3]]

✓ ✗ I have stated no.[1]

✓ ✗ I have explained that jaw shape is not a homologous structure.[2]

✓ ✗ I have explained that jaw shape evolved independently in each lake.[3]

b [Divergence due to mutations in structural genes in such a short period of time is quite rare.[1]][A mutation in a master gene controlling jaw formation in development would be a likely explanation since mutations in master genes cause large phenotypic changes over a much shorter period of time.[2]]

✓ ✗ I have explained that the recent divergence of these species through mutations in regular genes is unlikely.[1]

✓ ✗ I have explained why a master gene is a more likely explanation for jaw formation.[2]

c [The *BMP4* gene encodes a signalling protein responsible for jaw formation in cichlids. Jaw shape varies depending on the amount of *BMP4* that is expressed during embryonic development.[1]][This variation in jaw shape and length in cichlid populations led to different phenotypes that are acted upon by natural selection.[2]][Cichlids with different jaw shapes adapted to different niches in the lakes of Africa resulting in adaptive radiation.[3]][Different jaw types are better adapted to different dietary niches within each lake, resulting in the current diversity.[4]]

✓ ✗ I have explained the molecular mechanism for *BMP4* in jaw formation in cichlids.[1]

✓ ✗ I have explained that *BMP4* expression varies within cichlids.[2]

✓ ✗ I have explained how variation in *BMP4* expression led to adaptive radiation in cichlids.[3]

✓ ✗ I have referred to the scenario in my response.[4]

Key science skills

12 a [The independent variable is the presence or absence of the master gene.[1]][The dependent variable is the amount of movement of bacteria.[2]]

✓ ✗ I have stated the correct independent variable.[1]

✓ ✗ I have stated the correct dependent variable.[2]

b i [Hypothesis 2 is less likely because it involves mutations occurring in several different genes, which is incredibly unlikely to occur after only four days of bacterial growth.[1]][Hypothesis 1 is a more likely explanation since only one gene needs to be mutated to become a master gene.[2]][Therefore, hypothesis 1 is the more likely explanation.[3]]

✓ ✗ I have explained why hypothesis 2 is unlikely.[1]

✓ ✗ I have explained why hypothesis 1 is more likely.[2]

✓ ✗ I have concluded the correct hypothesis.[3]

ii [Food supply should be kept constant in all dishes between the two strains. The experiment should be repeated under the exact same environmental conditions (e.g. temperature, humidity, food supply) to ensure consistency between experimental outcomes.[1]]

Other acceptable responses include:

- Dishes should be kept in sterile conditions to ensure they are not contaminated by foreign bacteria.
- Amount of bacteria added to each dish should be constant.
- Timepoints for each observation should be the same.

✓ ✗ I have described two suitable controls.[1]

Chapter 13 Review

SECTION A

1	C	**2**	A	**3**	C	**4**	A
5	C	**6**	B	**7**	D	**8**	B
9	C	**10**	C	**11**	A	**12**	D
13	D						

SECTION B

14 a [Selection pressures such as food availability[1]][will cause bats that are more adapted to feeding on certain food sources to have a survival advantage.[2]][If this advantage has a genetic basis,[3]][they will pass on their alleles to the next generation[4]][and over time the frequency of the advantageous allele will increase in the gene pool.[5]]

✓ ✗ I have identified a selection pressure such as food availability or feeding location.[1]

✓ ✗ I have stated that better adapted bats will have an advantage.[2]

✓ ✗ I have specified the advantageous phenotype must be heritable.[3]

✓ ✗ I have stated that alleles from adapted bats are more likely to be passed on.[4]

✓ ✗ I have stated that these advantageous alleles will increase in frequency in the gene pool.[5]

✓ ✗ I have referred to the scenario in my response.

b i [Mexican long-tongued bat.[1]]

✓ ✗ I have identified the correct species.[1]

ii [This bat feeds in narrow spaces with small gaps,[1]][so a shorter echolocation signal would allow the bat to detect nearby objects.[2]]

Other acceptable responses include:

- Since these bats don't eat insects, they don't need a longer echolocation signal to detect prey that is far away.
- A shorter signal is less likely to be heard by predators.

✓ ✗ I have used information from the scenario in my response.[1]

✓ ✗ I have given a reasonable explanation for the shorter echolocation signal being advantageous.[2]

c [Velvety free-tailed bat.[1]]

✓ ✗ I have identified the correct species.[1]

d [The biologist could compare the DNA sample from the unknown bat to the other bats using DNA hybridisation or they could compare nucleotide differences between DNA sequences.[1]]

Other acceptable responses include:

- They could compare nucleotide differences between mtDNA sequences.

✓ ✗ I have stated two ways the biologist could determine species identity using DNA.[1]

15 a [Red-naped snakes and golden-crowned snakes.[1]]

✓ ✗ I have identified the two correct species.[1]

b [Broad-headed snakes, tiger snakes, and white-lipped snakes.[1]]

✓ ✗ I have identified the three correct species.[1]

c [The temperature at which half the DNA becomes single-stranded indicates how similar the two sequences are[1]][and the higher the temperature the more recently the two species shared a common ancestor.[2]]

✓ ✗ I have explained what the melting temperature means.[1]

✓ ✗ I have explained what temperature suggests about relatedness.[2]

16 a [Mitochondrial DNA sequences could be compared between species.[1]][If the mutation rate is known,[2]][the number of mutations that accumulate within mtDNA may indicate time since divergence.[3]]

Other acceptable responses include:

- The number of mutations that accumulate in nuclear DNA between species may indicate time since divergence.
- The number of amino acid differences that accumulate between species may indicate time since divergence.
- Scientists could use DNA hybridisation to estimate how related the species are – the less similar their DNA the longer ago they diverged.
- Fossil or stratigraphic evidence such as the sequence of fossils may indicate divergence time.

✓ ✗ I have identified a technique that could be used.[1]

✓ ✗ I have specified that the mutation rate is needed.[2]

✓ ✗ I have explained how this technique could estimate divergence time.[3]

b i [Adaptive radiation is a process in which a number of different species rapidly diverge from a common ancestor in a relatively short period of time.[1]]

✓ ✗ I have defined adaptive radiation.[1]

ii [Although new species are formed, the number of mutations that have accumulated between them will have been small[1]][due to the recent divergence.[2]][As a result, it will be harder to distinguish between species since these differences are vital for determining relatedness using molecular homology.[3]]

✓ ✗ I have stated that the number of mutations between species will be small.[1]

✓ ✗ I have explained that this is due to the recent divergence.[2]

✓ ✗ I have stated that this makes it difficult to determine relatedness using molecular homology.[3]

✓ ✗ I have signposted my response using terms such as: as a result, this results in.

iii [The *BMP4* gene encodes a signalling molecule[1]][that is responsible for controlling jaw formation in African cichlid fish.[2]][Since *BMP4* controls the expression of many other genes,[3]][slight changes in *BMP4* expression in the embryo can drastically change the jaw shape.[4]][The accumulation of mutations in the *BMP4* gene over a short period of time has allowed diversity in jaw shape and length to develop, resulting in the variety of the current cichlid population.[5]]

✓ ✗ I have referred to BMP4 as a signalling molecule or *BMP4* as a master gene.[1]

✓ ✗ I have identified that *BMP4* controls jaw formation.[2]

✓ ✗ I have explained that *BMP4* controls the expression of other genes.[3]

✓ ✗ I have described the effect of *BMP4* on phenotype.[4]

✓ ✗ I have explained how mutations in *BMP4* have resulted in adaptive radiation in African cichlids.[5]

17 a [*Isurus paucus*.[1]]

✓ ✗ I have stated the correct species.[1]

b i [The model that suggests that the mutation rate can be used to determine relatedness between two organisms.[1]]

✓ ✗ I have defined the molecular clock.[1]

ii [Mitochondrial DNA has a higher mutation rate than nuclear DNA and mitochondrial DNA does not undergo recombination.[1]]

Other acceptable responses include:

- While nuclear DNA is inherited from both parents, mitochondrial DNA is inherited only from the mother, making it easier to trace lineages with mtDNA.

✓ ✗ I have given two advantages of using mitochondrial DNA.[1]

✓ ✗ I have used comparative language such as: higher.

c [These results are unexpected since more nucleotide changes typically indicates more distant relatedness.[1]][These results are likely due to a limitation of the molecular clock model.[2]][Mutation rates are not always constant and may vary between species[3]][which may explain why *Perca fluviatilis* and *Ichthyosaura alpestris* have the same number of nucleotide differences but *I. alpestris* is more closely related to humans. In this case, *I. alpestris* has a higher mutation rate than *P. fluviatilis*.[4]]

Other acceptable responses include:

- The different groups may have experienced different selection pressures that would have influenced the mutation rate of these two species.

✓ ✗ I have explained why these results are unexpected.[1]

✓ ✗ I have referred to the molecular clock model.[2]

✓ ✗ I have identified that the mutation rate varies.[3]

✓ ✗ I have explained a limitation of the molecular clock model for determining relatedness between *I. alpestris*, *P. fluviatilis*, and humans.[4]

d [Using multiple regions of the genome would increase the amount of data[1]][and would reduce the likelihood of any results that are due to chance.[2]]

✓ ✗ I have identified that this would increase the amount of data.[1]

✓ ✗ I have identified that the likelihood of results being due to chance is reduced.[2]

14A Defining 'human'

Theory review questions

1 **a** Bipedal **b** Mammals
c Primates **d** Prehensile
e Hominins

2 C **3** B

4 A **5** D

Exam-style questions

Within lesson

6 C **7** C **8** B **9** D

10 B **11** A **12** B

13 **a** [Two features that identify this skull as a hominoid skull are its cranium size, which is larger than other primates, and its Y5 molar teeth, which are unique to hominoids.[1]]

✓ ✗ I have stated two features that are unique to the hominoid superfamily of primates.[1]

✓ ✗ I have used comparative language such as: larger.

b [Hominoids have a broad rib cage and do not have a tail.[1]] [These features indicate they are more closely related to *Homo sapiens* than other primate species.[2]]

Other acceptable responses include:

- Hominoids have a shorter spine between the rib cage and pelvis.

✓ ✗ I have stated two structural features that are present in hominoids.[1]

✓ ✗ I have stated that these features indicate they are more closely related to *Homo sapiens*.[2]

14 **a** [Binocular vision, prehensile hands, and an opposable thumb.[1]]

Other acceptable responses include:

- Sensitive fingertips.
- Flat fingernails.
- Flexible spine.
- Mobile shoulder joints.
- Relatively large cranium for body weight.
- Forward-facing eyes.

✓ ✗ I have identified three features of primates.[1]

b [The species would not be classified as a primate.[1]] [This is because in order to be classified as a primate a species needs to have a number of primate features, not just one.[2]]

✓ ✗ I have stated that the species would not be classified as a primate.[1]

✓ ✗ I have explained why the species would not be classified as a primate.[2]

15 **a** [Skeleton 1 is the hominin skeleton.[1]]

✓ ✗ I have correctly stated which skeleton is the hominin skeleton.[1]

b

Skeletal	Differences	Significance
1. Pelvis	Hominins have more bowl-shaped pelvis compared to hominoids.	This provides support for the upper body of hominins while walking upright.
2.Spine	Hominins have an S-shaped whereas hominoids have a C-shaped spine.	This allows hominins to stay upright for extended periods of time.

Other acceptable responses include:

Skeletal	Differences	Significance
Foot	Hominin feet have two arches and a larger heel compared to hominoids.	This makes upright locomotion more energy-efficient for hominins.
Rib cage	Hominins have a more barrel-shaped rib cage compared to hominoids.	This allows hominins to remain upright for longer periods of time.
Angle of femur	Hominins have a greater angle of femur compared to hominoids	This increases stability when walking and standing upright for hominins

✓ ✗ I have completed the table appropriately.

✓ ✗ I have used comparative language such as: compared, whereas.

✓ ✗ I have used appropriate biological terminology such as: bowl-shaped pelvis, S-/C-shaped spine, barrel-shaped rib cage, angle of femur.

Multiple lessons

16 D **17** A

Key science skills

18 **a** [Chimpanzee.[1]]

✓ ✗ I have identified which species is most closely related to humans.[1]

b [DNA sequences from the same gene are compared between two species.[1]] [Changes in the sequence from one nucleotide to another accumulate over time[2]] [and so more nucleotide changes indicate more distant relatedness.[3]]

✓ ✗ I have stated that the same gene from each species are compared.[1]

✓ ✗ I have stated that nucleotide changes accumulate over time.[2]

✓ ✗ I have identified that more nucleotide changes indicate more distant relatedness.[3]

c [Skeletal structure/morphology.[1]]

✓ ✗ I have identified another type of information that could be obtained from the skeletons.[1]

d [Systematic error.[1]]

✓ ✗ I have correctly identified the type of error that has taken place.[1]

14B The last 3.6 million years of human ancestors

Theory review questions

1 **a** *Australopithecus* **b** Bipedal
c Brow ridge **d** Foramen magnum
e Bowl **f** *Homo neanderthalensis*
g Cultural evolution

2 C **3** A
4 A **5** D
6 B

Exam-style questions

Within lesson

7 B **8** A **9** D **10** B
11 C **12** C **13** D **14** A
15 D **16** D

17 **a** [The skull would have a heavier brow ridge and relatively small braincase.[1]]

Other acceptable responses include:

- A more sloped face.
- A less parabolic jaw (U-shaped jaw).
- A less central foramen magnum.
- Larger teeth.
- No chin.
- More prognathic/protruding jaw.

✓ ✗ I have stated two features that are characteristic of *Australopithecus* but absent in *Homo*.[1]

✓ ✗ I have used comparative language such as: heavier.

b **i** [Yes, it would be bipedal[1]][because it was only from 2 million years ago and bipedalism evolved in hominins 4 million years ago.[2]]

✓ ✗ I have stated that the species is bipedal.[1]

✓ ✗ I have explained my answer with reference to the timeframe that hominins diverged.[2]

✓ ✗ I have referred to the scenario in my response.

ii [A bowl-shaped pelvis is a structural feature of bipedalism[1]][as it provides upright hominins with more support whilst walking on two legs.[2]][A central foramen magnum is also a structural feature of bipedalism,[3]][and made it easier for hominins to hold their heads upright and look forwards whilst walking upright on two legs.[4]]

Other acceptable responses include:

- Short arm to leg ratio, as less time was spent in trees and more time walking/running.
- The femur set at a valgus angle between the knee and hip, to help with balance and support as the feet are in the middle of the body.
- An S-shaped spine, to support upright walking.
- Larger heel, to make bipedalism less impactful to the foot.
- Toes aligned, as no longer need to grasp branches.
- Non-grasping feet, as no longer need to grasp branches.

✓ ✗ I have identified a first structural feature that is indicative of bipedalism.[1]

✓ ✗ I have explained the role in bipedal locomotion for the first structural feature.[2]

✓ ✗ I have identified a second structural feature that is indicative of bipedalism.[3]

✓ ✗ I have explained the role in bipedal locomotion for the second structural feature.[4]

iii [Bipedalism freed the hands for toolmaking and enabled individuals to see above vegetation to scan for predators.[1]]

Other acceptable responses include:

- Carry young.
- Reach higher food.
- Engage in cultural activities and rituals.

✓ ✗ I have identified two ways that bipedalism changed behaviour.[1]

✓ ✗ I have made sure that I have not discussed ways that bipedalism affected physiology or function.

Multiple lessons

18 D

19 **a** [Opposable thumbs allow primates to make grasping movements and hold both 'precision' and 'power' grips.[1]][Furthermore, opposable thumbs enabled hominins to develop fine motor skills and make tools.[2]]

✓ ✗ I have stated what movements opposable thumbs enable.[1]

✓ ✗ I have stated functional and cultural consequences of opposable thumbs for hominins.[2]

b [Among the ancestors of *Homo floresiensis*, variation in height would have existed.[1]][Moreover, height would have been a heritable trait.[2]][On the Indonesian island where they lived, there would have been a selection pressure[3]][that made it advantageous for *H. floresiensis* to be short.[4]][Perhaps the selection pressure was that they used less energy with smaller bodies, so didn't need to eat as much when food was limited.[5]][Over time, shorter *H. floresiensis* would have had more offspring than taller *H. floresiensis*, leading to an overall smaller population.[6]][In comparison, *H. sapiens* and *H. neanderthalensis* would have been exposed to different selection pressures that made it advantageous to be taller.[7]]

- I have stated that variation in height existed in the ancestral population.[1]
- I have stated that this variation was heritable.[2]
- I have explained that there would have been a selection pressure acting on the population.[3]
- I have explained that some individuals were fitter than others under this selection pressure.[4]
- I have suggested a possible selection pressure.[5]
- I have explained what would happen to the population's average height over time.[6]
- I have compared this to *H. sapiens* and *H. neanderthalensis*.[7]
- I have signposted my response using terms such as: moreover, over time, in comparison.

c [There is evidence that *H. floresiensis* could hunt large animals and use stone tools.[1]][Neither of these would be possible without high levels of cooperation and communication, including passing knowledge on to new generations.[2]]

- I have identified two pieces of evidence for well-developed communication and social cooperation.[1]
- I have explained why these are indicators of well-developed communication and social cooperation.[2]

Key science skills

20 a [There would be no *H. neanderthalensis* DNA in modern African *H. sapiens*.[1]][This is because, while they shared a common ancestor, the two species did not interbreed.[2]]

- I have stated that they would not share DNA.[1]
- I have explained why they would not share DNA.[2]

b [Scientists could have used the mitochondrial DNA (mtDNA) molecular clock to construct this phylogenetic tree.[1]][The mtDNA sequence between Neanderthals, African humans, and non-African humans could be compared.[2]][More differences in mtDNA sequences indicates more distant relatedness, so humans would have less mtDNA differences between each other than with Neanderthals, showing they are more closely related.[3]]

Other acceptable responses include:

- Nuclear DNA.
- DNA hybridisation.

- I have suggested a technique to build phylogenies.[1]
- I have explained how the technique works.[2]
- I have stated how the technique reveals relatedness.[3]

14C Interpreting the human fossil record

Theory review questions

1 a *Homo neanderthalensis*
b Out of Africa hypothesis
c interbreeding, or crossbreeding
d *Homo denisova*

2 B
3 B
4 C
5 D
6 A

Exam-style questions

Within lesson

7 C
8 B
9 C
10 D
11 B

12 a [Since the *Homo luzonensis* fossils aren't well preserved[1]][this mixture of features may be a misinterpretation of the actual morphology of *Homo luzonensis*.[2]]

Other acceptable responses include:

- These traits may be analogous structures that have evolved independently in *Homo luzonensis* and other hominin species.
- *Homo luzonensis* may share traits with multiple hominin species because it is a transitional fossil between them.

