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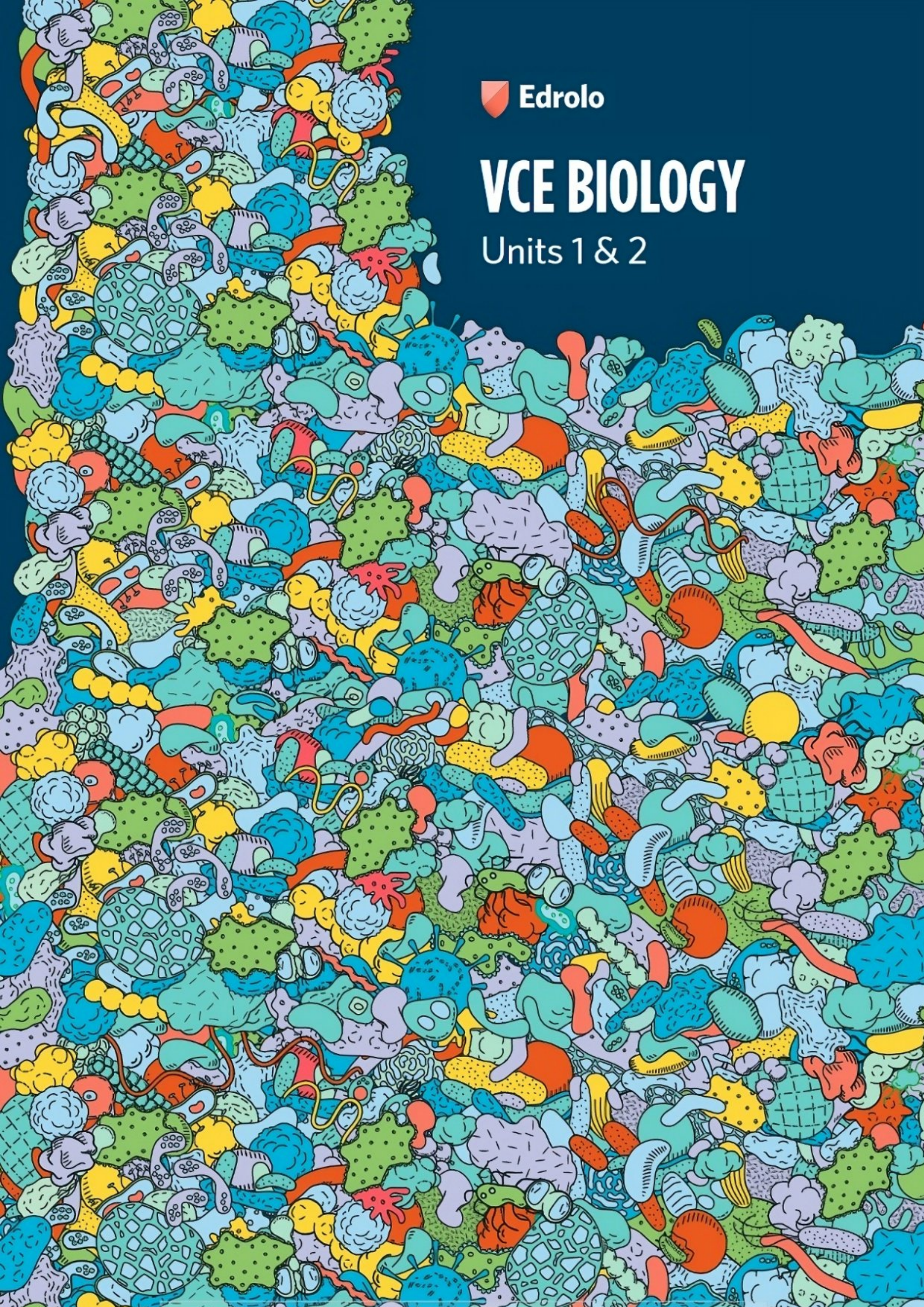
VCE BIOLOGY

Units 1 & 2



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VCE BIOLOGY

Units 1 & 2

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Edrolo

At Edrolo, we're transforming the way the students learn and teachers teach.

Our mission is simple: to improve education.

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Our offices sit upon the lands of Australia's first peoples – the Wurundjeri people of the Kulin Nations. As we work together, we acknowledge this and pay our respects to Elders both past and present, and emerging leaders. Aboriginal and Torres Strait Islander peoples are advised that this book may contain names or images of people who are now deceased.

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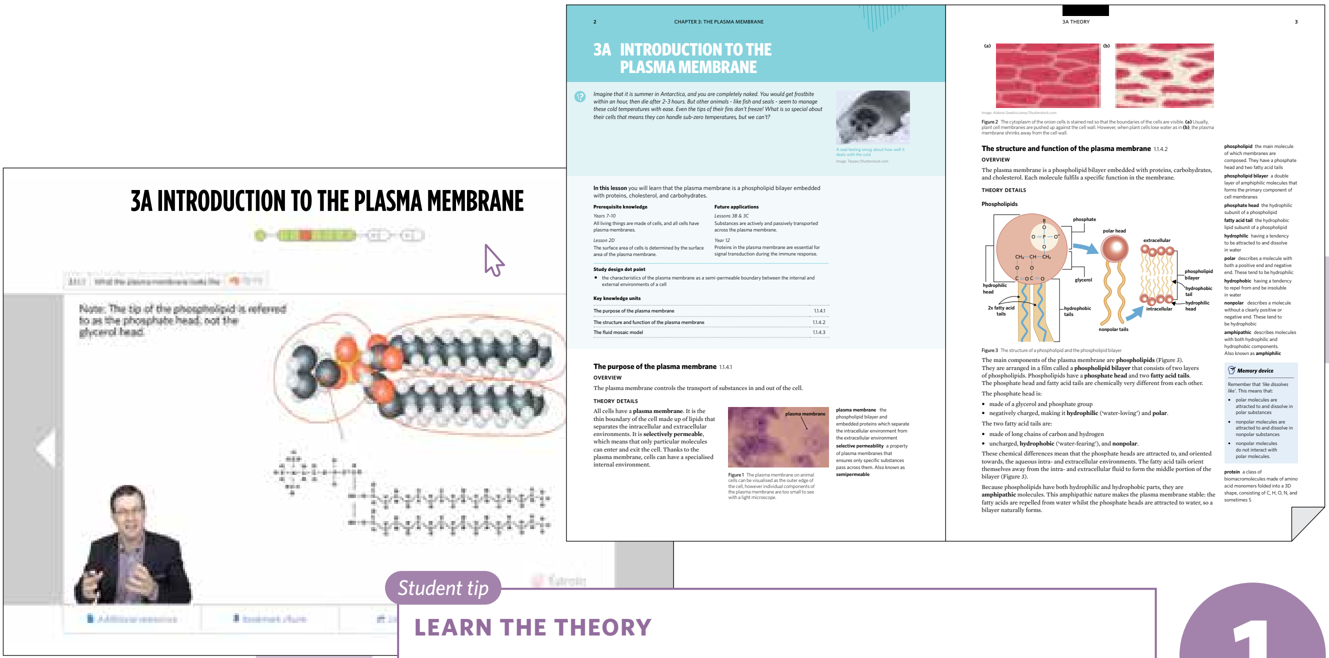
CONTENTS

USING THIS RESOURCE TO TEACH AND LEARN



Student tip

LEARN THE THEORY

Every dot point in your study design is covered in our video lessons and textbook theory – perfect to use for pre-learning, during class, and as revision.