- I have identified a characteristic of the *H. luzonensis* fossils.[1]
- I have given a reasonable explanation for the anatomy of *Homo luzonensis*.[2]

b [The *Homo floresiensis* fossils were astonishing because they resembled *Australopithecus* in morphology, suggesting relatedness.[1]][This is unexpected for two reasons. Firstly, *H. floresiensis* was dated to between 60 000 and 100 000 years ago, which is after the extinction of *Australopithecus* that is hypothesised to have occurred around 2 million years ago.[2]][Secondly, *H. floresiensis* was found in Flores in eastern Indonesia whereas *Australopithecus* is only known from sub-Saharan Africa.[3]]

- I have stated the similarity to *Australopithecus* suggests relatedness.[1]
- I have described the difference in age.[2]
- I have described the difference in geographic range.[3]
- I have referred to the scenario using terms such as: firstly, secondly.

c

Evidence	Justification	Limitation
1. Fossil anatomy	The teeth and bones don't resemble any other single hominin species, suggesting a new species.	The fossils were scarce and poorly preserved, hard to draw conclusions from this little evidence.

2. Uranium-series dating	The fossils were dated to around 50 000 years ago, and look unlike any other hominins from that period and location, suggesting it's a new species.	Uranium-series dating can be unreliable when dating bones and teeth.

- I have filled in the table completely.
- I have referred to the text in each justification and limitation.
- I have used appropriate biological terminology such as: suggests, supports, hominin, dating.

Multiple lessons

13 a [Scientists could compare DNA from a known Neanderthal to the human genome using molecular homology.[1]] [Regions with incredibly high sequence homology indicate regions of Neanderthal DNA within the human genome.[2]]

- I have suggested molecular homology using DNA.[1]
- I have explained that high sequence homology indicates Neanderthal DNA.[2]

b [Interbreeding occurred between *H. neanderthalensis* and ancestors of present-day European, East Asian, and Australian Aboriginal *H. sapiens*.[1]] [DNA was exchanged between each species[2]] [via gene flow[3]] [and was passed from one generation to the next.[4]]

- I have stated that interbreeding occurred between *H. neanderthalensis* and non-African *H. sapiens*.[1]
- I have stated that DNA was exchanged between these two species.[2]
- I have identified that gene flow occurred.[3]
- I have stated that this exchanged DNA is inherited.[4]
- I have not identified this as genetic drift.

c i [The Out of Africa hypothesis is supported by this evidence since Neanderthals would have interbred with *H. sapiens* that migrated into Eurasia from Africa.[1]] [This Neanderthal DNA would have remained in this group of humans as they colonised Europe, Asia, and Australia.[2]] [to create the populations seen in the diagram.[3]]

- I have stated that Neanderthals interbred with *H. sapiens* in Eurasia.[1]
- I have explained how modern *H. sapiens* diverged from this Eurasian ancestor.[2]
- I have linked my explanation to the data.[3]

ii [The DNA evidence does not support the multiregional hypothesis since interbreeding between Neanderthals and *H. sapiens* would have to have occurred independently between European, East Asian and Australian Aboriginal *H. sapiens* populations, which is unlikely.[1]] [Furthermore, there is no evidence of Neanderthals ever being found in Australia.[2]]

- I have explained that multiple independent interbreeding events would need to have occurred to support the other hypothesis.[1]
- I have explained that lack of Neanderthal fossils in Australia does not support the other hypothesis.[2]

Key science skills

14 a [Suggests *Homo sapiens* and Denisovans are not different species since they could interbreed.[1]]

- I have stated the correct implication.[1]

b [Denisovan DNA is not present in African *H. sapiens* because the two populations did not interbreed.[1]] [However, Denisovans did interbreed with the ancestors of modern-day Asian and Australian *H. sapiens*, which explains the presence of Denisovan DNA in their genomes.[2]]

- I have explained the absence of Denisovan DNA in African *H. sapiens*.[1]
- I have explained the presence of Denisovan DNA in Asian and Australian *H. sapiens*.[2]

c [Interbreeding between *H. sapiens* and Denisovans occurred twice independently, once in East Asia and again in Papua New Guinea.[1]] [This is evident because, firstly, the different amounts of Denisovan DNA in Papua New Guineans and East Asians may be due to different amounts of DNA being exchanged through two separate interbreeding events.[2]] [Secondly, the higher similarity of Siberian Denisovan DNA to the DNA in the East Asian genome compared to the DNA in the Papua New Guinean genome suggests less divergence between the exchanged genetic material.[3]] [This would mean the interbreeding event with East Asians occurred more recently, and therefore separately, than the Papua New Guinean interbreeding event.[4]]

- I have suggested that two separate interbreeding events occurred.[1]
- I have explained how the first finding suggests separate interbreeding events.[2]
- I have explained how the second finding suggests an earlier interbreeding event.[3]
- I have inferred that this more recent interbreeding event would have been separate.[4]
- I have signposted my response by using terms such as: firstly, secondly.
- I have used comparative language such as: higher, compared to, fewer.

d [This DNA could belong to another unidentified hominin species that humans interbred with in the past.[1]]

Other acceptable responses include:

- These sequences could simply be DNA from Neanderthals or Denisovans that have mutated to become unrecognisable.

- I have given a reasonable explanation.[1]

Chapter 14 Review

SECTION A

1	C	**2**	D	**3**	B
4	C	**5**	B	**6**	B
7	D	**8**	C	**9**	A

SECTION B

10 a [Species 2.[1]]

✓ ✗ I have identified which species is more closely related to *Homo sapiens*.[1]

b [Species 2 doesn't have a tail.1]

Other acceptable responses include:

Species 2 has a larger skull.

Species 2 has a shorter spine between the rib cage and pelvis.

Species 2 has longer arms than legs.

✓ ✗ I have identified one feature of skeleton 2.[1]

c [Species 2 would most likely have sat upright.[1]][This is suggested by the width of the rib cage.[2]]

Other acceptable responses include:

- The lack of a tail.
- A shorter spine between the rib cage and pelvis.

✓ ✗ I have identified that species 2 would likely have sat upright.[1]

✓ ✗ I have stated a feature of the skeleton that indicates the primate would have sat upright.[2]

11 a [Firstly, the pelvis shape in hominins is more bowl-shaped compared to the longer, more narrow pelvis of primates. Secondly, hominins have an S-shaped spine, whereas other primates have a C-shaped spine.[1]]

Other acceptable responses include:

- The foramen magnum has become more central.
- The ribcage has become more barrel-shaped.
- The arm-leg ratio has decreased.
- The foot arch has increased.
- The big toe has become more protruding.
- The heel size has increased.

✓ ✗ I have correctly identified two structural changes.[1]

✓ ✗ I have used comparative language such as: compared, whereas.

✓ ✗ I have signposted my response using terms such as: firstly, secondly.

b [One behavioural effect of bipedalism in hominins is that they carried their young.[1]][This was possible because becoming bipedal meant hominin hands became free.[2]][Another behavioural effect of bipedalism in hominins is that they could raise their head to scan for predators.[3]][This was possible because standing on two legs gave them extra height.[4]]

Other acceptable responses include:

- Toolmaking due to free hands.
- Reaching higher food due to increased height.
- Engaging in artistic pursuits due to free hands.
- Spend longer time in the open foraging and hunting due to energy-saving bipedal movement.
- Cooking due to free hands.
- Use of fire due to free hands.

✓ ✗ I have identified one behavioural effect of bipedalism.[1]

✓ ✗ I have explained how becoming bipedal led to this behaviour.[2]

✓ ✗ I have identified a second behavioural effect of bipedalism.[3]

✓ ✗ I have explained how becoming bipedal led to this behaviour.[4]

✓ ✗ I have signposted my response using terms such as: one, another.

12 a [A less central foramen magnum and a smaller braincase.[1]]

Other acceptable responses include:

- A more sloped face.
- A larger brow ridge.
- More prognathic/protruding jaw.
- A less parabolic jaw (U-shaped jaw).
- Larger teeth.
- No chin.

✓ ✗ I have stated two features that distinguish the genuses *Homo* and *Australopithecus*.[1]

✓ ✗ I have used comparative language such as: less, more, smaller, larger.

b i [Based on the diagram, the earliest appearance of the genus *Homo* was just over 2 million years ago with the species *Homo habilis*.[1]][If *Homo naledi* were a 'link' between the *Australopithecus* genus and the *Homo* genus then it would need to have existed before *Homo habilis*, over 2 million years ago and after the first appearance of *Australopithecus* over 4 million years ago.[2]][This explanation matches the first group of scientists' dating of *H. naledi* fossils to be over 2 million years old, and supports their hypothesis that *H. naledi* is a 'link'.[3]]

✓ ✗ I have stated that the first appearance of the *Homo* genus was over 2 million years ago.[1]

✓ ✗ I have stated when *H. naledi* must have existed for it to be a link between *Homo* and *Australopithecus*.[2]

✓ ✗ I have shown the link between the scientists' dating of the fossils and the diagram.[3]

✓ ✗ I have referred to the figure in my response.

✓ ✗ I have used appropriate biological terminology such as: hypothesis, supports, *Homo*.

ii [Comparison of mtDNA sequences[1]][between *Homo neanderthalensis* and *Homo sapiens* from Eurasian and African populations.[2]][Such a comparison would reveal that *Homo neanderthalensis* and Eurasian *Homo sapiens* share sequences that are not found in African *Homo sapiens*,[3]][suggesting interbreeding between *Homo neanderthalensis* and Eurasian *Homo sapiens*.[4]]

Other acceptable responses include:

- Comparing Nuclear DNA.
- DNA hybridisation.

✓ ✗ I have suggested an appropriate method.[1]

✓ ✗ I have suggested a comparison between *Homo neanderthalensis*, Eurasian *Homo sapiens*, and African *Homo sapiens*.[2]

✓ ✗ I have explained the results of such an experiment.[3]

✓ ✗ I have explained how this evidence would support the hypothesis.[4]

13 a [Skull B.[1]]

✓ ✗ I have correctly identified the gorilla skull.[1]

b [The presence of a sagittal crest, relatively smaller cranial capacity, and larger canine teeth.[1]]

Other acceptable responses include:

- A less central foramen magnum.
- A larger brow ridge.
- A U-shaped/rectangular dental arch.

✓ ✗ I have identified three features of the gorilla skull that differentiate it from the *Homo sapiens* skull.[1]

✓ ✗ I have used comparative language such as: more, larger.

14 a [A more posterior foramen magnum and a relatively smaller braincase.[1]]

Other acceptable responses include:

- A more prominent brow ridge.
- A more U-shaped dental arch.
- Larger canine and molar teeth.
- A less central foramen magnum.

✓ ✗ I have identified two features of the skull that would indicate it belonging to *Australopithecus* and not *Homo*.[1]

✓ ✗ I have used comparative language such as: more, relatively.

✓ ✗ I have not included features common to all primates in my response.

b [A more C-shaped spine and a larger arm-leg ratio.[1]]

Other acceptable responses include:

- A more funnel-shaped ribcage.
- A longer, more narrow pelvis.
- A flatter foot.
- A less protruding big toe.
- A small heel.

✓ ✗ I have identified two non-skull features that would indicate it belonging to *Australopithecus* and not *Homo*.[1]

✓ ✗ I have used comparative language such as: more, larger.

✓ ✗ I have not included features common to all primates in my response.

15 a [Longer arms and prehensile feet.[1]]

✓ ✗ I have identified two skeletal features.[1]

b [The cranial capacity of the fossil's skull.[1]][This suggests that the species would have had a large brain and would have been capable of language,[2]][which is a key component of cultural evolution.[3]]

✓ ✗ I have identified a feature of the fossil.[1]

✓ ✗ I have explained what the identified feature implies about the species' cognitive capacity.[2]

✓ ✗ I have related this back to the process of cultural evolution.[3]

c [Using the molecular clock model to compare nucleotide sequences between the three species would indicate their relatedness.[1]][Comparing the genomes of each species with each other using DNA hybridisation would also indicate their relatedness.[2]]

Other acceptable responses include:

- Using the molecular clock model to compare amino acid sequences between the three species would indicate their relatedness.
- Comparing homologous or vestigial structures may give an indication of their relatedness.
- Finding fossil evidence of a common ancestor and dating it would give an indication of the relationship between the three species.

✓ ✗ I have stated one method that could be used to determine relatedness between the three species.[1]

✓ ✗ I have stated second method that could be used to determine relatedness between the three species.[2]

d [Interbreeding resulting in the creation of fertile offspring may have occurred between bonobos and *P. t. troglodytes* and *P. t. schweinfurthii*.[1]][Firstly, the map shows the bonobos, *P. t. troglodytes*, and *P. t. schweinfurthii* live in adjacent areas, so it's possible that individuals may have met and successfully mated.[2]][Additionally, one percent of these two chimpanzee subspecies genomes is shared with bonobos, suggesting an exchange of genetic material.[3]]

✓ ✗ I have stated a hypothesis that explains the shared DNA.[1]

✓ ✗ I have used geographic evidence to support the hypothesis.[2]

✓ ✗ I have used genetic evidence to support the hypothesis.[3]

✓ ✗ I have signposted by response using words such as: firstly, additionally.

BONUS – CARTOON QUESTION ANSWERS

Multiple choice questions

1 D. a shorter, bowl-shaped pelvis

2 C. language

Short answer questions

3 [Bipedalism allowed the ancestors of Homo douchensis to reach higher food while foraging [1]] [and engage in cultural activities such as making art.[2]]

Other acceptable responses include:

- Carry young.
- Freed hands for toolmaking.
- See above vegetation to search for predators and food.

✓ ✗ I have identified one ways that bipedalism changed behaviour.[1]

✓ ✗ I have identified a second way that bipedalism changed behaviour.[2]

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4 [Among the ancestors of *Homo douchensis*, variation in cranial capacity would have existed.[1]][Moreover, cranial capacity would have been a heritable trait.[2]][In the environment of *Homo douchensis*' ancestors there would have been a selection pressure[3]] [that made it advantageous for *Homo douchensis* to be capable of abstract thinking, which required a larger cranial capacity.[4]][Over time, ancestors of *Homo douchensis* with larger cranial capacities would have had more offspring, leading to the large cranial capacity of *Homo douchensis* we see today.[5]]

✓ ✗ I have stated that variation in cranial capacity existed in the ancestral population.[1]

✓ ✗ I have stated that this variation was heritable.[2]

✓ ✗ I have explained that there would have been a selection pressure acting on the population.[3]

✓ ✗ I have explained that some individuals were fitter than others under this selection pressure.[4]

✓ ✗ I have explained what would have to the population's average cranial capacity over time.[5]

✓ ✗ I have signposted my response using terms such as: moreover, over time.

15A Enzymes that cut, paste, and multiply DNA

Theory review questions

1 **a** Polymerases **b** Sticky end
c Ligases **d** Restriction enzymes
e Recognition site **f** Blunt end

2 D **3** C

4 B **5** B

Exam-style questions

Within lesson

6 C **7** B **8** C **9** A

10 **a** [To act as molecular scissors that cut phosphodiester bonds along nucleic acid strands[1]][at a specific recognition site.[2]]

✓ ✗ I have stated the role of restriction enzymes.[1]

✓ ✗ I have identified where they operate.[2]

b [Four.[1]]

✓ ✗ I have identified the number of fragments produced.[1]

c [10, 20, 30, and 40 [1]][kbp.[2]]

✓ ✗ I have identified the four fragment lengths.[1]

✓ ✗ I have given my answer in kilobase pairs.[2]

Multiple lessons

11 **a** [Transcription.[1]]

✓ ✗ I have identified the correct process.[1]

b [The ribosome binds to and reads the mRNA, initiating translation.[1]] [The tRNA delivers specific amino acids to the ribosomes, as prescribed by the order of codons on the mRNA.[2]][Amino acids are joined by condensation polymerisation, elongating into a polypeptide chain.[3]][Once the stop codon is reached, the translation is terminated and the GFP polypeptide chain is released.[4]]

✓ ✗ I have stated that the ribosome binds to and reads the mRNA.[1]

✓ ✗ I have explained that tRNA delivers amino acids to the ribosomes.[2]

✓ ✗ I have identified how amino acids are joined.[3]

✓ ✗ I have described the termination process.[4]

✓ ✗ I have referred to GFP in my response.

✓ ✗ I have used appropriate biological terminology such as: mRNA, tRNA, ribosome, codon, amino acid, elongation, termination, initiation.

c [Restriction enzymes (endonucleases).[1]]

✓ ✗ I have identified the correct enzyme.[1]

d [To join fragments of DNA together by catalysing the formation of phosphodiester bonds between nucleotides to form the sugar-phosphate backbone.[1]]

✓ ✗ I have identified the role of DNA ligase.[1]

Key science skills

12 **a** [Polymerase.[1]]

✓ ✗ I have identified the correct enzyme.[1]

b **i** [Sticky end restriction enzymes cleave DNA with overhanging additional nucleotides.[1]][The overhanging nucleotides are attracted to unpaired complementary nucleotides on another sticky-ended fragment so[2]][they can join two target fragments together in the right orientation more easily.[3]]

✓ ✗ I have explained what sticky-end restriction enzymes do.[1]

✓ ✗ I have explained the effect of the overhanging nucleotides.[2]

✓ ✗ I have summarised how this is useful.[3]

ii [SalI, HindIII, and ClaI.[1]]

✓ ✗ I have stated the correct sticky end restriction enzymes.[1]

c **i** [The test tube without an enzyme acts as a control[1]][and shows that the changes in the other test tubes are due to the independent variable (restriction enzyme) rather than any confounding variables.[2]]

✓ ✗ I have labelled the test tube as a control.[1]

✓ ✗ I have explained the purpose of a control.[2]

✓ ✗ I have referred to the scenario in my response.

ii [The concentration and the volume of the restriction enzyme in each sample.[1]]

Other acceptable responses include:

- The temperature of each test tube during incubation must be the same.

✓ ✗ I have identified two controlled variables.[1]

NOTE: Saying 'same amount of DNA buffer solution' or 'the same incubation time' is not acceptable since Ahmed and Sunitha already considered it in the scenario.

iii [Sunitha is correct[1]][as one recognition site for HindIII is present in the DNA sample.[2]]

✓ ✗ I have named who is correct.[1]

✓ ✗ I have given evidence by referring to the number of recognition sites for HindIII in the sample.[2]

d **i** [They cannot identify the enzyme[1]][as its recognition site does not match any of the known samples that they completed.[2]]

✓ ✗ I have stated whether the enzyme can be identified.[1]

✓ ✗ I have explained that the recognition site is different to the other enzymes.[2]

✓ ✗ I have referred to the scenario in my response.

ii [The restriction enzyme must produce sticky ends as there are overhanging nucleotides.[1]][The recognition site for this enzyme is 5′ G G A T C C 3′ and the cut occurs between the two guanine nucleotides.[2]]

✓ ✗ I have identified the type of restriction enzyme.[1]

✓ ✗ I have stated the recognition site.[2]

15B Polymerase chain reaction

Theory review questions

1 **a** *Taq* polymerase **b** Primer **c** Denaturing stage **d** Annealing

2 A **3** C

4 D **5** C

Exam-style questions

Within lesson

6 C **7** A

8 **a** [Polymerase chain reaction.[1]]

✓ ✗ I have identified the method.[1]

b [DNA is heated to approximately 94 °C[1]][to denature and separate the strands.[2]]

✓ ✗ I have stated an approximate temperature for stage 1.[1]

✓ ✗ I have explained what happens to the DNA in stage 1.[2]

c [Primers are added to the mixture[1]][to bind to complementary nucleotide sequences of each single-stranded polynucleotide chain. This allows *Taq* polymerase to begin building a complementary strand.[2]]

✓ ✗ I have named these molecules.[1]

✓ ✗ I have explained the purpose of these molecules.[2]

d [Stage 3 must occur at 72 °C.[1]][This is the optimum temperature for *Taq* polymerase to elongate the strand of DNA.[2]]

✓ ✗ I have identified the temperature stage 3 must occur at.[1]

✓ ✗ I have explained why it must occur at a specific temperature.[2]

Multiple lessons

9 A **10** C

11 **a** [Polymerase chain reaction.[1]]

✓ ✗ I have named the process.[1]

b [*Taq* polymerase[1]][is required in the extending stage to bind complementary nucleotides to the single-stranded DNA.[2]]

Other acceptable responses include:

- A segment of DNA is required initially that then undergoes PCR to be amplified.
- A large supply of the four different nucleotide bases is required for *Taq* polymerase to create a new strand complementary to the single-strand.
- DNA primers are required to bind to single-stranded DNA to initiate the complementary strand and allow *Taq* polymerase to extend it.

✓ ✗ I have identified a substance required for PCR.[1]

✓ ✗ I have explained the purpose of the substance in PCR.[2]

c **i** [The process is DNA hybridisation.[1]][This involves heating DNA to 95 °C to break the hydrogen bonds between strands.[2]][Single strands from both species are then mixed together and cooled, allowing the two strands to form hydrogen bonds with each other, creating double-stranded hybrid DNA.[3]][Hybrid DNA is then reheated and the temperature at which half of the DNA becomes single-stranded is noted. This temperature is known as the melting temperature (T_m)[4]][and can be used to determine the relatedness of two species.[5]]

✓ ✗ I have identified the process.[1]

✓ ✗ I have described the denaturation stage.[2]

✓ ✗ I have described the hybridisation stage.[3]

✓ ✗ I have described the melting stage.[4]

✓ ✗ I have mentioned that the melting temperature is used to determine relatedness.[5]

✓ ✗ I have not explained the polymerase chain reaction in my response.

ii [*Homo sapiens*.[1]]

✓ ✗ I have stated the species that Ötzi belongs to.[1]

Key science skills

12 **a** **i** [Polymerase chain reaction.[1]]

✓ ✗ I have named the process.[1]

ii [In the denaturing stage, the mixture is heated to approximately 94 °C to denature the DNA and separate the strands.[1]][In the annealing stage, DNA is cooled to approximately 55 °C to allow primers to attach to the single-stranded DNA.[2]][In the extending stage, the DNA is heated to 72 °C and *Taq* polymerase copies the strands.[3]][The cycle is then repeated to produce more copies.[4]]

✓ ✗ I have explained the denaturing stage.[1]

✓ ✗ I have explained the annealing stage.[2]

✓ ✗ I have explained the elongation stage.[3]

✓ ✗ I have stated that the cycle is repeated.[4]

b i [Mohammad's method was unsuccessful,[1]][as the temperature he applied for the first step of PCR was far too low and would not have denatured the double-stranded DNA.[2]]

✓ ✗ I have identified whose method was unsuccessful.[1]

✓ ✗ I have justified my response.[2]

ii [Systematic error.[1]]

✓ ✗ I have identified the correct measurement error type.[1]

c [They must calibrate their machine so their temperatures are accurate.[1]]

Other acceptable responses include:

- Mutagens inducing mutations that change the DNA.
- Spontaneous mutations changing the DNA.
- Avoid contamination with other DNA samples.
- Account for heat loss.

✓ ✗ I have identified a possible factor that could influence the experiment.[1]

d [DNA primers join to their complementary nucleotide sequence in the specific segment of single-stranded DNA[1]][and allow *Taq* polymerase to start copying the DNA.[2]]

✓ ✗ I have stated that the primers bind to the end of the DNA.[1]

✓ ✗ I have explained how primers help *Taq* polymerase.[2]

15C Gel electrophoresis

Theory review questions

1 a Electrodes **b** Standard ladder
c Gel electrophoresis **d** Base pair (bp) or kilobase
e Ethidium bromide

2 A **3** B
4 D **5** D
6 C

Exam-style questions

Within lesson

7 D **8** A **9** D

10 a [Molecular size and charge.[1]]

✓ ✗ I have stated both properties.[1]

b i [The individuals corresponding to lanes 2 and 4 are homozygous for the D18S51 STR and so contain twice the amount of DNA for that allele, resulting in a thicker band.[1]][The lanes with two bands are heterozygous and so contain fragments of two different sizes.[2]]

✓ ✗ I have explained why there is only one band in some lanes.[1]

✓ ✗ I have explained why there are two bands in some lanes.[2]

✓ ✗ I have used appropriate biological terminology such as: heterozygous, homozygous.

ii [Four.[1]]

✓ ✗ I have stated the correct number of alleles.[1]

iii [Fragment A.[1]]

✓ ✗ I have stated the correct fragment.[1]

iv [Suspect in lane 6.[1]][The bands in this lane are identical to the bands in the blood sample found on the victim in lane 3.[2]]

✓ ✗ I have identified the correct suspect.[1]

✓ ✗ I have explained my reasoning.[2]

Multiple lessons

11 B **12** D **13** D
14 B **15** C **16** A

Key science skills

17 a [Blood sample 2.[1]]

✓ ✗ I have identified the correct blood sample.[1]

b [The blood samples could come from humans or other animals that the mammoth fought.[1]]

✓ ✗ I have proposed a likely hypothesis for the presence of blood samples.[1]

18 a i [Polymerase chain reaction.[1]]

✓ ✗ I have named the correct process for amplifying DNA.[1]

ii [The sample is heated to around 94°C in order to break down the hydrogen bonds in the DNA, denaturing it.[1]][DNA is then cooled to around 55°C to allow primers to bind to regions at either end of the region of interest.[2]][The sample is then heated to around 72°C to allow *Taq* polymerase to make a copy of the region of interest using the primer as a starting point.[3]][This doubles the amount of DNA in the sample. This process is repeated many times to amplify the DNA sample.[4]]

✓ ✗ I have described the denaturation stage of PCR.[1]

✓ ✗ I have described the primer binding (annealing) stage of PCR.[2]

✓ ✗ I have described the extension stage of PCR, mentioning *Taq* polymerase.[3]

✓ ✗ I have specified that this process must be repeated many times.[4]

- I have stated approximate temperatures for each of the three stages.
- I have signposted my response using terms such as: firstly, secondly.

b [It could be due to contamination of that sample.[1]]

- I have suggested contamination.[1]

c [Sample B is Riku's mother. Sample C is his maternal grandfather. Sample D is his father.[1]]

- I have correctly identified the three samples in the gel.[1]

d i [A standard ladder allows a researcher to measure the molecular size of a molecule[1]][by comparing it to a series of molecules of a known size.[2]]

- I have stated that standard ladders measure molecular size.[1]
- I have stated how standard ladders work.[2]

ii [No.[1]][In this experiment, the purpose is to compare the relatedness between individuals.[2]][This is achievable by simply observing whether bands of different individuals are the same size as each other or not. Exact measurements of base pair length wouldn't be necessary.[3]]

- I have stated that a ladder is not necessary.[1]
- I have stated the purpose of this experiment.[2]
- I have explained why a standard ladder is unnecessary for this experiment.[3]

15D Bacterial transformation

Theory review questions

1 a Gene of interest (or desired gene or insert DNA)
b Plasmid vector
c Transformation
d Reporter gene
e Antibiotic selection
f Recombinant plasmid

2 D
3 A
4 B
5 B

Exam-style questions

Within lesson

6 D
7 B
8 C
9 C
10 C

Multiple lessons

11 a ['Transform' refers to the uptake of a plasmid by a bacterium.[1]]

- I have stated that transformation is the uptake of plasmids by bacteria.[1]
- I have used appropriate biological terminology such as: plasmid, bacteria.

b i [Restriction enzymes are used to cut the plasmid vector[1]][and the gene of interest[2]][allowing the gene to be inserted into the plasmid.[3]]

- I have stated that the restriction enzymes cut the plasmid.[1]
- I have stated that the restriction enzymes cut the gene of interest.[2]
- I have explained that this makes it possible to insert the gene of interest into the plasmid.[3]
- I have used appropriate biological terminology such as: plasmid, vector.

ii [DNA ligase is used to insert the gene of interest into the plasmid vector to form a single piece of DNA.[1]]

- I have stated that DNA ligase inserts the gene of interest into the plasmid vector.[1]
- I have used appropriate biological terminology such as: plasmid, vector.

c [The scientists should observe colonies of transformed bacteria on the nutrient agar.[1]][Transformed bacteria should form colonies because they contain the *tcl* gene, conferring resistance to tetracycline in the culture.[2]][The untransformed bacteria would be unable to form colonies and die[3]][since they do not contain the *tcl* gene.[4]]

- I have stated that transformed bacteria would form colonies.[1]
- I have explained why transformed bacteria would form colonies.[2]
- I have stated that untransformed bacteria would not form colonies.[3]
- I have explained why untransformed bacteria would not form colonies.[4]
- I have used appropriate biological terminology such as: transformed, culture, resistance.

d [The genetic code is universal,[1]][meaning that a human gene can be expressed by bacteria, despite the gene coming from a different species.[2]]

- I have stated that the genetic code is universal.[1]
- I have explained the meaning of the term 'universal'.[2]

Key science skills

12 A
13 B
14 D

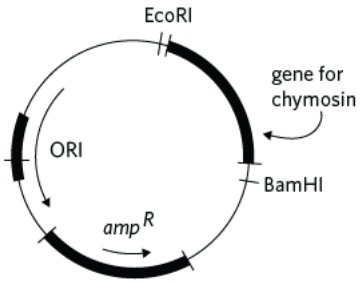
15 a [Non-pathogenic means this bacteria does not cause disease.[1]][Recombinant means the bacteria contains foreign DNA.[2]]

- I have explained the meaning of 'non-pathogenic'.[1]
- I have explained the meaning of 'recombinant'.[2]

b [Polymerase chain reaction.[1]]

✓ ✗ I have stated the polymerase chain reaction.[1]

c



✓ ✗ I have drawn the chymosin gene where the HindIII recognition site was located.

d [The vector in this experiment is the plasmid[1]][since it is needed to transport the chymosin gene into the bacteria.[2]]

✓ ✗ I have identified the plasmid as the vector.[1]

✓ ✗ I have justified my response by referring to a vector as a means of transferring a foreign gene into a cell.[2]

e i [The bacterial growth in plate A would form a lawn as the bacteria in this plate are untransformed bacteria, which readily grow on nutrient agar.[1]][There would be no growth on plate B. These bacteria have not been transformed and are not ampicillin-resistant, therefore they are unable to grow on ampicillin-containing nutrient agar.[2]][The bacterial growth in plate C would form a lawn. Both transformed and untransformed bacteria would be able to grow since this plate contains only nutrient agar.[3]][The bacteria in plate D would form colonies. Bacteria in these colonies have been transformed and contain the ampicillin-resistance gene and so will still be able to grow on ampicillin-containing agar. Untransformed bacteria would not survive since they do not contain the ampicillin-resistance gene.[4]][None of these results were unexpected.[5]]

✓ ✗ I have explained that all bacteria are able to grow on nutrient agar.[1]

✓ ✗ I have explained that untransformed bacteria are not able to grow on ampicillin-containing agar.[2]

✓ ✗ I have explained that all bacteria are able to grow on nutrient agar.[3]

✓ ✗ I have explained that transformed bacteria are able to grow on ampicillin-containing agar.[4]

✓ ✗ I have identified that none of the results were unexpected.[5]

✓ ✗ I have used appropriate biological terminology such as: lawn, colony, transformed.

ii [Plate D will contain only transformed bacteria[1]][since the ampicillin will kill off any untransformed bacteria.[2]]

✓ ✗ I have identified plate D.[1]

✓ ✗ I have justified my answer by referring to antibiotic selection.[2]

✓ ✗ I have not said plate C since it will contain both untransformed and transformed bacteria.

iii [Plates A and B are controls.[1]][Plate A shows that untransformed bacteria are able to grow on nutrient agar.[2]] [Plate B shows that untransformed bacteria are unable to survive on ampicillin-containing media, meaning that the bacterial colonies on plate D must be transformed bacteria.[3]][Both plates show that the results generated by plates C and D are due to the exposure to heat-shocked plasmids and not any other confounding variables.[4]]

✓ ✗ I have identified plates A and B as controls.[1]

✓ ✗ I have explained that the purpose of plate A is to show regular bacterial growth.[2]

✓ ✗ I have explained that the purpose of plate B is to show the effect of antibiotics on untransformed bacteria.[3]

✓ ✗ I have explained that the purpose of a control is to show that the independent variable is due to the dependent variable and not confounding variables.[4]

Chapter 15 Review

SECTION A

1	C	**2**	A	**3**	B	**4**	C
5	C	**6**	D	**7**	B	**8**	C
9	D	**10**	D	**11**	A	**12**	B
13	C	**14**	A	**15**	B		

SECTION B

16 a [Restriction enzyme.[1]]

Other acceptable responses include:

- Endonucleases.

✓ ✗ I have named the enzyme.[1]

b [In the denaturing stage, the mixture is heated to approximately 94 °C to break H bonds and denature the DNA, separating the strands.[1]][In the annealing stage, DNA is cooled to approximately 55 °C to allow primers to form H bonds with, and attach to, the single-stranded DNA.[2]][In the extending stage, the DNA is heated to 72 °C and *Taq* polymerase copies the strands by extending the primers.[3]][The cycle is then repeated to produce more copies.[4]]

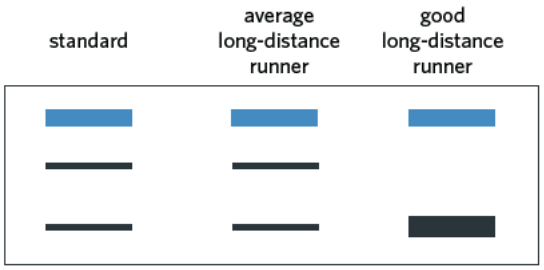
✓ ✗ I have explained the denaturing stage.[1]

✓ ✗ I have explained the annealing stage.[2]

✓ ✗ I have explained the extending stage.[3]

✓ ✗ I have stated that the cycle is repeated.[4]

17 a



- I have drawn a gel with wells at the top.
- I have labelled the three lanes.
- I have included the standard bands.
- I have drawn all bands in the correct place.

b [The average long-distance runner is heterozygous for the *577* allele and should have one band corresponding to each allele in the standard.[1]][The good long-distance runner is homozygous for the shorter *577X* allele and so should only show one band corresponding to the shorter fragment[2]][which is positioned further away from the well as shorter fragments travel faster.[3]]

- I have explained what a heterozygous lane looks like.[1]
- I have explained what a homozygous lane looks like.[2]
- I have stated that shorter fragments travel faster.[3]
- I have referred to the standard.
- I have used appropriate biological terminology such as: homozygous, heterozygous, fragment, allele.

c [The standard ladder contains the known alleles and shows the relative location of each allele on the gel.[1]][It is used to confirm which band corresponds to which allele.[2]]

- I have identified that the standard ladder shows the placement of the alleles on the gel.[1]
- I have explained that the standard is necessary to identify alleles.[2]

18 a [At 94 - 95 °C, the DNA will denature[1]][and the hydrogen bonds binding the two DNA strands break[2]][producing single-stranded DNA.[3]]

- I have stated that DNA will denature.[1]
- I have explained that the hydrogen bonds will break.[2]
- I have identified that single-stranded DNA will be produced.[3]

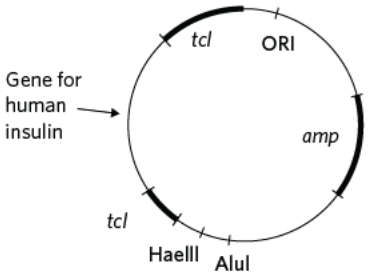
b [The temperature was reduced in the annealing stage so that the DNA primers could form H bonds and attach to the single-stranded DNA molecules.[1]][The temperature was then raised to 72 °C for the extending stage as it is the optimum temperature for *Taq* polymerase.[2]][This allows *Taq* polymerase to catalyse the formation of phosphodiester bonds between nucleotides at a high rate. Ultimately, this forms a complementary DNA strand to the single-stranded DNA.[3]]

- I have explained why the temperature is reduced in the annealing stage.[1]
- I have explained why the temperature is increased in the extending stage.[2]
- I have described the benefits of *Taq* polymerase operating at its optimum temperature.[3]

19 a [The gene for insulin is cut from human DNA and inserted into plasmids[1]][through the use of the same restriction enzymes and DNA ligase.[2]][The recombinant plasmids are then introduced to bacteria.[3]][Only some bacteria will take up the recombinant plasmid, and these are selected for using antibiotics.[4]][Transformed bacteria will then transcribe and translate the new gene to produce human insulin,[5]][which scientists can extract for use.[6]]

- I have explained that genes are inserted into plasmids.[1]
- I have stated the enzymes are used to splice the gene and plasmid.[2]
- I have stated that the recombinant plasmid is introduced to the bacteria.[3]
- I have explained that not all bacteria will uptake the recombinant plasmid.[4]
- I have explained the process that transformed bacteria will undergo to produce the new proteins.[5]
- I have stated that insulin is extracted from the bacterial culture.[6]
- I have used appropriate biological terminology such as: restriction enzyme, ligase enzyme, recombinant plasmid, transformed bacteria.

b i



- I have drawn a circular plasmid.
- I have labelled the restriction sites for HaeIII and AluI.
- I have included the other genes on the plasmid.
- I have labelled the gene for human insulin.

ii [The culture of bacteria are grown on an agar plate containing ampicillin[1]][to kill the untransformed bacteria.[2]][However, bacteria that have uptaken the recombinant plasmid have inherited resistance to ampicillin[3]][and will continue to thrive with the human insulin gene.[4]][Scientists can then extract these bacteria.[5]]

- I have explained what should be included in the agar plate.[1]

- ✓ ✗ I have identified which bacteria will die.[2]
- ✓ ✗ I have described that the resistance to ampicillin is inherited by transformed bacteria.[3]
- ✓ ✗ I have stated that transformed bacteria contain the human insulin gene.[4]
- ✓ ✗ I have stated that scientists can extract transformed bacteria.[5]
- ✓ ✗ I have not stated that the bacteria are selected for using tetracycline.

c i [EcoRI is a sticky-end restriction enzyme[1]][which means after each cut, there are overhanging nucleotides[2]][unlike the other blunt-end restriction enzymes with no overhanging nucleotides.[3]]

- ✓ ✗ I have classified the which type of restriction enzyme EcoRI is.[1]
- ✓ ✗ I have explained the features of this type.[2]
- ✓ ✗ I have compared EcoRI to the other restriction enzymes.[3]

ii [EcoRI results in overhanging nucleotides,[1]][which means that fragments of DNA that have also been cut with EcoRI can form H bonds between the complementary base pairs between each strand.[2]][Additionally, blunt-ended cuts can result in target fragments being inserted back-to-front.[3]][Both of these factors mean that using EcoRI makes successful recombination more likely than using AluI or HaeIII.[4]]

- ✓ ✗ I have stated what feature is beneficial.[1]
- ✓ ✗ I have outlined how sticky ends affect specificity with target DNA.[2]
- ✓ ✗ I have outlined how sticky ends affect the orientation of insert-DNA.[3]
- ✓ ✗ I have stated that recombination is more likely to be successful if using sticky cuts.[4]
- ✓ ✗ I have signposted my response using terms such as: additionally.