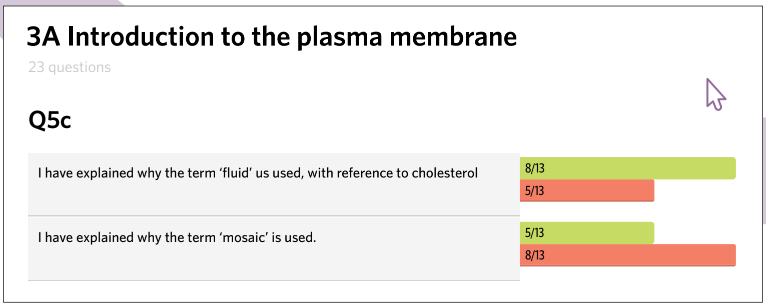
1

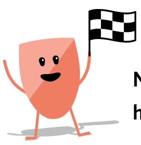
Teacher tip

EVALUATE STRENGTHS AND AREAS FOR IMPROVEMENT

Teachers see class-level data and individual student responses – use this to provide feedback, differentiate student learning, plan future lessons, and inform the revision program of your students.

4





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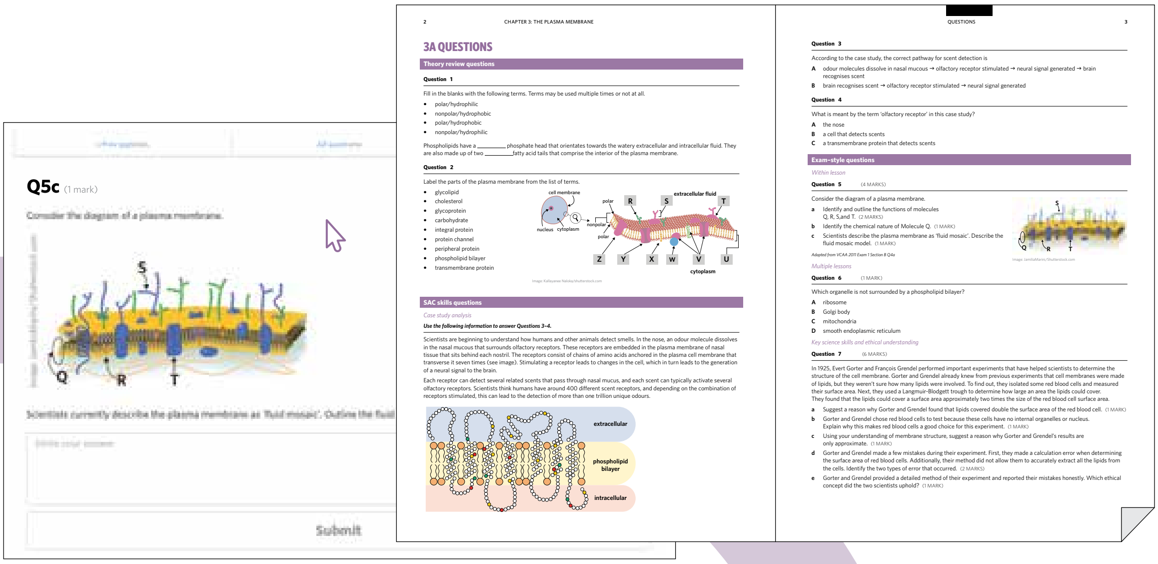


2

Student tip

CHECK FOR UNDERSTANDING

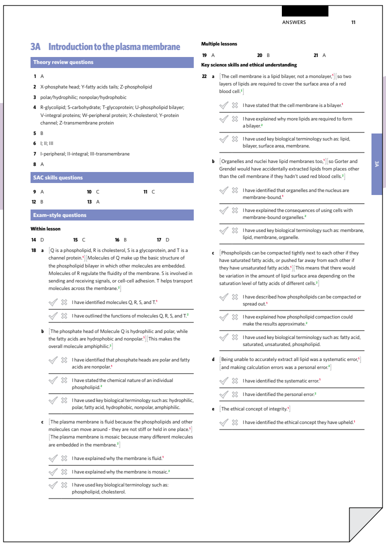
Each lesson has theory review questions, SAC skill questions, and exam-style questions so you can apply your knowledge in different ways to consolidate your learning. You'll also find tests/exams within each area of study.