16A The ethics of manipulating DNA

Theory review questions

1 **a** Short tandem repeats (STR) **b** *Ex vivo*
c Clone **d** Gene therapy
e *In vivo* **f** DNA profiling or DNA fingerprinting
g Genetic engineering **h** Genetic screening

2 C **3** A

4 B **5** B

Exam-style questions

Within lesson

6 D **7** D **8** A

9 B **10** D **11** C

12 A **13** A **14** B

15 **a** [The viral vector has been modified to contain genes that encode for the production of the defensins protein.[1]][When introduced into the citrus tree, the modified virus integrates its own DNA into the nuclear DNA of the citrus trees,[2]][allowing the trees to produce the defensins protein and providing a natural resistance to citrus greening.[3]]

- I have described the genetic makeup of the modified viral vector.[1]
- I have explained what effect the viral vector has on the genetic makeup of the citrus trees.[2]
- I have explained how this causes a resistance to citrus greening in treated trees.[3]
- I have referred to the scenario in my response using terms such as: citrus tree, defensins.
- I have used appropriate biological terminology such as: viral vector, DNA.

b [The treatment could have unforeseen consequences in future generations when exposed to new environments.[1]]

Other acceptable responses include:

- The treatment may have unforeseen effects on people ingesting the fruit.
- The treatment may reduce the fitness of treated trees when not at risk of citrus greening.
- The treatment may induce a response within the tree's immune system.
- The viral vector may still be pathogenic.

- I have identified an ethical concern of treating trees with a viral vector.[1]

Multiple lessons

16 D **17** A **18** D

19 **a** [Suspect 3 is most likely to have been at the crime scene.[1]]

- I have correctly identified the most likely suspect.[1]

b [The amount of DNA extracted from the crime scene would be too little for use in gel electrophoresis.[1]] [PCR was used to amplify the total amount of available DNA for use in gel electrophoresis.[2]]

- I have explained how much DNA can be extracted from trace blood samples.[1]
- I have explained how PCR could have been useful in this situation.[2]

c [Benefit: DNA profiling can accurately identify individuals from trace amounts of DNA.[1]][Concern: The individual whose DNA has been sequenced may not own the DNA data.[2]]

Other acceptable responses include:

- Benefit: DNA profiling could help identify bodies after tragedies.
- Benefit: DNA profiling could assist in matching organ donors and patients.
- Concern: Many people may have access to the DNA data.
- Concern: Many people may not consent to having their DNA sequenced.

- I have identified an ethical benefit of DNA profiling.[1]
- I have identified an ethical concern of DNA profiling.[2]

Key science skills

20 **a** [*In vivo* describes experimental processes taking place within an organism,[1]] [whereas *ex vivo* describes experimental processes taking place outside of an organism, usually in a lab.[2]]

- I have explained what the term *in vivo* means.[1]
- I have explained what the term *ex vivo* means.[2]
- I have used comparative language such as: whereas.

b **i** [The tadpole at the end of treatment A is genetically identical to animal Y, as all genetic material from animal X has been destroyed.[1]] [Whereas, the tadpole at the end of treatment B is genetically similar to animal X, but also contains genes which have been inserted by the viral vector.[2]]

- I have described the genetic makeup of the tadpole after treatment A.[1]
- I have described the genetic makeup of the tadpole after treatment B.[2]
- I have used comparative language such as: whereas.
- I have used appropriate biological terminology such as: viral vector, genetically identical, clone.

ii [The scientists were testing the effectiveness of each treatment[1]] [as indicated by tadpole survival rates.[2]][20% of embryos in treatment A survived as normal tadpoles,[3]][and 28% of embryos in treatment B survived as normal tadpoles.[4]][Therefore, the scientists would have concluded that treatment B is the most effective procedure for treating this genetic disease.[5]]

✓ ✗ I have identified what the scientists were testing in the experiment.[1]

✓ ✗ I have identified what measurement scientists would have used to indicate effectiveness.[2]

✓ ✗ I have stated the results of treatment A.[3]

✓ ✗ I have stated the results of treatment B.[4]

✓ ✗ I have stated which treatment type is the most effective.[5]

iii [A potential experimental control could include allowing the embryos of animal X to develop in similar environmental conditions to treatments A and B, but not receive any treatment.[1]][Rates of early embryo formation and final survival as normal tadpoles would be recorded.[2]][If the rates of development to normal tadpoles in the control were less than either treatment A or B, then the treatments were having a positive effect on normal tadpole development.[3]]

✓ ✗ I have described a potential experimental control.[1]

✓ ✗ I have stated that individual stages of development will be recorded.[2]

✓ ✗ I have explained how the results of this control could be used to help determine the effectiveness of each treatment.[3]

iv [The rate of survival of tadpoles would have likely been lower than the current treatment A.[1]][This is because incompatibilities between nuclear DNA and other sources of genetic information, such as mtDNA, would have arisen.[2]]

✓ ✗ I have stated a likely rate of survival if the embryo were fertilised with a donor nucleus of a different species.[1]

✓ ✗ I have explained the likely rate of survival.[2]

16B Genetic modification for agriculture

Theory review questions

1 **a** GM food **b** Ethical implications **c** Genetically modified organism (GMO) **d** Social implications **e** Transgenic organism (TGO) **f** Biological implications

2 B **3** C **4** A **5** C

Exam-style questions

Within lesson

6 D **7** A **8** B **9** C **10** C **11** A **12** A

13 **a** [Some people consider genetically modifying foods as 'playing God'.[1]]

Other acceptable responses include:

- GM foods are not naturally occurring.
- Companies that own the patents for GM crops can make unfair rules regarding use of their product.

✓ ✗ I have stated a reasonable ethical implication of GM foods.[1]

✓ ✗ I have referred to the scenario by specifying an implication relevant to GM crops.

b [Golden rice contains higher levels of beta-carotene, a precursor to vitamin A.[1]][Increasing vitamin A in the diets of people in poorer countries will reduce the incidence of vitamin A deficiency.[2]][Reduced vitamin A deficiency will result in improved public health.[3]]

✓ ✗ I have stated that golden rice contains increased levels of beta-carotene, a precursor to vitamin A.[1]

✓ ✗ I have stated that increased golden rice intake will reduce vitamin A deficiency.[2]

✓ ✗ I have stated that decreasing vitamin A deficiency improves public health in poorer countries.[3]

✓ ✗ I have used appropriate biological terminology such as: beta-carotene, vitamin A, deficiency.

c **i** [Improved nutrition through increased intake of vitamin A.[1]]

Other acceptable responses include:

- Saves lives as avoids vitamin A deficiency.
- Increased intake of vitamin A improves health, leading to benefits to the community.

✓ ✗ I have stated a beneficial biological implication of golden rice.[1]

ii [Farmers can save rice to be used in the next year's harvest, which can lead to increased profits.[1]]

Other acceptable responses include:

- Golden rice improves socioeconomic levels because of a reduction in death and disease.
- Increases public health resulting in increased morale.
- Proven safe to eat for consumers.

✓ ✗ I have stated a beneficial social implication of golden rice.[1]

iii [Bt cotton reduces the environmental impacts of insecticides.[1]]

Other acceptable responses include:

- Increases crop yield due to less predation from insects.

✓ ✗ I have stated a beneficial biological implication of Bt cotton.[1]

iv [Bt cotton might contribute to skin allergies in farmers.[1]]

Other acceptable responses include:

- Genes might get into weed crops and reduce the number of predators for insects that feed on Bt cotton.
- Could reduce insect pest population which may impact the food web.

✓ ✗ I have stated a detrimental biological implication of Bt cotton.[1]

Multiple lessons

14 a i [Inserting the gene from the bacteria may give algae the ability to tolerate highly acidic conditions.[1]] [Such algae will be less likely to leave the coral tissues due to environmental changes, thus reducing susceptibility to bleaching.[2]]

✓ ✗ I have explained the effect of the gene insertion on algae.[1]

✓ ✗ I have explained how such algae will reverse coral bleaching.[2]

✓ ✗ I have referred to the scenario in my response.

ii [Less coral bleaching would result in increased tourism to the Great Barrier Reef.[1]]

Other acceptable responses include:

- Public outcry due to introduced GM algae may cause people to boycott the Great Barrier Reef and reduce tourism.
- Reducing coral bleaching will improve public morale.

✓ ✗ I have suggested a social implication of creating GM coral to reverse coral bleaching.[1]

b i [This is not considered genetic modification[1]] [since there is no alteration to DNA using genetic engineering technologies.[2]] [This is simply just introducing algae from one population to another.[3]]

✓ ✗ I have correctly identified whether this approach is genetic modification or not.[1]

✓ ✗ I have supported my answer by referring to the definition of genetic modification.[2]

✓ ✗ I have supported my answer by referring to the scenario.[3]

ii [Coral in the Great Barrier Reef will be less susceptible to coral bleaching due to the introduction of algae that are more tolerant to warmer conditions.[1]]

Other acceptable responses include:

- the genetic diversity of algae in the coral reef may be reduced due to the introduced algae out-competing the local algae.
- the genetic diversity of algae in the coral reef will be increased due to introduction of alleles from a new gene pool.

✓ ✗ I have given an example of a biological implication of this approach.[1]

✓ ✗ I have used appropriate biological terminology such as: algae, coral.

Key science skills

15 C **16** B **17** A

18 a [The independent variable is treatment with viral vector[1]] [whilst the dependent variable is presence/absence of citrus greening.[2]]

✓ ✗ I have identified the independent variable.[1]

✓ ✗ I have identified the dependent variable.[2]

b [Citrus trees containing the viral vector will be less affected by citrus greening than trees without the viral vector.[1]]

✓ ✗ I have stated a plausible hypothesis.[1]

✓ ✗ I have referred to both the independent and dependent variable.

c [The genetic engineers need to use a sufficient number of trees for both the treatment and control groups. They should also ensure that the trees in each group are kept in the same environmental conditions (e.g. light and water).[1]]

Other acceptable responses include:

- The same number of incisions are made in each tree.
- Same amount of viral vector delivered into each tree in the treatment group.
- All trees are treated at the same time.

✓ ✗ I have outlined two measures that would increase the reliability of this experiment.[1]

✓ ✗ I have referred to the scenario in each of my answers.

d [Extensive field trials are necessary in order to ensure the method is safe for use on the organism being modified.
They also assess the effect of GM crops on an ecosystem (eg. pollinators, soil).[1]]

Other acceptable responses include:

- To ensure the method is safe for use on products for human consumption.
- To ensure the GMO does not impact on the environment negatively.
- To ensure the GMO does not impact on wildlife negatively.
- To ensure that the GMO does not spread uncontrollably to nearby crops.
- To assess the ability of the GM crop to grow in an agricultural setting.

✓ ✗ I have outlined two reasons why field trials are necessary.[1]

16C Modern disease management

Theory review questions

1 a Pandemic **b** Antibiotics
c Narrow spectrum **d** Antimicrobial resistance
e Epidemic **f** Vector

2 B **3** B

4 D **5** D

Exam-style questions

Within lesson

6 C **7** C **8** D

9 a [Polio is spread via the faecal-oral route.[1]][Therefore, an effective method to prevent the spread of it would be to increase/improve sanitation and hygiene.[2]]

Other acceptable responses include:

- Specific examples of improving sanitation/hygiene e.g. washing hands.

✓ ✗ I have identified how the virus is spread.[1]

✓ ✗ I have stated a method for preventing the spread of polio.[2]

✓ ✗ I have not stated a method that could not be identified using the information provided such as: vaccination.

b [Ebola.[1]]

✓ ✗ I have correctly identified the least contagious disease.[1]

c i [That the disease has not spread beyond a specific population in a specific place.[1]]

✓ ✗ I have stated what the term epidemic means.[1]

ii [Scientists could test for the presence of the virus by using an enzyme-linked immunosorbent assay.[1]][This test identifies the presence of antibodies in the blood by using antigens from pathogens.[2]]

Other acceptable responses include:

- Visualising the pathogen.
- Use of biochemical testing.
- Use of molecular techniques, including hybridisation-based detection, amplification-based detection, or whole genome sequencing.

✓ ✗ I have identified one method of pathogen identification that could be used in this case.[1]

✓ ✗ I have described this method.[2]

iii [Authorities would quarantine the traveller until they showed no signs of disease.[1]][This would prevent the disease from entering the Australian population.[2]]

Other acceptable responses include:

- Testing for the presence of the virus.

✓ ✗ I have identified an appropriate course of action.[1]

✓ ✗ I have stated why this course of action would be taken.[2]

✓ ✗ I have used appropriate biological terminology such as: quarantine.

Multiple lessons

10 B **11** A

12 a [1958.[1]]

✓ ✗ I have identified the correct year.[1]

b [No, antibiotics would not be effective in treating this person[1]][because measles is a viral disease and antibiotics only work against bacteria.[2]]

✓ ✗ I have correctly stated if antibiotics would be effective.[1]

✓ ✗ I have explained why antibiotics would not be effective in this situation.[2]

c i [Herd immunity.[1]]

✓ ✗ I have correctly identified the type of immunity the government is trying to achieve.[1]

ii [By immunising a large proportion of the population, there are fewer people who could carry the disease.[1]][This means that the spread of the disease is limited, protecting those who haven't been immunised.[2]]

✓ ✗ I have stated how herd immunity works at a population level.[1]

✓ ✗ I have stated how this protects people who are unvaccinated.[2]

d [Firstly, mucus production in the airways helps protect against inhaled viral pathogens.[1]][Secondly, if the virus did invade the body, interferons would be released to combat infection.[2]]

Other acceptable responses include:

- Release of pro-inflammatory cytokines.
- White blood cells (e.g. NK cells, macrophages) would be recruited to destroy viral particles or remove cells that have been infected by the virus.
- Cilia in the airways would sweep trapped pathogens from the respiratory tract.

✓ ✗ I have identified one innate immune mechanism.[1]

✓ ✗ I have identified a second innate immune mechanism.[2]

✓ ✗ I have signposted my response using terms such as: firstly, secondly.

✓ ✗ I have not referred to other pathogens such as bacteria in my response.