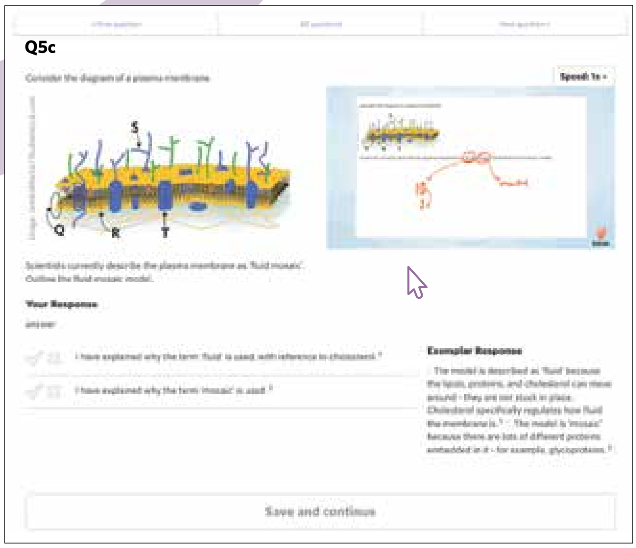
3

Student tip

SELF-ASSESS AND GET FEEDBACK

At the back of your textbook you'll find exemplar responses and checklists for every SAC and exam-style question. In your Edrolo account, you'll find video solutions as well as the interactive checklists and exemplar responses. Use these answers to target your revision and get the greatest impact from your study time. This enables you to focus on the parts of the theory you struggled with, and ask your teacher for support if you get totally stuck!





FEATURES OF THIS BOOK

Edrolo's VCE Biology Units 1 & 2 textbook has the following features.

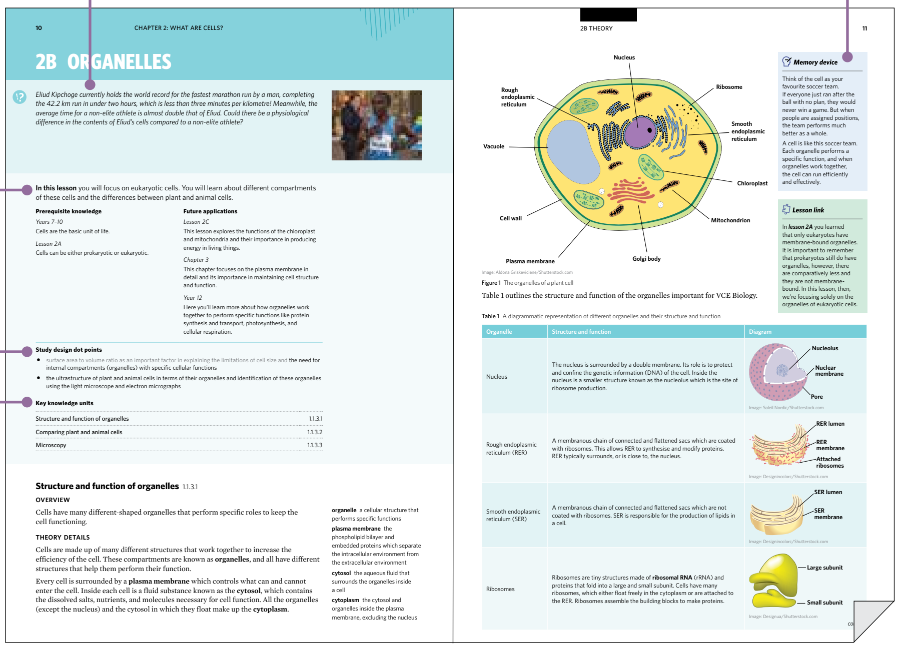
Hooks pose a real-life problem that you should be able to solve by the end of the lesson.