Key science skills

13 C

14 a [The higher the concentration of antibiotics the lower the amount of bacterial growth.[1]]

✓ ✗ I have identified the expected difference.[1]

b [This is an example of a random error[1]][because it affects the precision of a measurement and is unpredictable and inconsistent between repeated measurements.[2]][This uncertainty could be reduced by using a measuring device that has smaller, more precise units of measurement such as a ruler with 1mm markings instead of 1 cm markings.[3]]

- ✓ ✗ I have stated what type of error could occur.[1]
- ✓ ✗ I have stated why this is a type of random error.[2]
- ✓ ✗ I have provided a way to reduce this error.[3]

c [The size of the zone of inhibition of bacterial growth around the antibiotic.[1]][This is because the amount of bacterial growth changes depending on the concentration of antibiotic.[2]]

- ✓ ✗ I have correctly identified the dependent variable in this experiment.[1]
- ✓ ✗ I have justified my response by referring to the definition of a dependent variable.[2]

d [That different bacteria will have different sensitivities to the same antibiotic.[1]]

- ✓ ✗ I have stated the hypothesis of this experiment.[1]

e [Sharon would expect that the antifungal drug would have no effect on bacterial growth.[1]][This is because antifungals are not effective against bacteria and only work against fungi.[2]]

- ✓ ✗ I have stated the result Sharon would expect to obtain.[1]
- ✓ ✗ I have stated why Sharon would expect this result by referring to the limitations of antifungals.[2]

16D Rational drug design

Theory review questions

1 **a** Neuraminidase **b** Rational drug design
c Influenza **d** Host cell
e Relenza **f** Haemagglutinin

2 D **3** B

4 B

Exam-style questions

Within lesson

5 C **6** C **7** A

8 **a** [Rational drug design is a process that involves first identifying the molecular cause of a disease[1]][and secondly designing a medicine that is complementary in shape and charge to it to interfere with its functioning,[2]][bringing about a therapeutic benefit for the patient.[3]]

- ✓ ✗ I have stated that rational drug design involves identifying the cause of a disease.[1]
- ✓ ✗ I have stated that rational drug design involves creating a medicine that is complementary in shape and charge to the disease-causing molecule.[2]
- ✓ ✗ I have stated that this has a therapeutic benefit.[3]
- ✓ ✗ I have used appropriate biological terminology such as: complementary, therapeutic benefit.
- ✓ ✗ I have signposted my response using terms such as: firstly, secondly.

b [The structure of Imatinib must be complementary in shape and charge to the active site of the bcr-abl enzyme.[1]]

- ✓ ✗ I have stated what the information provided suggests about the structure of Imatinib.[1]
- ✓ ✗ I have used appropriate biological terminology such as: complementary, active site.

c [Imatinib is an effective treatment because it specifically targets the bcr-abl enzyme,[1]][blocking its active site and inhibiting the enzyme.[2]][This means that the abnormal cell division that leads to cancer is prevented.[3]]

- ✓ ✗ I have stated that Imatinib is selective for the bcr-abl enzyme.[1]
- ✓ ✗ I have stated that Imatinib inhibits the bcr-abl enzyme.[2]
- ✓ ✗ I have stated the therapeutic effect of inhibiting bcr-abl.[3]

Multiple lessons

9 B **10** B

11 **a** [Relenza selectively binds to the active site of neuraminidase on the surface of the influenza virus[1]][and blocks it, inhibiting its function.[2]][This means that neuraminidase can't cut the connection between the virus and the host cell,[3]][meaning newly reproduced virus cannot escape from the host cell.[4]][This limits the spread of infection and reduces the severity of symptoms/duration of illness.[5]]

- ✓ ✗ I have stated that Relenza selectively binds to the active site of the neuraminidase enzyme.[1]
- ✓ ✗ I have stated that Relenza inhibits neuraminidase.[2]
- ✓ ✗ I have outlined the function of neuraminidase.[3]
- ✓ ✗ I have stated the effect of inhibiting neuraminidase.[4]
- ✓ ✗ I have stated the therapeutic effect of inhibiting neuraminidase.[5]
- ✓ ✗ I have used appropriate biological terminology such as: selectively, active site, neuraminidase, inhibiting.

b

	Relenza	Influenza vaccine
Method of administration	Oral/inhalation	Injection
Mechanism of action	Blocks the active site of neuraminidase	Exposes the immune system to antigens that do not cause influenza, to stimulate the creation of antibodies
Purpose of administration	Prophylaxis and early treatment	Prophylaxis

Key science skills

12 a [Exposure to the drug Relenza.[1]]

✓ ✗ I have identified the independent variable.[1]

b [The studies examined the effect of Relenza on two different populations.[1]][The *Lancet* study focused on a population affected by the H1N1 pandemic at all stages of infection,[2]][whereas the *BMJ* study focused on people already recovering from mild to moderate influenza.[3]][Relenza is only effective at managing symptoms if given early during infection, and this explains why the *BMJ* study found Relenza to have only a mild effect compared to the robust effect of the *Lancet* study.[4]]

✓ ✗ I have identified a difference between the two studies that accounts for their differing findings.[1]

✓ ✗ I have described the population of the *Lancet* study.[2]

✓ ✗ I have described the population of the *BMJ* study.[3]

✓ ✗ I have stated how the mechanism of Relenza would alter its effect in each population.[4]

✓ ✗ I have used comparative terminology such as: whereas, compared.

c [A randomised control study cannot be performed on hospitalised patients because their illness must be severe or life-threatening for them to have been hospitalised.[1]][In a randomised control study they might be assigned to a control group and therefore not receive any treatment.[2]][This is unethical, as not being given treatment could result in an increase in their symptoms and possible death.[3]][Therefore, they should be excluded from the trial and given the treatment.[4]]

✓ ✗ I have identified a feature of the population that explains why a randomised control study should not be performed.[1]

✓ ✗ I have outlined how a randomised control study is structured.[2]

✓ ✗ I have explained the ethical issue with performing a randomised control study on this population.[3]

✓ ✗ I have stated that this population should be excluded from the randomised control study.[4]

d [No.[1]][The *BMJ* study was conducted on a similar population recovering from a mild to moderate season influenza outbreak and found that neuraminidase inhibitor drugs only had a minor effect.[2]]

✓ ✗ I have stated whether influenza drugs should be stockpiled.[1]

✓ ✗ I have justified my answer using the information provided by the article.[2]

Chapter 16 review

SECTION A

1	D	**2**	A	**3**	D	**4**	B
5	C	**6**	A	**7**	C	**8**	B
9	D	**10**	B	**11**	D	**12**	C
13	B	**14**	A	**15**	A		

SECTION B

16 a [Blood sample 2.[1]]

✓ ✗ I have identified the correct sample.[1]

b [Blood sample 5.[1]]

✓ ✗ I have identified the correct sample.[1]

c [Because Ötzi and chimpanzees belong to different species, there would be many nucleotide differences between the two strands of DNA, due to an accumulation of mutations.[1]][On the other hand, there would be no differences between DNA strands sourced from the same individual.[2]][Therefore, there would be fewer hydrogen bonds holding the hybridised DNA strands together, causing a lower melting temperature.[3]]

✓ ✗ I have described the nucleotide differences within the Ötzi-chimpanzee hybridised DNA.[1]

✓ ✗ I have described the nucleotide differences within the pure DNA samples.[2]

✓ ✗ I have explained why this causes a lower melting temperature in the hybridised DNA.[3]

✓ ✗ I have used appropriate biological terminology such as: hydrogen bonds, nucleotide differences, melting temperature.

17 a [Drought-tolerant corn would have increased survival during droughts.[1]][This increases crop productivity since there would be fewer crops dying from weather conditions.[2]]

✓ ✗ I have stated what effect drought tolerance would have on corn.[1]

✓ ✗ I have stated what effect drought-tolerant corn would have on crop productivity.[2]

b i [The Cas9 system can be designed to digest any section of DNA using a guide RNA, whereas individual restriction enzymes can only recognise one site.[1]]

Other acceptable responses include:

- The CRISPR-Cas9 protein is generally quicker and cheaper to use than restriction enzymes.

✓ ✗ I have given one advantage of using CRISPR-Cas9 over restriction enzymes.[1]

ii [Scientists could insert the three drought tolerance genes (NOT, TOO, and HOT) into *Z. mays* to create[1]][a transgenic crop.[2]][Inserting these genes could give *Z. mays* the drought tolerance trait.[3]]

✓ ✗ I have suggested inserting the three genes (NOT, TOO, and HOT) into *Z. mays*.[1]

✓ ✗ I have used the term transgenic/transgene/transgenesis in my answer.[2]

✓ ✗ I have stated the consequences for *Z. mays* plants of inserting NOT, TOO, and HOT into their genome.[3]

iii [The public may have a negative response to GMO corn on an ethical basis.[1]]

Other acceptable responses include:

- These three genes alone may not give *Z. mays* drought tolerance.
- Inserting these genes may result in off-target effects on *Z. mays*.
- Pollen from GM cornfields may fertilise non-GM corn from other fields, resulting in the unwanted spread of GM corn and legal disputes.
- Widespread use of GM corn could result in a decrease in genetic diversity among the corn population.

✓ ✗ I have given a likely disadvantage of GMO corn.[1]

18 a [Afghanistan.[1]]

✓ ✗ I have correctly identified the country with the highest number of polio infections in 1983.[1]

b i [An epidemic describes when the incidence of a particular disease within a particular area increases unexpectedly and dramatically.[1]]

✓ ✗ I have described the concept of an epidemic.[1]

ii [No,[1]] [because there isn't a sudden or unusual increase in the occurrence of polio in this time period in the given regions.[2]]

✓ ✗ I have stated if the graph supports the occurrence of a pandemic.[1]

✓ ✗ I have justified my answer.[2]

✓ ✗ I have not referred to the geographic distribution of polio in my answer.

c [Systematic error.[1]]

✓ ✗ I have stated that this is an example of a systematic error.[1]

d i [The structure of neuraminidase was analysed to determine the shape of the active site.[1]] [The shape of Relenza was specifically designed to bind to the active site of neuraminidase,[2]] [inhibiting this enzyme.[3]] [Neuraminidase can no longer sever the connection between the virus and the host cell,[4]] [limiting the spread of the influenza infection to healthy cells.[5]]

✓ ✗ I have stated that the structure of the active site of neuraminidase was determined.[1]

✓ ✗ I have stated that the shape of Relenza allows it to bind to the active site of neuraminidase.[2]

✓ ✗ I have stated that Relenza inhibits neuraminidase.[3]

✓ ✗ I have explained the functional effect this has on neuraminidase.[4]

✓ ✗ I have explained the benefit of Relenza on restricting the influenza infection.[5]

✓ ✗ I have used appropriate biological terminology such as: active site, neuraminidase, inhibition.

ii [Random mutations that cause antibiotic resistance can spontaneously arise in the genomes of bacteria.[1]] [When bacteria are exposed to antibiotics, the antibiotics impose a selection pressure and individuals without resistance mutations are killed.[2]] [Surviving bacteria reproduce,[3]] [passing on the antibiotic resistance allele and increasing its frequency in the population.[4]] [This can create a bacterial population with increased antibiotic resistance.[5]]

✓ ✗ I have explained how antibiotic resistance can spontaneously arise in bacteria.[1]

✓ ✗ I have explained that antibiotics impose a selection pressure on bacteria.[2]

✓ ✗ I have stated that antibiotic-resistant bacteria survive and reproduce.[3]

✓ ✗ I have explained the change in allele frequency.[4]

✓ ✗ I have explained the overall effect on the bacterial population.[5]

✓ ✗ I have used appropriate biological terminology such as: selection pressure, resistance.

19 a [These children would not be considered transgenic organisms[1]] [since the inserted healthy allele comes from humans[2]] [rather than another species.[3]]

Other acceptable responses include:

- The genetic modification may be due to a point mutation in the target gene which is not transgenic since DNA from another species is not being inserted.
- The genetic modification may be due to the deletion of DNA which is not transgenic since DNA from another species is not being inserted.

✓ ✗ I have stated they are not transgenic.[1]

✓ ✗ I have referred to the genetic modification used in germline gene therapy.[2]

✓ ✗ I have justified my response by referring to the definition of transgenic.[3]

b [Widespread germline gene therapy would alter the gene pool,[1]] [increasing the frequency of normal alleles within the population[2]] [and decrease the frequency of deleterious alleles in the human population.[3]] [This would decrease human genetic diversity,[4]] [reducing the adaptive potential of human populations should new selection pressures arise.[5]]

- ✓ ✗ I have stated that germline gene therapy would alter the gene pool.[1]
- ✓ ✗ I have explained the effect on normal allele frequency.[2]
- ✓ ✗ I have explained the effect on deleterious allele frequency.[3]
- ✓ ✗ I have explained the effect on the human gene pool.[4]
- ✓ ✗ I have explained the consequence of a reduced gene pool.[5]
- ✓ ✗ I have referred to the scenario.
- ✓ ✗ I have used appropriate biological terminology such as: gene pool, normal, deleterious, genetic diversity, adaptive potential.

c [Ethical issue 1: Germline gene therapy will alter the DNA of unborn children without their prior consent.[1]][Ethical issue 2: The decisions of individuals who use germline gene therapy will impact future human evolution, which has consequences on the entire human population.[2]][Biological implication: The decisions of individuals who use germline gene therapy will impact future human evolution, decreasing genetic diversity and making the population more susceptible to new selection pressures.[3]]

Other acceptable responses include:

- Ethical implication: People should have the right to alter DNA in their own cells.
- Ethical implication: People should have the right to protect their future children from genetic disorders using DNA technology.
- Biological implication: The future children of parents undergoing germline cell therapy will be unaffected by the faulty allele.

- ✓ ✗ I have given an ethical implication of germline gene therapy.[1]
- ✓ ✗ I have given a second ethical implication of germline gene therapy.[2]
- ✓ ✗ I have given a biological implication of germline gene therapy.[3]
- ✓ ✗ I have not repeated the same implication.

GLOSSARY

5

5′ methyl cap (five-prime cap) a molecule added to the 5′ end of pre-mRNA during RNA processing p. 120

A

absolute age provides an estimate of the age (in years) of a fossil or rock p. 453

accurate a measurement that is close to the 'true' value of the quantity being measured p. 4

acetyl CoA the product of pyruvate oxidation that is an input into the Krebs cycle p. 221

acquired immunodeficiency syndrome (AIDS) a life-threatening condition caused by an untreated infection with the human immunodeficiency virus (HIV) in which an individual's immune system is no longer able to function normally p. 367

activation energy the energy required to initiate a reaction p. 52, 147

active immunity protection against a pathogen created by antibodies produced by an individual's own immune system p. 355

active site the part of the enzyme to which the substrate binds p. 147, 648

active transport the movement of molecules across a semipermeable membrane requiring an energy input p. 75, 81

adaptive radiation rapid divergent evolution, producing a wide array of species/forms p. 470

ADP adenosine diphosphate, the unloaded form of ATP p. 166

advantageous phenotype a biochemical, physical, or behavioural trait that increases an individual's fitness in its local environment p. 403

aerobic cellular respiration cellular respiration that occurs in the presence of oxygen. It involves three stages, during which glucose and oxygen are converted into ATP, CO_2, and water p. 213

afferent lymphatic vessel thin-walled structures that collect lymph from the tissues of the body and deliver it to lymph nodes p. 340

agarose gel a sponge-like gel used in gel electrophoresis that contains pores for DNA fragments to move through p. 582

agglutination the clumping of particles together in a solution p. 330

allele frequency the proportion of certain alleles in a gene pool p. 396, 403, 412

alleles variants of a gene p. 396, 411

allergen a non-pathogenic antigen that triggers an allergic reaction p. 303, 368

allergic reaction an inappropriate immune response to a non-pathogenic antigen p. 303, 368

allergy a cluster of syndromes experienced by a person who has had an allergic reaction p. 368

allolactose an inducer molecule that binds to the *lac* repressor to release it from the operator region p. 133

allopatric speciation the geographic separation of a population from a parent population resulting in the evolution of a new species p. 419

allosteric site a region on an enzyme that is not the active site p. 159

alpha helix a coiled secondary structure of proteins p. 101

alternative splicing process during gene expression where different exons may be spliced, resulting in a single gene producing multiple mRNA strands p. 121

amino acid the monomer of proteins p. 99, 117

amino group the functional group on amino acid molecules that is made up of one nitrogen and two hydrogens (NH_2). Also known as an amine group p. 100

amniocentesis sampling amniotic fluid from within the womb for use in genetic screening p. 614

amphipathic describes molecules with both hydrophilic and hydrophobic components. Also known as amphiphilic p. 67

amplify to make many copies of a molecule p. 576

anabolic an endergonic reaction where larger molecules are formed from smaller molecules p. 52

anaerobic cellular respiration cellular respiration that occurs in the absence of oxygen. It involves glycolysis, followed by further reactions that convert pyruvate into lactic acid, or ethanol and carbon dioxide. Also known as fermentation p. 213, 230

analogous structure a structure present in two or more species that fulfils the same function but does not originate from a common ancestor p. 470

ancestral trait a trait that is found in the ancestor of a species, but not necessarily in the species itself p. 490

aneuploidy when a cell or organism varies in the usual number of chromosomes in its genome by the addition or loss of a chromosome p. 394

animal cell eukaryotic cells that do not contain a cell wall or chloroplasts and are found in organisms in the kingdom Animalia p. 41

annealing stage second step in PCR when the primer bonds to a DNA strand by complementary base pairing p. 576

antibiotic selection the process of culturing bacteria on antibiotic-containing medium, which only allows transformed bacteria to grow p. 594

antibiotics medications used to kill bacteria or slow their growth p. 638

antibody a protein produced by plasma cells during the adaptive immune response that is specific to an antigen and combats pathogens in a variety of ways. Also known as immunoglobulin p. 99, 329, 374

anticodon the sequence of three nucleotides on a tRNA molecule that recognises a specific sequence of three nucleotides (codon) on an mRNA strand p. 109, 122

antigen a substance that is recognised by the immune system as either foreign or self. A foreign antigen will trigger an immune response p. 303, 375

antigen-antibody complex formed by the interaction between antigen and antibody molecules p. 330

antigen-presenting cell a subgroup of phagocytes that display the antigens from consumed pathogens on their surface and interact with the adaptive immune system p. 318, 328

antimicrobial agent an agent that kills or slows the growth of microorganisms. Includes antiseptics, disinfectants, antifungals, antivirals, and antibacterial agents p. 640

antimicrobial resistance the ability of a microorganism to survive exposure to an antimicrobial agent p. 640

antiparallel a characteristic of DNA strands, describing how each strand runs in an opposite direction to the other. One strand runs in a 3' → 5' direction and the other runs in a 5' → 3' direction p. 108

antiseptic a substance that is applied to living tissue to kill or slow the growth of microorganisms p. 639

antivenom a medication containing antibodies that is used to treat people who have received a venomous bite or sting p. 356

antivirals medications used to treat viral infections p. 638

apoptosis the controlled death of cells in the body. Also known as programmed cell death p. 284

apoptotic bodies vesicles containing cell contents that are released from a dying cell during apoptosis and engulfed by phagocytes p. 285

archaea a domain of prokaryotic cell that is similar in size and structure to bacteria, but are different genetically and usually live in extreme environments p. 444

arm to leg ratio the ratio of arm length to leg length. Tree-dwelling hominids have longer arms and shorter legs, or a larger arm to leg ratio p. 536

artificial active immunity protection conferred by antibodies produced by an individual's own immune system due to medical intervention (e.g. a vaccination) p. 355

artificial immunity protection against a pathogen as a result of a medical intervention. Also known as induced immunity p. 355

artificial passive immunity protection conferred by externally produced antibodies injected as a medical intervention p. 355

artificial selection the alteration of a population's gene pool due to direct human action, usually selecting for a desired trait. Also known as selective breeding p. 425

aseptic surgically clean and free from contamination by microorganisms. Also known as sterile p. 10

ATP adenosine triphosphate, a high energy molecule that, when broken down, provides energy for cellular processes p. 52, 75, 166, 212, 220, 237

ATPase an enzyme in the inner mitochondrial membrane that uses the concentration gradient of H^+ to synthesise ATP from ADP and P_i p. 222

Australopithecus the genus name for an ancient hominin ancestor from which the genus *Homo* evolved p. 536

autoantibodies antibodies directed against an organism's own tissues p. 364

autocrine signalling when a cell releases a signalling molecule that acts on itself p. 263

autoimmune disease a disease in which an individual's immune system initiates an immune response against their own cells p. 303, 364

autoreactive a cell that recognises a self-tissue as non-self p. 364

autotroph an organism that makes its own food from inorganic substances. Phototrophs and chemotrophs are examples of autotrophs p. 444

axon the long projection of a neuron along which an electrical signal is transmitted p. 365

B

B lymphocyte a type of lymphocyte that plays an important role in humoral immunity and differentiates into plasma cells and B memory cells p. 328, 374

B memory cell a differentiated B lymphocyte that is responsible for providing long-lasting immunological memory of an antigen p. 329

background extinction rate expected rate of extinctions within a geographic area p. 471

bacterium (pl. bacteria) a group of single-celled, prokaryotic, microscopic organisms. They can live symbiotically with other organisms and/or act as pathogens p. 304

band a line seen in the gel after running gel electrophoresis that corresponds to a collection of DNA fragments of a specific size p. 582

bar graph a graph that shows changes in categorical variables using filled rectangles p. 22

base deletion mutation when a nucleotide is removed from a gene, affecting every codon from that point forward p. 394

base insertion mutation when a nucleotide is added to a gene, affecting every codon from that point forward p. 394

base pair (bp) a unit of measurement that corresponds to one nucleotide p. 583

beta-pleated sheet a folded secondary structure of proteins p. 101

biogeography the study of the geographic distribution of species over geological time p. 462

biological implications consequences that affect ecosystems, environments, or public health p. 627

bipedal using two legs for walking upright p. 528

blebbing the bulging of the plasma membrane to form separate apoptotic bodies p. 285

block mutations a mutation that affects a large chunk of DNA, or an entire gene p. 394

blunt end a straight cut by a restriction enzyme resulting in no overhanging nucleotides p. 569

bone marrow semi-solid tissue found within bones. Serves as the primary site of the creation of red blood cells and leukocytes p. 342

bone morphogenetic protein 4 (*BMP4*) a master gene that is important for beak formation in Galápagos finches and jaw formation in African cichlid fish p. 509

booster vaccine a vaccination given to a person after the completion of a vaccination program to boost their existing immunity against a disease. Also known as a booster shot p. 356

bottleneck effect the reduction in genetic diversity that occurs when a large proportion of a population is removed due to a chance event p. 412

bowl-shaped pelvis the description of the shape of a *Homo sapiens* pelvis. Non- or partially-bipedal primates have comparatively flat pelvises p. 536

branch a line on a phylogenetic tree that represents an evolutionary path p. 489

branch length the length of a branch sometimes denotes evolutionary distance or time p. 489

broad-spectrum agent a type of antimicrobial agent that affects a wide variety of microorganisms p. 640

brow ridge a bony ridge above the eye sockets. It is found in all primates, but is greatly reduced in *Homo sapiens* p. 529, 536

buffer an ion-filled solution that carries current through the agarose gel p. 582

bulk transport the type of active transport that uses vesicles to move large molecules or groups of molecules into or out of the cell p. 81

bya short for 'billion years ago'. Also written as Ba and Ga p. 442

C

Cambrian a geological time period ~535 mya during which many new groups of living things evolved, including major phyla that still exist today p. 444

cancer a disease caused by the uncontrolled replication of cells p. 286

canine teeth a type of tooth in mammals that is relatively long and pointed p. 529

carbohydrate the class of biomacromolecules made from monosaccharide monomers consisting of C, H, and O. Also known as saccharides or sugars p. 50

carboxyl group the functional group on amino acid molecules that contains a hydroxyl (-OH) and an oxygen double-bonded to a carbon atom p. 100

carrier an organism that is infected with and spreads a disease p. 638

caspase enzymes that cleave specific intracellular proteins during apoptosis p. 284

catabolic an exergonic reaction where larger molecules are broken down into smaller molecules p. 52

catalyse to increase the rate of a reaction p. 146

catalyst a substance capable of catalysing reactions p. 146

categorical variables factors that are qualitative, typically describing a characteristic such as gender, birth order (1st, 2nd, 3rd), or nationality p. 22

causation demonstrated when change in one variable leads to reliable change in another p. 24

cell the smallest functional unit of a living organism p. 40

cell wall a sturdy border outside the plasma membrane that provides strength and structure to plant, bacteria, and fungal cells p. 44

cell-mediated immunity a component of the adaptive immune system in which infected/abnormal cells are destroyed by cytotoxic T cells. Also known as T cell immunity p. 328

cellular pathogen a pathogen that has a cellular structure and exhibits the processes of a living organism. Examples include bacteria, fungi, protozoa, and parasites such as worms p. 304

cellular respiration the biochemical process in all living things that converts glucose into ATP. Can be aerobic or anaerobic respiration p. 212

cerebrum the part of the brain responsible for complex functions, such as language and learning p. 538

chemical barrier a component of the first line of defence that features the use of chemicals to protect against pathogen invasion p. 311

chlorophyll a chemical found in the thylakoids of chloroplasts. It is responsible for absorbing light energy in photosynthesis p. 183, 190

chloroplast a membrane-bound organelle only found in plant and algal cells that is the site of photosynthesis p. 44, 183, 197

cholesterol a steroid alcohol that regulates fluidity in plasma membranes p. 68

Chordata a group of animals including fish, amphibians, birds, reptiles, and mammals. Also known as chordates p. 463

chorionic villus sampling sampling cells adhered to the placental wall for use in genetic screening p. 614

chromosome the structure made of protein and nucleic acids that carries genetic information p. 107

cilium (pl. cilia) thin, hair-like projections that protrude from eukaryotic cells p. 44, 311

clonal deletion the process by which autoreactive immature lymphocytes are normally destroyed. Occurs in the bone marrow for B cells and the thymus for T cells p. 365

clonal expansion the process in which many copies of a lymphocyte are generated p. 329

clonal selection the process in which B and T cells encounter an antigen that matches their antigen-binding site, then generate many copies of themselves p. 329, 342

clone to make a genetically identical organism or section of DNA p. 612

coding strand the strand of DNA not transcribed by RNA polymerase, contains an identical sequence to the mRNA strand produced (except thymine is replaced with uracil in mRNA) p. 119

codon the sequence of three nucleotides in mRNA coding for one amino acid p. 117

coenzyme a non-protein organic cofactor that assists enzyme function. They release energy and are recycled during a reaction p. 166

cofactor any organic or inorganic molecule, such as a coenzyme or metal ion, that assists enzyme function p. 166

comparative anatomy the study of the similarities and differences in structure between animals, including fossils of extinct species. Also known as structural morphology p. 470

comparative embryology the comparison of embryo development and structures across species p. 463

competition an interaction between organisms in which both are harmed when trying to use the same limited resource. Can exist within or between species p. 403

competitive inhibition the hindrance of an enzyme through blocking the active site and prevention of substrate from binding p. 159

complement proteins a number of different types of proteins found in the blood that opsonise, cause lysis, and attract phagocytes to invading pathogens p. 319

complementary base pairing describes which nucleotides can form hydrogen bonds with each other; C pairs with G, A pairs with T (or U in RNA) p. 108

concentration gradient the difference in solute concentration between two adjacent areas p. 74

condensation reaction a reaction where two small molecules join to form one larger molecule, producing water as a by-product in the process p. 52, 100

conformational change a change in the three dimensional shape of macromolecules such as proteins p. 148

confounding variable an uncontrolled variable that affects the validity of the results p. 7

conjugation process in which bacteria exchange genetic material via direct cell-to-cell contact p. 640

contagious a property of disease meaning that it can be transmitted from one organism to another through direct or indirect contact p. 636

continental drift the movement of tectonic plates around Earth over millions of years p. 462

control group a group of individuals/samples that are not exposed to the independent variable. Also known as an experimental control, control treatment, or 'the control' p. 7

controlled variable a factor that is kept constant throughout the experiment. Also known as a constant variable p. 8

convergent evolution evolution of analogous traits due to similar selective pressures p. 470

correlation demonstrated when there is a statistical relationship between two variables p. 24

coupled inquiry an investigation in which students extend or build upon an initial, teacher-proposed question p. 20

covalent bond a chemical bond formed by sharing electrons between two non-metal atoms p. 48

cranial capacity the volume of the braincase, usually measured in cubic centimetres (cc or cm^3) p. 536

cranium the part of the skull that covers the brain p. 528

crista (pl. cristae) the folds of the inner membrane of mitochondria. The site of the electron transport chain p. 214

cultural evolution the change in socially-transmitted information, beliefs, language, attitudes, or skills over time p. 539

culture a lab technique in which cells/organisms are grown in a sterile environment with a nutrient supply p. 594

cuticle a waxy protective film covering the surface of a plant leaf p. 312

cytochrome c a protein embedded in the inner mitochondrial membrane. Involved in the electron transport chain of aerobic cellular respiration and the mitochondrial pathway of apoptosis p. 284

cytokine a signalling protein released by cells (typically in the immune system) that has an effect on other cells p. 263, 275, 319, 329

cytoplasm the cytosol and organelles inside the plasma membrane, excluding the nucleus p. 42

cytoskeleton the microscopic web of protein filaments in the cytoplasm. It provides structure, support, and transports products around the cell p. 44, 68

cytosol the aqueous fluid that surrounds the organelles inside the plasma membrane p. 42, 221

D

death receptor pathway the pathway of apoptosis which is initiated by the reception of extracellular death signalling molecules. Also known as the extrinsic pathway p. 284

degenerate a property of the genetic code which means that a single amino acid can be coded for by more than one codon p. 118

degranulation the release of granule contents from a cell p. 320

deleterious alleles that have an overall negative effect on individual fitness when expressed p. 396, 427

demyelination the disease process of multiple sclerosis in which the myelin sheath surrounding the axon is destroyed by the cells of the immune system p. 366

denaturation stage first step in PCR when hydrogen bonds are broken and individual strands of DNA are separated p. 576

denature to irreversibly change a protein's tertiary structure p. 149, 198, 238

dendritic cell a type of white blood cell that engages in phagocytosis and antigen presentation p. 318

dependent variable (DV) the factor(s) changed by the manipulation of the IV p. 3, 22

derived trait a trait that has been acquired in the time since two species diverged p. 425, 490

developmental biology the study of the processes through which organisms grow and develop p. 463

differentiation the process in which cells develop specialised characteristics, typically transforming them from one cell type to another p. 329

diffusion the passive movement of molecules from areas of high concentration to areas of low concentration (down the concentration gradient) p. 73

disadvantageous phenotype a biochemical, physical, or behavioural trait that lowers an individual's fitness in its local environment p. 403

disinfectant a substance that is applied to non-living materials to kill or slow the growth of microorganisms p. 639

divergent evolution when a common ancestor speciates into two or more descendant species p. 469

DNA (deoxyribonucleic acid) a double-stranded nucleic acid chain made up of nucleotides. DNA carries the instructions for proteins which are required for cell and organism survival p. 107, 117

DNA hybridisation a technique that determines relatedness between DNA sequences by measuring the temperature at which they break apart and become single-stranded p. 500

DNA profiling the process of identification using genetic information. Also known as DNA fingerprinting p. 615

double helix double-stranded DNA in the nucleus of eukaryotic cells forms a double helix structure, where each DNA strand wraps around a central axis p. 109

E

effector a molecule or organ that responds to a signal and produces a response p. 256

efferent lymphatic vessels thin-walled structures that collect lymph that has drained through lymph nodes and returns it to the circulation p. 340

electrode conductors of electricity that are attached to both ends of a gel allowing a current to pass through it p. 582

electron a negatively charged component of atoms p. 48

electron transport chain (ETC) the name for the third stage of respiration, it refers to a series of proteins embedded in the inner membrane of the mitochondria p. 221, 237

elongation stage third step in PCR where nucleotides are added to synthesise a complementary strand of DNA p. 576

embryo a stage of offspring development, not unique to chordates p. 463

embryonic development process that occurs during the gestation period where structures of the animal are formed under the direction of molecular signals p. 508

emigration the movement out of a population p. 412

endergonic a reaction that stores energy, the products have a greater energy than reactants p. 52

endocrine signalling when a cell releases a signalling molecule into the blood to act on a distant target cell p. 263

endocrine system the collection of glands in animals responsible for producing hormones that can be transported in the bloodstream p. 263

endocytosis a type of bulk transport that moves large substances into the cell p. 83

endonuclease any enzyme that acts like molecular scissors to cut nucleic acid strands at specific recognition sites p. 569

endosymbiosis when one organism lives inside another in a mutually beneficial relationship p. 184, 214, 444

enzyme an organic molecule, typically a protein, that catalyses (speeds up) specific reactions p. 99, 146

enzyme inhibition the inactivation of an enzyme by a molecule that binds to the enzyme and prevents it from interacting with the substrate p. 648

enzyme inhibitor a molecule that binds to and prevents an enzyme from functioning p. 158

enzyme-linked immunosorbent assay (ELISA) a technique used to identify a pathogen by determining the presence of antigen or antibodies in a sample p. 638

enzyme-substrate complex the structure formed when enzyme and substrate are bound together p. 148

epidemic a dramatically increased occurrence of a disease in a particular community at a particular time p. 637

error the difference between the measured value and the true value of what is being measured p. 4

ethanol an alcohol that is produced along with carbon dioxide during anaerobic cellular respiration in yeast, bacteria, and plants p. 231

ethical implications considerations based on moral or religious beliefs p. 616, 627

ethidium bromide a fluorescent dye that binds to DNA fragments in a gel and allows them to be visualised p. 582

eukaryote a group of single and multi-celled organisms with a nucleus and linear strands of DNA. Animals, plants, fungi, and protists are eukaryotic p. 40, 444

evolution the change in the genetic makeup of a population over successive generations p. 405

evolutionary relationship the relatedness of organisms based on shared ancestry p. 488

ex vivo scientific processes being performed on cells, tissues, or organs outside of the body p. 613

exergonic a reaction that releases energy, the products have less energy than reactants p. 52

exocytosis a type of bulk transport that moves large substances out of the cell p. 81

exons sequences of DNA that code for proteins. They make up the mRNA molecule p. 121

experimental group a group of individuals/samples in which the independent variable is manipulated. Also known as the treatment group p. 7

experimenter bias the inclination for scientists conducting research to alter their results based on their prior beliefs, for example by selecting an unrepresentative sample or by recording the results they expect to see p. 4

F

facilitated diffusion a type of passive transport where molecules move through a phospholipid bilayer with the aid of a membrane protein p. 74

$FADH_2$ a proton and electron carrier created in the Krebs cycle p. 221

fatty acid tail the hydrophobic lipid subunit of a phospholipid p. 67

femur angle the angle between the top and bottom of the femur when standing. It is greater in hominins when compared to other primates p. 529

fertile having the ability to produce offspring p. 418

first line of defence a component of the innate immune system characterised by the presence of physical, chemical, and microbiological barriers to keep pathogens out of the host organism p. 311

fitness a measure of how well an organism survives and reproduces in its environment p. 403

flagellum (pl. flagella) a tail-like structure that attaches to the side of the cell body and is used for locomotion on single-celled organisms p. 44

flora naturally occurring, non-pathogenic bacteria present in an organism p. 311

flowering plants a group of plants that reproduce using flowers, fruit, and seeds (as opposed to plants like moss, ferns, and conifers, which reproduce with spores or cones). Also known as angiosperms p. 445

fluid mosaic model the theory of how the plasma membrane is structured p. 69

foramen magnum the hole in the base of the skull through which the spinal cord passes p. 529, 536

foreign DNA DNA that is not found naturally within an organism p. 593

fossil the preserved body, impressions, or traces of an ancient organism p. 451

fossil succession the principle that fossils of the same age will be in the same layer of sedimentary rock, and fossils found in a higher or lower sedimentary layers will be younger or older respectively. Also known as the law of superposition p. 454

fossilisation the process by which an organism becomes a fossil p. 451

fossilisation bias certain organisms are more likely to be fossilised, based on physical and behavioural characteristics p. 461

founder effect the reduction in genetic diversity that occurs when a population is derived from a small group of colonising ancestors p. 412

frameshift mutations a mutation that involves the insertion or deletion of one or two nucleotides, affecting every codon from that point forward p. 394

fungi eukaryotic organisms characterised by spore production and chitinous cell walls. They can act as a pathogen and cause a number of different diseases in humans p. 304

G

gall abnormal outgrowths of tissue in plants designed to limit the spread of an invading pathogen p. 312

gel electrophoresis a technique that separates DNA fragments based on their molecular size p. 581

gene a section of DNA that carries the code to make a protein p. 108, 117, 403

gene expression the process of reading the information stored within a gene to create a functional product, typically a protein p. 119

gene flow the flow of alleles in and out of a population due to the migration of individuals p. 411

gene of interest the gene we wish to express in recombinant bacteria. This gene often encodes a protein we wish to produce in commercial quantities. Also known as the desired gene or insert DNA p. 593

gene pool all the genes in a population p. 396, 412

gene regulation the control of gene expression, typically achieved by switching transcription on or off p. 132

gene therapy the use of genetic technologies to treat genetic disorders p. 613

genetic code the set of rules by which information is encoded in genetic material p. 117

genetic drift the dramatic change in allele frequencies due to a chance event p. 412

genetic engineering the use of genetic technologies to alter DNA and RNA p. 613

genetic screening testing an individual's DNA to characterise their susceptibility to particular genetic diseases p. 614

genetic variation the differences in DNA sequences between individuals p. 405

genetically modified organism (GMO) an organism with genetic material that has been altered using gene engineering technology p. 625

genome the complete set of DNA within an organism p. 108

geographic barrier a physical factor that prevents gene flow, and thereby stops two populations from breeding together p. 419

geological time scale a system of chronological dating described in eras, eons, periods, epochs, and ages p. 443

germline cell cells involved in the generation of gametes in eukaryotes p. 396

gland a group of cells that secrete chemical substances for use in the body or to be discharged into the surroundings p. 263

glucose a six-carbon carbohydrate that comes from the food we eat p. 212, 221

glycolipid a phospholipid bound to a carbohydrate p. 68

glycolysis the first stage of aerobic respiration in which glucose is split into two pyruvate molecules p. 220

glycoprotein a protein bound to a carbohydrate p. 68

GM food genetically modified crops that are used for human or animal consumption p. 627

Golgi body an organelle made of flattened sacs of membrane involved in modifying, sorting, and packaging proteins p. 43, 83

gracile having a slender or fine build p. 536

granum (pl. grana) a stack of thylakoids p. 183, 190

H

haemagglutinin a protein on the surface of the influenza virus that attaches the virus to the host cell p. 648

half-life the time taken for half the mass of a radioisotope to break down into its products p. 453

hay fever an allergic reaction to pollen that causes inflammation of the nose resulting in itching, runny nose, sneezing, and swollen and watery eyes. Also known as allergic rhinitis p. 368

herbicide tolerance a trait that increases a plant's resistance to chemicals typically toxic to plants p. 627

herd immunity protection conferred to non-immune individuals when a high percentage of the population is immune to the same disease. Herd immunity can often be achieved through high vaccination rates p. 357

heritable transmissible from parent to offspring (i.e. encoded in genes) p. 403

histamine a molecule released by mast cells that plays a key role in inflammation p. 319

hominin a member of the taxonomic tribe Hominini that includes modern humans and our direct ancestors p. 528

hominoid a member of the superfamily Hominoidea that includes apes and humans p. 528