Explore boxes include memory devices, lesson links, case studies, and theory in action boxes which help broaden your understanding of the theory.

Learning timelines outline what you have already learned in previous lessons or from Years 7–10, what you will learn in this lesson, and how this knowledge will be used in future lessons or in Year 12.

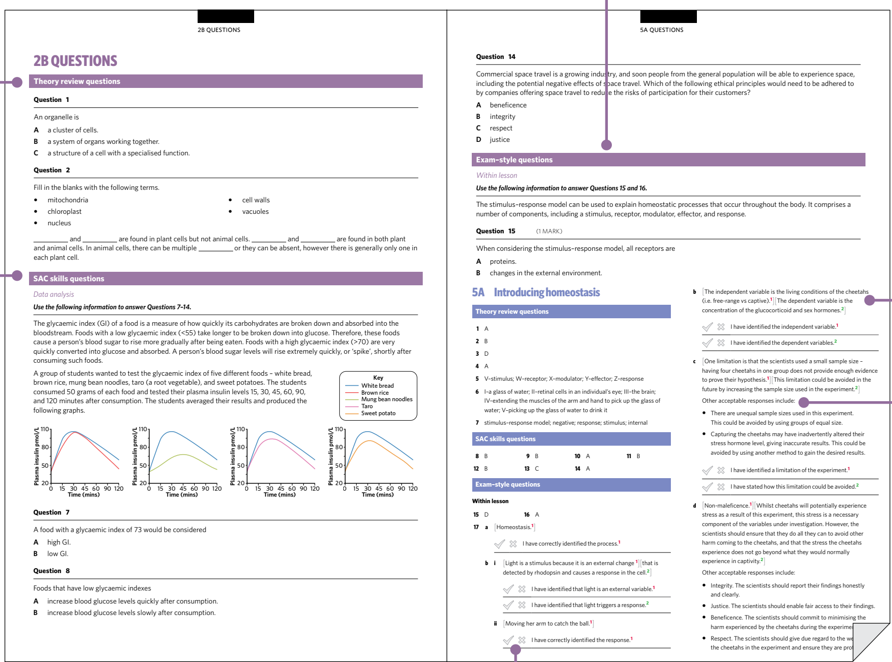
Study design dot points from the VCAA curriculum provide explicit links between our lessons and the syllabus.

Key knowledge units break down the theory into smaller chunks and can be used to help navigate the corresponding theory lesson videos online.



Theory review questions test if students can remember the basic theory and overcome common misconceptions. They are stepping stones between the content and exam-style questions.

Exam-style questions reflect the style of your end-of-year exam in Year 12. These include questions from both within the lesson and from multiple lessons, plus questions that test key science skills and ethical understanding in the context of the theory that you just learned.



Exemplar responses are provided for every exam-style question to show you what a full mark response could look like.