Homo denisova commonly called Denisovans, they are an extinct hominin species that lived alongside *Homo sapiens* with whom they are believed to have interbred. Their status as a distinct species or subspecies of *Homo sapiens* is still debated p. 549

Homo erectus an extinct hominin species that existed around 2 mya p. 536

Homo habilis an extinct hominin species that existed around 2.3 mya p. 536

Homo heidelbergensis an extinct hominin species that existed around 500 000 years ago and was the common ancestor of Neanderthals and modern humans p. 536

Homo neanderthalensis commonly called Neanderthals, they are an extinct hominin species that lived in cold climates alongside *Homo sapiens* with whom they are believed to have interbred p. 536, 549

Homo sapiens the species name for modern humans p. 527, 536

homologous structure a structure present in two or more species that may look and function very differently in each species, but is derived from a common ancestor p. 470

homozygous identical alleles at the same location on homologous chromosomes p. 427

hormone a signalling molecule released from endocrine glands that regulates the growth or activity of target cells p. 263, 274

host cell an animal or plant cell that has a pathogen living inside it p. 648

human immunodeficiency virus (HIV) a viral blood-borne infection that targets immune cells, particularly helper T cells, and destroys them, eventually leading to an acquired immunodeficiency p. 366

humoral immunity a component of the adaptive immune system in which pathogens are neutralised or destroyed via the production and secretion of antibodies. Also known as B cell immunity p. 328

hybridoma the product of the fusion between a mouse's extracted B lymphocyte and a myeloma cell p. 375

hydrogen bonds an intermolecular bond between a hydrogen of one molecule and an electronegative atom in another p. 49

hydrophilic having a tendency to be attracted to and dissolve in water p. 50, 67, 274

hydrophobic having a tendency to repel from and be insoluble in water p. 50, 67, 274

hygiene hypothesis a theory that suggests autoimmune diseases arise through a lack of contact with foreign antigens during childhood p. 365

hypertonic describes a solution with a higher solute concentration when compared to another p. 74

hyphae branching filaments of a fungus p. 304

hypothesis a testable statement that describes how experimenters expect the dependent variable to change as the independent variable changes p. 4

hypotonic describes a solution with a lower solute concentration when compared to another p. 74

I

immigration the movement into a population p. 412

immune deficiency a state in which the immune system is no longer able to protect the body against infection or disease. Also known as an immunodeficiency p. 366

immunological memory the ability of the immune system to quickly and aggressively combat a previously encountered pathogen due to T and B memory cells p. 328

impression fossil a fossil formed when an organism is encased in material but decomposes or is removed and the gap is filled with another substance. Also known as cast and mould fossils p. 452

in vitro processes or experiments performed on cells outside a living organism (e.g. in a culture dish, test tube) p. 4

in vivo processes or experiments performed in the body p. 4, 613

inbreeding sexual reproduction between two related individuals p. 414, 427

independent variable (IV) the factor(s) that is manipulated in an experiment p. 3, 22

index fossil a group of widespread fossils which existed for a short period and have a known age. Can be used as a reference to easily determine the age of unknown fossils p. 454

induced fit model a theory describing the model of the enzyme-substrate complex where a change in the conformation of the active site occurs when the substrate binds p. 149

inducer a molecule that enables the expression of the reporter by binding to the promoter sequence of the reporter gene p. 594

infectious disease a disease that is caused by a microorganism and can be transmitted between individuals p. 636

inflammatory response a series of biochemical events that occur in the body as a result of infection and/or trauma. Characterised by swelling, redness, pain, and heat in the affected tissue p. 319

influenza an illness caused by infection with the influenza virus. Also known as the flu p. 648

innate immune system a component of the immune system that is comprised of generalised and non-specific defences and/or responses to pathogens. Also known as the non-specific immune system p. 318

insect resistance a trait that gives plants extra chemical defences that kill attacking insects p. 626

integral protein a protein that is permanently secured to the plasma membrane p. 68

interbreeding refers to the mating between different species (e.g. between *Homo sapiens* and other closely related species such as Neanderthals and Denisovans). Also known as crossbreeding p. 549

interferons a cytokine released by virally infected cells that increases the viral resistance of neighbouring uninfected cells p. 319

intermolecular force an attraction or repulsion that exists between molecules p. 49

intramolecular force a bond that joins together the atoms within a molecule p. 49

introns sequences of DNA that do not code for proteins. They are spliced out during RNA processing p. 120

ion a charged atom or group that has lost or gained electrons p. 48

ionic bond a chemical bond formed by donating and accepting electrons p. 48

irreversible inhibition enzyme inhibition that involves stronger bonds that cannot be broken p. 159

isotonic describes a solution with the same solute concentration when compared to another p. 74

K

kilobase (kb) a unit of measurement that corresponds to one thousand nucleotides. Also written as kbp p. 583

L

***lac* operon** an operon in *E. coli* that contains a regulatory gene, promoter, operator, and three structural genes useful for digestion of lactose as an energy source p. 132

lactic acid the product of anaerobic cellular respiration in animals p. 230

lactic acid fermentation anaerobic cellular respiration in animals that involves glucose being broken down into pyruvate during glycolysis, followed by a conversion into lactic acid p. 230

lane the column of gel corresponding to each sample of DNA p. 583

leaf the end of a branch that shows the current (or final) form of a species p. 489

leukocytes a group of blood cells responsible for protecting the body against pathogens and foreign material. Also known as white blood cells p. 318

ligase an enzyme that joins two DNA or two RNA fragments together by catalysing the formation of phosphodiester bonds p. 570

light-dependent stage the first stage of photosynthesis, where light energy splits water molecules inside the thylakoid membranes p. 183, 190

light-independent stage the second stage of photosynthesis where carbon dioxide is used to form glucose in the stroma of the chloroplast. Also known as the Calvin cycle or the dark stage p. 183, 190

limiting factor the factor that restricts the reaction rate in a given process p. 197

lineage a direct sequence of species that evolved from a common ancestor p. 488

lipid the class of biomacromolecules typically made from fatty acids and glycerol monomers consisting of C, H, and O. Characterised by their nonpolar nature. Examples include fats, oils, and waxes p. 50

loaded the form of a coenzyme that can release stored chemical energy by donating a proton (H^+), electron, or chemical group p. 166

lock and key model a theory describing the enzyme-substrate complex, where the substrate fits into the active site perfectly like a lock and key p. 149

logbook a record of all your practical investigations. Maintaining a logbook is a compulsory component of VCE Biology p. 16

lumen the space contained within a tubular or circular membrane p. 42

lymph a pale fluid that flows through the lymphatic system and has a high concentration of leukocytes p. 339

lymph node a small secondary lymphoid tissue of the lymphatic system that is where antigen-presenting cells activate the adaptive immune system p. 341

lymphatic capillaries the smallest form of lymphatic vessel. Located in the spaces between cells p. 340

lymphatic system a large network of vessels and tissues throughout the body that form an important component of both the circulatory and immune systems p. 339

lysosome a vesicle containing digestive enzymes p. 43, 83

M

macrophage a type of leukocyte found throughout the body that engages in phagocytosis and antigen presentation p. 318

major histocompatibility complex (MHC) proteins a group of proteins present on the surface of self cells that enable the immune system to distinguish between self/non-self material. Also known as self-antigens p. 303

mammal warm-blooded vertebrates belonging to the taxonomic class Mammalia that have mammary glands, hair/fur, three middle ear bones, and one lower jawbone p. 527

mass extinction period of rapid species extinction, reducing biodiversity. Evident when the extinction rate is much greater than the background extinction rate p. 471

mast cell a type of leukocyte responsible for releasing histamine during allergic and inflammatory responses p. 319, 368

master gene a gene that controls the expression of a large number of genes in early development p. 509

maternally inherited only inherited from the mother, not the father p. 500

melting temperature (T_m) the temperature at which half of the DNA strands in a sample become single-stranded p. 500

membrane attack complex (MAC) a pore formed by complement proteins in the cell membranes of a pathogen, disrupting the membrane and leading to the pathogen's death p. 320, 330

membrane-bound organelles structures within a cell that are enclosed by a membrane p. 40

messenger RNA (mRNA) RNA molecules that are produced during transcription and carry genetic information from the DNA to the ribosomes p. 109, 117

microbiological barrier a component of the first line of defence in which the presence of normal flora limits the growth of pathogenic bacteria p. 311

missense mutation a mutation in which a nucleotide is substituted for another, changing the codon and coding for a different amino acid. Therefore, there is an effect on protein structure p. 393

mitochondrial DNA (mtDNA) circular DNA found in mitochondria p. 500

mitochondrial matrix the space inside the inner membrane of the mitochondria. The site of the Krebs cycle p. 214

mitochondrial pathway the pathway of apoptosis which is initiated by the detection of internal cellular damage. Also known as the intrinsic pathway p. 284

mitochondrion (pl. mitochondria) a double-membraned organelle that is the site of aerobic respiration p. 43, 83, 214

molecular clock a model that suggests the mutation rate can be used to determine relatedness between two organisms p. 499

molecule two or more atoms joined by covalent bonds to form a single chemical entity p. 48

monoclonal describes a clone of a cell formed asexually from a singular cell or organism p. 374

monoclonal antibodies (mAbs) identical laboratory-made antibodies produced by B cell clones p. 374

monomer a molecule that forms the smallest basic unit of a polymer p. 50, 100

motor protein a protein that converts chemical energy into mechanical work p. 99

multicellular an organism that consists of more than one cell. Most multicellular organisms have different cells (or groups of cells) specialised for different functions p. 444

multiple sclerosis (MS) an autoimmune disease in which the myelin sheath surrounding axons in the nervous system is destroyed by the body's own immune cells p. 365

mummified fossil a fossil formed when the body is under conditions that slow down or stop the decaying process p. 452

mutagens agents that can cause mutations in DNA p. 396

mutation rate the average number of mutations that occur in a gene or genome over time p. 499

mya short for 'million years ago'. Also written as Ma p. 442

myelin sheath a layer of protein-rich fatty material that wraps around an axon, increasing the speed of electrical transmission in the axon p. 366

myeloma cells rapidly dividing cancerous plasma cells which are fused with extracted B cells from mice to produce hybridomas p. 375

N

NAD^+ the unloaded form of NADH p. 166

NADH a coenzyme that is a proton (H^+) and electron carrier in cellular respiration p. 166, 220

$NADP^+$ the unloaded form of NADPH p. 166

NADPH a coenzyme that is a proton (H^+) and electron carrier in photosynthesis p. 166, 190

narrow-spectrum agent a type of antimicrobial agent that affects a small variety of microorganisms p. 640

natural active immunity protection against a pathogen conferred by antibodies produced by an individual's own immune system without medical intervention p. 355

natural immunity protection against a pathogen formed without medical intervention p. 355

natural killer (NK) cell a leukocyte responsible for the recognition and destruction of damaged and/or infected host cells p. 319

natural passive immunity protection against a pathogen conferred by antibodies produced by another individual's immune system without medical intervention (e.g. breastfeeding) p. 355

natural selection organisms that are better adapted to their local environmental selection pressures are more likely to survive and pass on their genes p. 405, 425

neuraminidase an enzyme on the surface of the influenza virus that releases the virus from the host cell p. 649

neuron a specialised cell that transmits electrical impulses in the nervous system p. 266, 365

neurotransmitter a signalling molecule that is produced and released by neurons and travels across a synapse p. 263, 275

neutrophil the most common type of leukocyte in the body. Engages in phagocytosis of pathogens and foreign material, as well as the release of cytokines p. 318

node the splitting point between two branches on a phylogenetic tree, representing a speciation event p. 489

non-cellular pathogen a pathogen that does not have a cellular structure or exhibit the processes of a living organism. Examples include viruses and prions p. 304

non-competitive inhibition the hindrance of an enzyme by binding to an allosteric site and changing the conformation of the active site to prevent substrate from binding p. 159

non-overlapping a property of the genetic code which means that nucleic acids are read in successive sets of three and each nucleotide is part of only one codon p. 118

non-recombinant plasmid a plasmid that has either ligated with itself rather than with the gene of interest or was never cut in the first place. These plasmids are selected against using antibiotic selection or reporter genes p. 594

non-self antigen a molecule from outside the body that is recognised by the immune system and initiates an immune response. Also known as a foreign antigen p. 303

non-specific describes a component of the immune system that responds the same way to all pathogens p. 311

nonpolar describes a molecule without a clearly positive or negative end. These tend to be hydrophobic p. 49, 69

nonsense mutation a mutation in which a nucleotide is substituted for another, changing the codon to a stop codon, ceasing transcription on the gene. Therefore, there is an effect on protein structure p. 393

nuclear DNA DNA that is located in the nucleus of a cell p. 109, 500

nucleic acid the class of macromolecules that includes DNA and RNA. All nucleic acids are polymers made out of nucleotide monomers p. 50, 108

nucleotide the monomer unit of nucleic acids. Made up of a nitrogen-containing base, a sugar molecule (ribose in RNA and deoxyribose in DNA), and a phosphate group p. 108

nucleus an organelle present in eukaryotic cells consisting of a double membrane that contains the cell's genetic material p. 43

numerical variables factors that are measured as a number such as height, count of population, and age p. 22

nutrient agar a jelly-like substance containing nutrients needed for bacterial survival in culture p. 594

O

offspring children of a parent p. 403

oligodendrocyte a cell of the nervous system specialised to support the function of neurons p. 366

open inquiry an investigation that is student-centred, whereby students develop their own question and experiment p. 20

operator a short region of DNA that interacts with regulatory proteins to alter the transcription of an operon p. 132

operon a cluster of linked genes that all share one promoter region and are transcribed at the same time p. 132

opposable digit a digit (either the thumb or the big toe) that is able to touch all the other digits on the same appendage p. 528

opsonisation the mechanism by which complement proteins attach to the surface of pathogens, making them easier to phagocytose p. 320

optimal the point at which, for a given condition (e.g. temperature), the maximum function of an enzyme occurs p. 149, 198, 238

organelle cellular structures that perform specific cellular functions p. 41

organic a molecule containing covalently linked carbon p. 50

origin of replication (ORI) a sequence found in prokaryotes that signals the start site of DNA replication p. 593

osmosis the passive transport of a solvent (typically water) through a semipermeable membrane from a hypertonic solution to a hypotonic solution p. 74

Out of Africa hypothesis a well-supported model for human migration that suggests *Homo sapiens* moved out of Africa in several waves and replaced other hominin species in Eurasia p. 548

outlier readings that vary drastically from other results p. 6

P

pandemic an epidemic that has spread across multiple countries and/or continents p. 637

paracrine signalling when a cell releases a signalling molecule that acts on a neighbouring target cell p. 263

parasite an organism that lives in or on another organism, usually deriving nutrition from the host organism p. 304

passive immunity protection against a pathogen conferred by externally produced antibodies p. 355

passive transport the movement of molecules through a semipermeable membrane and down the concentration gradient, without an input of energy p. 73

pathogen an agent that causes disease p. 303, 636, 648

peptide a short chain of amino acids p. 99

peptide bond the chemical bond linking two amino acid monomer subunits p. 101, 122

peptide hormone a protein signalling molecule that regulates physiology or behaviour p. 99

peripheral protein a protein that is temporarily secured to the plasma membrane p. 68

permineralised fossil a fossil formed when organic matter is gradually replaced by hard minerals. Also known as a mineralised fossil p. 451

personal error mistakes or miscalculations due to human fault. Can be eliminated by performing the experiment again correctly p. 4

phagocyte a group of leukocytes responsible for the endocytosis and destruction of pathogens and foreign material p. 285, 318

phagocytosis endocytosis of solid material or food particles p. 84, 285

phenotype the physical or biochemical characteristics of an organism, resulting from expression of a gene (or set of genes) and interaction with the environment p. 396, 412

pheromone chemicals that are excreted by one organism and produce a response in another organism p. 263

phosphate head the hydrophilic subunit of a phospholipid p. 67

phosphodiester bond the chemical bond linking a five-carbon sugar to a phosphate group p. 108

phospholipid the main molecule of which membranes are composed. They have a phosphate head and two fatty acid tails p. 67

phospholipid bilayer a double layer of amphiphilic molecules that forms the primary component of cell membranes p. 67

photolysis of water the reaction by which water is split into hydrogen and oxygen using light energy p. 190

photosynthesis the process of capturing sunlight energy to power the production of glucose and oxygen from carbon dioxide and water p. 182

phototroph an organism that uses light energy to make organic compounds for nutrition p. 444

phylogenetic tree a diagram used to show the relatedness between organisms p. 488

phylogenetics the study of the relatedness between organisms p. 488

physical barrier a component of the first line of defence that features solid or fluid obstacles that block pathogen entry e.g. skin, mucus p. 311

pinocytosis endocytosis of liquid or dissolved substances p. 84

placebo a substance that has no therapeutic benefit or side effects and can be used as a control when testing new drugs p. 3

plant cell eukaryotic cells that contain a cell wall or chloroplasts and are found in organisms in the kingdom Plantae p. 41

plasma cell a differentiated B lymphocyte that is responsible for the generation and secretion of antibodies during the humoral response p. 329

plasma membrane the phospholipid bilayer and embedded proteins which separate the intracellular environment from the extracellular environment p. 44, 66, 274

plasmid a small, circular loop of DNA that is separate from a chromosome, typically found in bacteria p. 569

plasmid vector a plasmid that is modified to be an ideal vector for transformation experiments p. 593

platelets a component of blood responsible for forming clots and stopping bleeding p. 321

point mutation a mutation that alters one nucleotide p. 393

polar describes a molecule with both a positive end and negative end. These tend to be hydrophilic p. 49, 69

poly-A tail a stretch of adenine nucleotides added to the 3' end of pre-mRNA during RNA processing p. 120

polymer a large molecule that is made up of small, repeated monomer subunits p. 50, 100

polymerase an enzyme that synthesises a polymer from monomers, such as forming a DNA strand from nucleic acids p. 570

polymerase chain reaction (PCR) a laboratory technique that results in the production of many identical copies of DNA over a short period of time through repeated thermal cycling p. 576

polypeptide a long chain of amino acids. Proteins can be made of one or many polypeptides p. 99

polyploidy when an organism contains additional sets of each chromosome in its genome p. 395

population a group of individuals of the same species living in the same location p. 403, 411

practical report a structured record of an experiment p. 17

precise two or more measurements that closely agree with each other p. 3

precursor messenger RNA (pre-mRNA) the immediate product of transcription of a DNA sequence. Requires modifications before it can undergo translation p. 119

prehensile the ability to grasp objects p. 528

primary data results collected from experiments, interviews, or surveys undertaken by the researcher p. 16

primary immune response the reaction of the immune system to an antigen it has not previously come into contact with p. 356

primary lymphoid tissue components of the lymphatic system that are responsible for the production and maturation of lymphocytes. Includes bone marrow and the thymus p. 340

primary structure the first level of protein structure, which is the order of amino acids in the chain p. 101

primate a member of the order Primates that's comprised of about 400 different living species and that share a number of features including opposable digits and binocular vision p. 527

primer a short, single strand of nucleic acids that act as a starting point for polymerase enzymes to attach p. 570, 576

prion an abnormally folded protein in the brain or central nervous system (CNS) of a mammal that induce other proteins to misfold. Causes a number of neurodegenerative diseases p. 304

product the transformed molecule(s) produced in a reaction p. 147

prokaryote a group of single-celled organisms with no nucleus and a circular loop of DNA. Bacteria and archaea are both prokaryotic p. 40, 443

promoter the sequence of DNA to which RNA polymerase binds p. 119, 132

prophylaxis a measure taken to prevent the onset of an illness p. 649

prosthetic group a non-protein group bound to a protein. For example, a vitamin or ion p. 102

protein a type of biomacromolecule made of amino acid chains folded into a 3D shape p. 50, 81, 99

protein carrier a polypeptide that undergoes conformational change to transport molecules across a membrane p. 74

protein channel a protein-based pore in a phospholipid bilayer that selectively enables transport of large or polar molecules p. 74

protein pump a polypeptide that transports molecules across a membrane against its concentration gradient with the aid of ATP p. 75

proteome all the proteins that are expressed by a cell or organism p. 99

protist a single-celled eukaryote from the kingdom Protista. Examples include amoeba and algae p. 444

protozoa a phylum of single-celled eukaryotes that can cause disease p. 304

pyroptosis a highly programmed form of cell death initiated by the human immunodeficiency virus in helper T cells p. 367

pyruvate pyruvate a three-carbon molecule which is formed from the splitting of glucose p. 220

Q

qualitative data non-numerical data, typically collected through observations and interviews. Also known as categorical data p. 3

quantitative data numerical data that expresses an amount or range of values p. 3

quaternary structure the level of protein structure where multiple polypeptide chains bond together, or prosthetic groups are added to form a fully functional protein p. 101

R

R-group the variable part of the amino acid molecule. It can be one of twenty variations and determines the identity of the amino acid p. 100

radioisotope a radioactive atom of a specific element. This atom breaks down into a more predictable and stable product p. 453

radiometric dating a dating technique used to determine the absolute age of a fossil by measuring the relative amounts of radioisotopes to their products p. 453

random coil a secondary structure of proteins that is neither alpha helix nor beta-pleated sheet p. 101

random error variation in results caused by uncontrollable conditions between replicates in the measuring process, resulting in a less precise spread of readings. Can be reduced using more replicates or refining the measurement process p. 4

rational drug design a process in which scientists study the shape and charge of a target molecule and design a complementary–shaped drug that gives rise to a therapeutic benefit p. 648

raw data results that have not been processed, manipulated, or formatted for use p. 17

reactant the molecule(s) that undergoes transformation into the product. When enzymes are involved, the reactant(s) is called a substrate p. 146

reading frame the order in which nucleotide triplets or codons are divided into a consecutive, non-overlapping sequence p. 394

reception the detection of a signal due to a change in the internal or external environment p. 255

receptor a structure that detects a signal, usually a protein p. 255

receptor protein a protein within or on the surface of a cell that binds with signalling molecules, leading to a change in cellular activity p. 99

recessive allele a trait that can be masked by a dominant allele on the homologous chromosome p. 427

recognition site a specific target sequence of DNA upon which a restriction enzyme acts p. 569

recombinant plasmid a plasmid vector that has ligated to the gene of interest to form a new single piece of circular DNA p. 594

regulatory gene a segment of DNA responsible for producing proteins that control the expression of other gene(s) p. 131, 508

relative age the age of a fossil as determined by relative dating techniques. Describes the age of a fossil compared to other fossils, instead of a fossil's age in years p. 454

Relenza a drug designed to combat the influenza virus p. 648

reliable describes a measurement, tool, or experiment that produces similar results when repeated and reproduced, and therefore can be trusted p. 5

repeatable an experiment/measurement in which scientists, using the methods they designed, can obtain the same result multiple times p. 5

replicates multiple experimental runs exposed to the same level of the IV p. 3

reporter gene a gene located on the plasmid vector that expresses an easily identifiable characteristic, allowing scientists to identify transformed bacteria. For example, green fluorescent protein (GFP) p. 593

representative sample the subset of a population (e.g. of bacteria, tomato plants, yeast) that takes part in the experiment and accurately reflects the characteristics of the larger group p. 5

repressor protein a protein coded for by a regulatory gene that prevents gene expression by binding to an operon p. 132

reproducible an experiment/measurement in which a group of scientists, using the original methods designed by others, can obtain the same results as another group's experiment p. 5

response the action of a cell, organ, or organism caused by a signal p. 255

restriction enzyme a bacterially-produced enzyme that acts like molecular scissors to cut nucleic acid strands at specific recognition sites. They are a type of endonuclease p. 569

reversible inhibition enzyme inhibition that involves weaker bonds that can be overcome p. 159

Rhesus antigen an antigen on the surface of red blood cells that can cause an immune response if not matched correctly between donor and receiver p. 331

ribosomal RNA (rRNA) RNA that is a key structural component of ribosomes, which assemble proteins p. 109, 122

ribosome an organelle made of rRNA and protein that is the site of protein synthesis. Can be free or attached to RER p. 43, 82, 120

ribosome subunit a structure that forms part of a ribosome. Each ribosome is comprised of a small and a large subunit p. 122

RNA (ribonucleic acid) a single stranded nucleic acid chain made up of nucleotides. Includes mRNA, rRNA, and tRNA p. 109, 117

RNA polymerase the enzyme responsible for copying a DNA sequence and constructing an mRNA sequence during transcription p. 119

robust having a larger and stronger build p. 536

root represents the most recent common ancestor for all members of the phylogenetic tree p. 489

rough endoplasmic reticulum (RER) a membranous organelle shaped like a series of connected, flattened cylinders that folds and transports proteins p. 43, 83

S

sagittal crest a ridge of bone running from front-to-back along the top of the skull p. 529

Sahelanthropus tchadensis an early hominin species that is thought to be the last common ancestor of modern humans and chimpanzees p. 536

saturation point the point at which a substance (e.g. an enzyme) cannot receive more of another substance (e.g. a substrate) p. 150

scatter plot a graph in which the relationship between variables is plotted using dots, through which a trendline may reveal correlation. Also known as a scattergram p. 22

School Assessed Coursework (SAC) an internally-marked assessment (e.g. practical report, test, media response) that contributes to your overall study score in VCE Biology p. 16

second line of defence a component of the innate immune system characterised by the non-specific response to injury and pathogens by a variety of cells and molecules p. 317

second messenger a group of small molecules that relay a signal from a transmembrane receptor during signal transduction. Also known as secondary messengers p. 275

secondary data results from sources other than the researcher's own investigations p. 16

secondary immune response the reaction of the immune system to an antigen it has previously been exposed to p. 356

secondary lymphoid tissue components of the lymphatic system that are responsible for the maintenance of mature lymphocytes and the activation of the adaptive immune response. Includes lymph nodes (including the tonsils) and the spleen p. 340

secondary structure the level of protein structure where the amino acid chain forms either alpha helices, beta pleated sheets, or random coils p. 101

secretory products the substances inside a vesicle that are being transported out of the cell p. 82

sedimentary rock rock that has formed through the accumulation of sediment and hardening under pressure p. 451

selection pressure a factor in the environment (e.g. limited resources, deforestation, changing temperature, predation) that impacts an individual's ability to survive and reproduce. It causes a struggle for survival p. 405

selectively permeable a property of cell membranes that ensures only specific substances pass across them. Also known as semipermeable p. 68, 73

sexual dimorphism a difference in appearance between sexes of the same species p. 536

short tandem repeats (STR) short, repeated sequences of nucleotides found in the non-coding regions of nuclear DNA p. 615

signal amplification a process during signal transduction whereby a single signal carried by a molecule is converted into many signals carried by many molecules p. 275

signal transduction the series of events that occur after the reception of a signal which results in the generation of a response p. 255, 273

signalling molecule a molecule which can interact with and initiate a response in a target cell p. 255, 263, 273

silent mutation a mutation in which a nucleotide is substituted for another, changing the codon, while coding for the same amino acid. Therefore, there is no effect on protein structure p. 393

smooth endoplasmic reticulum (SER) a membranous chain of connected and flattened sacs which are not coated with ribosomes. They are responsible for the production of lipids in a cell p. 43

social implications consequences that affect economics, politics, or society p. 616, 627

solute a substance dissolved in the solvent p. 74

solvent a liquid in which a solute is dissolved, forming a solution p. 74

somatic cell any cell in an organism that is not a germline cell p. 396

species a group of individuals who are able to breed with each other and produce viable and fertile offspring p. 418

spleen an organ located in the upper abdomen that serves a variety of functions in the immune system and the regulation of red blood cells p. 342

spliceosome the enzyme that removes introns from the pre-mRNA molecule during RNA processing p. 121

splicing process during gene expression where introns are cut out of a pre-mRNA molecule, and exons are joined together p. 120

standard ladder a mixture of DNA fragments of known length that are used in order to infer the size of fragments in a sample p. 582

start codon the sequence of three nucleotides in mRNA that signals the start of translation p. 118

sticky end a staggered cut (rather than straight cut) by a restriction enzyme resulting in overhanging nucleotides p. 569

stimulus (pl. stimuli) an event or molecule that can initiate a response p. 255

stimulus-response model a model that describes how a system responds to a stimulus via the three-step process of reception, transduction, and response p. 255, 273

stoma (pl. stomata) small pores on the leaf's surface that open and close to regulate gas exchange p. 183, 190, 196

stop codon the sequence of three nucleotides in mRNA that signals the end of translation p. 118

storage protein a protein that is a reserve of amino acids and metal ions p. 99

strata separate layers within sedimentary rock p. 454

stroma the fluid substance that makes up the interior of the chloroplasts. It is the site of the light-independent stage of photosynthesis p. 183, 191

stromatolite a rock structure formed when minerals (e.g. limestone) are trapped by prokaryotes p. 443

structural gene a segment of DNA that doesn't code for regulatory proteins, but codes for proteins that will be used functionally or structurally throughout a cell or organism p. 132, 509

structural protein a type of protein that confers strength and shape to cells p. 99

structured inquiry an investigation in which students explore a teacher-proposed question through a prescribed procedure p. 20

struggle (for survival) the battle for organisms to survive and reproduce in their environment, caused by selection pressures and limited resources p. 403

substrate the reactant of a reaction that an enzyme catalyses p. 146

sugar-phosphate backbone the strong covalently linked chain of five-carbon sugar molecules and phosphate groups in a nucleic acid chain p. 108

supercontinent a massive historical landmass (eg. Pangaea, Gondwana, Laurasia) that broke apart to form the modern continents p. 462

sympatric speciation the divergence of a species from an original species without the presence of a geographical barrier p. 419

synapse the junction between a neuron and a target cell where neurotransmitters cross p. 266, 365

systematic error faults that cause measurements to differ from the true value by a consistent amount each time a measurement is made, resulting in a less accurate result. Can be reduced by calibrating and maintaining instruments p. 4

T

T cytotoxic cell (T_c) a differentiated T lymphocyte that is responsible for the destruction of infected or abnormal cells p. 284, 332

T helper cells (T_h) a type of differentiated T lymphocyte that supports the functioning of a number of different immune cells, including the cloning and differentiation of selected T and B cells p. 328

T lymphocyte a type of lymphocyte that plays an important role in cell-mediated immunity which differentiates into cytotoxic T cells and T memory cells p. 328

T memory cell a differentiated T lymphocyte that is responsible for providing long-lasting immunological memory p. 333

***Taq* polymerase** a heat-resistant DNA polymerase enzyme that amplifies a single-stranded DNA molecule by attaching complementary nucleotides p. 576

TATA box a type of promoter region to which RNA polymerase binds p. 119

taxon (pl. taxa) a term referring to a group of organisms (eg. species, genus, family, phylum) p. 489

tectonic plates Earth's outer crust is divided into tectonic plates that float on the magma below. These movements explain several natural phenomena, including earthquakes and mountain range formation p. 462

template strand the strand of DNA transcribed by RNA polymerase to produce a complementary mRNA strand p. 119

termination sequence a sequence of DNA that signals the end of transcription p. 119

tertiary structure the 3D shape of the polypeptide chain p. 101

the fossil record documentation of fossils across time and space p. 461

the Krebs cycle the second stage of aerobic cellular respiration, where multiple reactions occur to create ATP and loaded NADH and $FADH_2$. Also known as the citric acid or TCA cycle p. 221

third line of defence a subset of the immune system within vertebrates that is comprised of the humoral and cell-mediated responses which create a specific immune response and form immunological memory. Also known as the adaptive immune system or specific immune response p. 328

thylakoid a flattened sac-like structure inside the chloroplast. Each thylakoid is made up of a chlorophyll-containing membrane enclosing a lumen. Thylakoids are the location of the light-dependent stage of photosynthesis p. 183, 190

thymus a primary lymphoid organ located in the chest. Serves as the site of T cell maturation p. 342

tonsils the name given to the two lymph nodes that reside at the back of the throat p. 342

trace fossil fossils of objects or structures indicating the presence of organisms, rather than the organisms themselves (e.g. nests, footprints, and burrows) p. 452

transcription the process whereby a sequence of DNA is used to produce a complementary sequence of mRNA p. 117

transcription factor proteins that bind to the promoter region and control the function of RNA polymerase p. 119

transduction cascade the relaying of a signal from a transmembrane receptor to the cytosol or nucleus, involving many second messengers and proteins p. 276

transfer RNA (tRNA) RNA that recognises individual codons on the mRNA strand and adds the corresponding amino acid to the polypeptide chain during protein synthesis p. 109, 122

transformation the process by which bacteria take up foreign DNA from their environment. Scientists use this process to introduce recombinant plasmids into bacteria p. 594

transformed data results that have been converted from their raw format into a more visually sensible presentation that is easier to analyse p. 17

transgenic organism (TGO) a type of GMO that contains genetic material from another species that has been artificially introduced p. 625

transitional fossil fossils that show an intermediate stage of evolution p. 461

translation the process whereby an mRNA sequence is used to produce a corresponding amino acid sequence to build a polypeptide p. 117

transmembrane protein an integral protein that spans from the intracellular to the extracellular side of the plasma membrane p. 68, 275

transport protein a protein that moves substances across membranes or around organisms p. 99

trendline a line that shows the main pattern followed by a set of points on a graph. Also known as a line of best fit p. 24

trichomes small hairs on the surface of plants used to deter pathogens and/or insects p. 312

triplet a sequence of three nucleotides in DNA coding for one amino acid p. 117

U

uncertainty a quantification of the error associated with a measurement, often represented by the symbol '±' after a reading p. 4

uncontrolled variable a factor that is not kept constant or accounted for throughout the experiment. Also known as an extraneous variable p. 8

universal a property of the genetic code which means that the same nucleic acid sequence codes for the same amino acids in all living things p. 118

unloaded the form of a coenzyme that cannot release stored chemical energy, but is free to accept a proton (H^+), electron, or chemical group p. 166

V

vaccination program a series of vaccinations designed to confer an individual with immunity to a disease. Also known as a vaccination schedule p. 356

vaccine a medical treatment containing antigens designed to stimulate an individual's immune system against a pathogen without causing disease p. 355

vacuoles a membrane-bound sac that is used for water and solute storage. It can also play a role in maintaining plant cell structure p. 44

valid a measurement or experiment that actually tests what it claims to be evaluating p. 5

vasodilation the expansion of blood vessels p. 320

vector a means of introducing foreign DNA into an organism; plasmids are a popular vector in bacterial transformation p. 593

vector an organism that is not affected by a disease but spreads it between hosts p. 639

venom inhibitors a molecule in the blood that locks onto venom molecules (e.g. snake or spider venom) and prevents them from reacting with cells in the body p. 319

vesicle a small fluid-filled organelle enclosed in a phospholipid membrane that transports substances around the cell p. 82

vestigial structure a part of an organism that has lost all or most of its usefulness as a result of evolution by natural selection p. 470

viable able to survive p. 418

virulence the potential of a pathogen to cause harm p. 356, 636

virus an infective agent composed of genetic material enclosed in a protein coat that requires a host cell to multiply p. 304, 648

W

well an indent in the gel into which a DNA sample is loaded p. 582

worm an invertebrate that can cause disease in its host by acting as a parasite p. 304

X

x-ray crystallography a technique used to determine the structure of target molecules p. 648

Y

yeast unicellular eukaryotic organisms from the kingdom Fungi p. 230

Z

zygote the cell formed by the combination of two gamete cells p. 463

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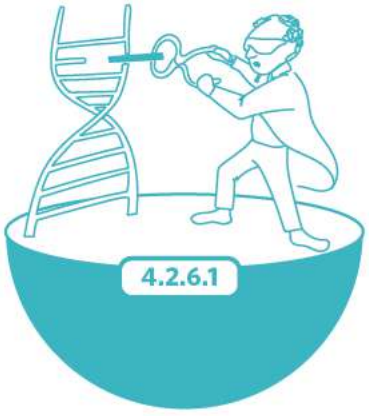
BONUS CHALLENGE: 'JOINING YOUR LEARNING TOGETHER'

Biology is like love. It's everywhere, it's beautiful, but it's sometimes really hard to understand. At Edrolo, if there's something we don't understand we find it helps to look at it in a different light. Rather than just re-reading the same passage from a textbook over and over, or endlessly copying out the Krebs cycle to memorise it, we try and represent concepts and ideas in a different way. We reckon it's a great way to make learning interesting, and think you should give it a go too.

On the back cover of our book, we've included some examples of drawings we've done to help explain difficult concepts. Of course, all the drawings include Andrew Douch because there's no one better at explaining difficult biology theories. See if you can identify the biological concepts being explored in each drawing.



Can you come up with your own drawing that helps explain a piece of biology theory? Or have you come up with another creative way to represent a piece of theory that you've found difficult, like a short story or song? A piece of macaroni art?

If so, we'd love you to send them through to #teambio at ***contentteam@edrolo.com***