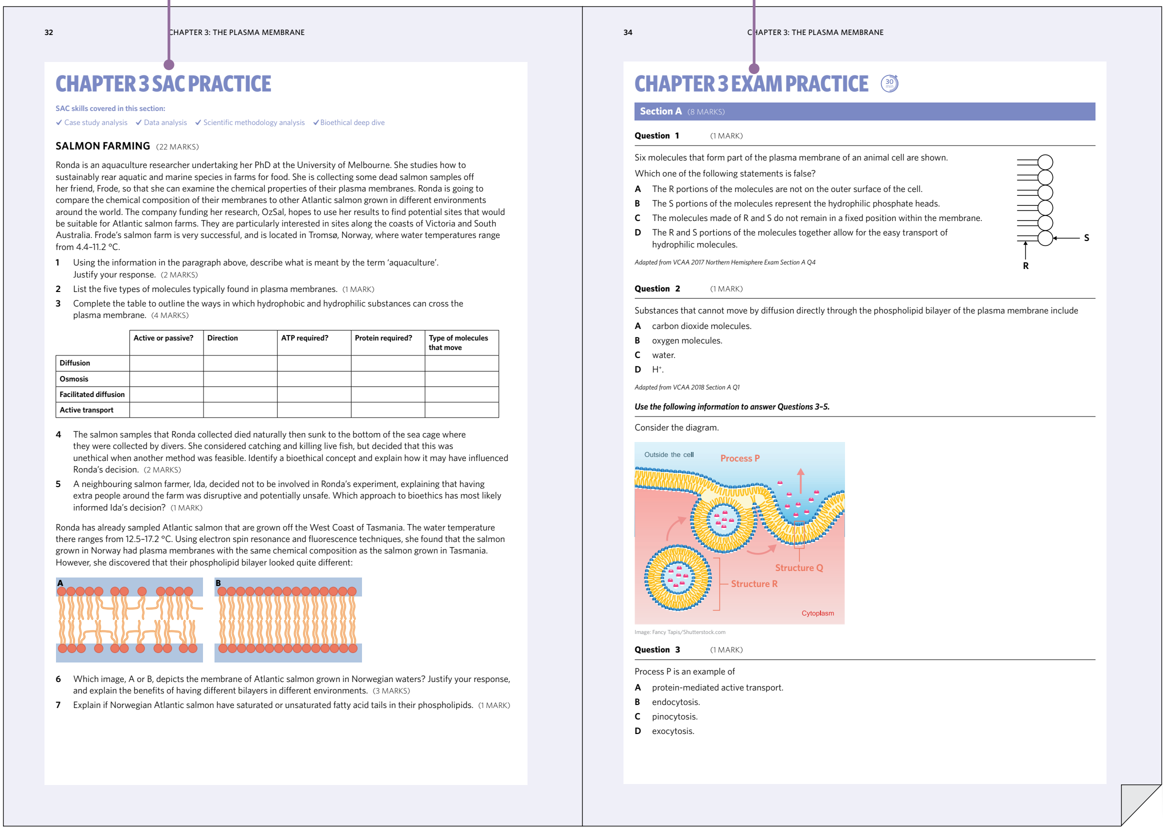
Other acceptable responses are included when there are multiple answers that could achieve full marks.

SAC skills questions build your skillset to tackle Year 12 SACs. You'll get to hone your ability to analyse case studies, evaluate bioethical issues, interpret data, and compare scientific methodologies.

Checklists break answers down into the smallest components required to get full marks. Checklists also show you how to articulate your response coherently, by including key terms or comparative language.

Practice SACs are activities that put your case study analysis, data analysis, scientific methodology comparison, and/or bioethical analysis skills to the test. It is important to develop these skills in Units 1 & 2, as these are the core SAC assessments in Units 3 & 4 from 2022 onwards.

The **practice exam** is a 20-mark set of questions that, if sat in 30 minutes, replicates the experience of a VCAA exam. Each chapter has a carefully selected ratio of multiple-choice and short-answer questions to reflect how the information is assessed on VCAA exams.



32 CHAPTER 3: THE PLASMA MEMBRANE

CHAPTER 3 SAC PRACTICE

SAC skills covered in this section:
✓ Case study analysis ✓ Data analysis ✓ Scientific methodology analysis ✓ Bioethical deep dive

SALMON FARMING (22 MARKS)

Ronda is an aquaculture researcher undertaking her PhD at the University of Melbourne. She studies how to sustainably rear aquatic and marine species in farms for food. She is collecting some dead salmon samples off her friend, Frode, so that she can examine the chemical properties of their plasma membranes. Ronda is going to compare the chemical composition of their membranes to other Atlantic salmon grown in different environments around the world. The company funding her research, OzSal, hopes to use her results to find potential sites that would be suitable for Atlantic salmon farms. They are particularly interested in sites along the coasts of Victoria and South Australia. Frode's salmon farm is very successful, and is located in Tromsø, Norway, where water temperatures range from 4.4–11.2 °C.

1 Using the information in the paragraph above, describe what is meant by the term 'aquaculture'. Justify your response. (2 MARKS)
2 List the five types of molecules typically found in plasma membranes. (1 MARK)
3 Complete the table to outline the ways in which hydrophobic and hydrophilic substances can cross the plasma membrane. (4 MARKS)

	Active or passive?	Direction	ATP required?	Protein required?	Type of molecules that move
Diffusion					
Osmosis					
Facilitated diffusion					
Active transport					

4 The salmon samples that Ronda collected died naturally then sunk to the bottom of the sea cage where they were collected by divers. She considered catching and killing live fish, but decided that this was unethical when another method was feasible. Identify a bioethical concept and explain how it may have influenced Ronda's decision. (2 MARKS)
5 A neighbouring salmon farmer, Ida, decided not to be involved in Ronda's experiment, explaining that having extra people around the farm was disruptive and potentially unsafe. Which approach to bioethics has most likely informed Ida's decision? (1 MARK)

Ronda has already sampled Atlantic salmon that are grown off the West Coast of Tasmania. The water temperature there ranges from 12.5–17.2 °C. Using electron spin resonance and fluorescence techniques, she found that the salmon grown in Norway had plasma membranes with the same chemical composition as the salmon grown in Tasmania. However, she discovered that their phospholipid bilayer looked quite different:

A B

6 Which image, A or B, depicts the membrane of Atlantic salmon grown in Norwegian waters? Justify your response, and explain the benefits of having different bilayers in different environments. (3 MARKS)
7 Explain if Norwegian Atlantic salmon have saturated or unsaturated fatty acid tails in their phospholipids. (1 MARK)

34 CHAPTER 3: THE PLASMA MEMBRANE

CHAPTER 3 EXAM PRACTICE

30 min

Section A (8 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 R and S do not remain in a fixed position within the membrane.
D The R and S portions of the molecules together allow for the easy transport of hydrophilic molecules.

S
R

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

Use the following information to answer Questions 3–5.

Consider the diagram.

Outside the cell
Process P
Structure Q
Structure R
Cytoplasm

Image: Fancy Tapis/Shutterstock.com

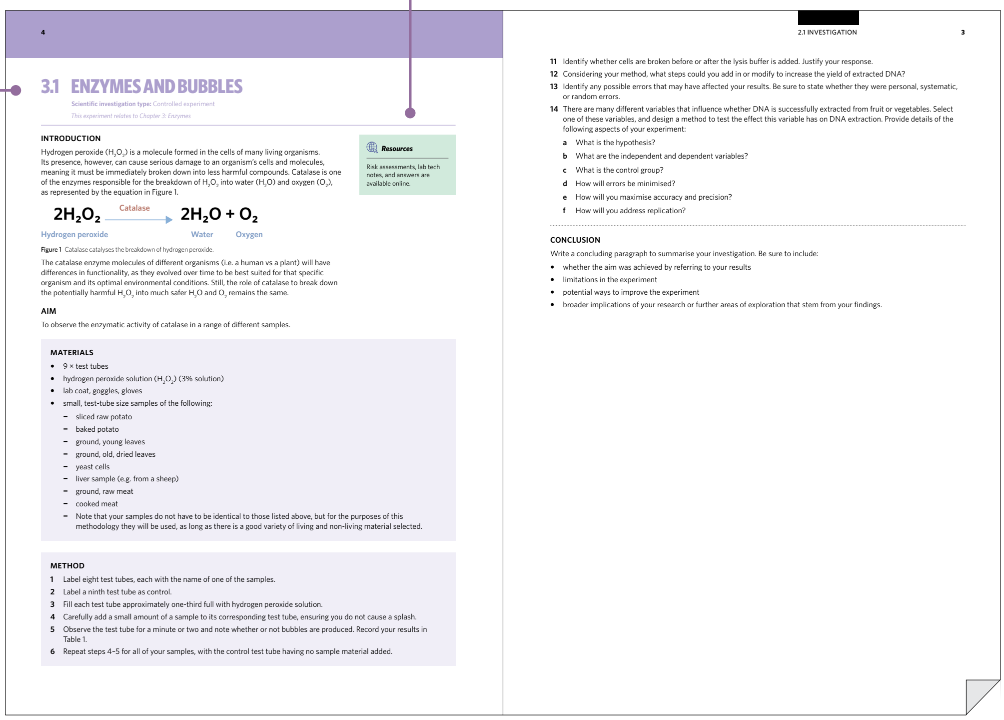
Question 3 (1 MARK)

Process P is an example of

A protein-mediated active transport.
B endocytosis.
C pinocytosis.
D exocytosis.

Risk assessments, **lab tech notes**, and **answers** are available online

Scientific investigations can be found at the back of the book which follow one of the scientific investigation types in the VCAA Biology study design (2022-2026)



4

3.1 ENZYMES AND BUBBLES

Scientific investigation type: Controlled experiment

This experiment relates to Chapter 3: Enzymes

INTRODUCTION

Hydrogen peroxide (H_2O_2) is a molecule formed in the cells of many living organisms. Its presence, however, can cause serious damage to an organism's cells and molecules, meaning it must be immediately broken down into less harmful compounds. Catalase is one of the enzymes responsible for the breakdown of H_2O_2 into water (H_2O) and oxygen (O_2), as represented by the equation in Figure 1.

Resources

Risk assessments, lab tech notes, and answers are available online.

$$\underset{\text{Hydrogen peroxide}}{2H_2O_2} \xrightarrow{\text{Catalase}} \underset{\text{Water}}{2H_2O} + \underset{\text{Oxygen}}{O_2}$$

Figure 1 Catalase catalyses the breakdown of hydrogen peroxide.

The catalase enzyme molecules of different organisms (i.e. a human vs a plant) will have differences in functionality, as they evolved over time to be best suited for that specific organism and its optimal environmental conditions. Still, the role of catalase to break down the potentially harmful H_2O_2 into much safer H_2O and O_2 remains the same.

AIM

To observe the enzymatic activity of catalase in a range of different samples.

MATERIALS

- 9 × test tubes
- hydrogen peroxide solution (H_2O_2) (3% solution)
- lab coat, goggles, gloves
- small, test-tube size samples of the following:
  - sliced raw potato
  - baked potato
  - ground, young leaves
  - ground, old, dried leaves
  - yeast cells
  - liver sample (e.g. from a sheep)
  - ground, raw meat
  - cooked meat
  - Note that your samples do not have to be identical to those listed above, but for the purposes of this methodology they will be used, as long as there is a good variety of living and non-living material selected.

METHOD

1 Label eight test tubes, each with the name of one of the samples.
2 Label a ninth test tube as control.
3 Fill each test tube approximately one-third full with hydrogen peroxide solution.
4 Carefully add a small amount of a sample to its corresponding test tube, ensuring you do not cause a splash.
5 Observe the test tube for a minute or two and note whether or not bubbles are produced. Record your results in Table 1.
6 Repeat steps 4–5 for all of your samples, with the control test tube having no sample material added.

2.1 INVESTIGATION 3

11 Identify whether cells are broken before or after the lysis buffer is added. Justify your response.
12 Considering your method, what steps could you add in or modify to increase the yield of extracted DNA?
13 Identify any possible errors that may have affected your results. Be sure to state whether they were personal, systematic, or random errors.
14 There are many different variables that influence whether DNA is successfully extracted from fruit or vegetables. Select one of these variables, and design a method to test the effect this variable has on DNA extraction. Provide details of the following aspects of your experiment:
  a What is the hypothesis?
  b What are the independent and dependent variables?
  c What is the control group?
  d How will errors be minimised?
  e How will you maximise accuracy and precision?
  f How will you address replication?

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- whether the aim was achieved by referring to your results
- limitations in the experiment
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

CHAPTER

1

General skills

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

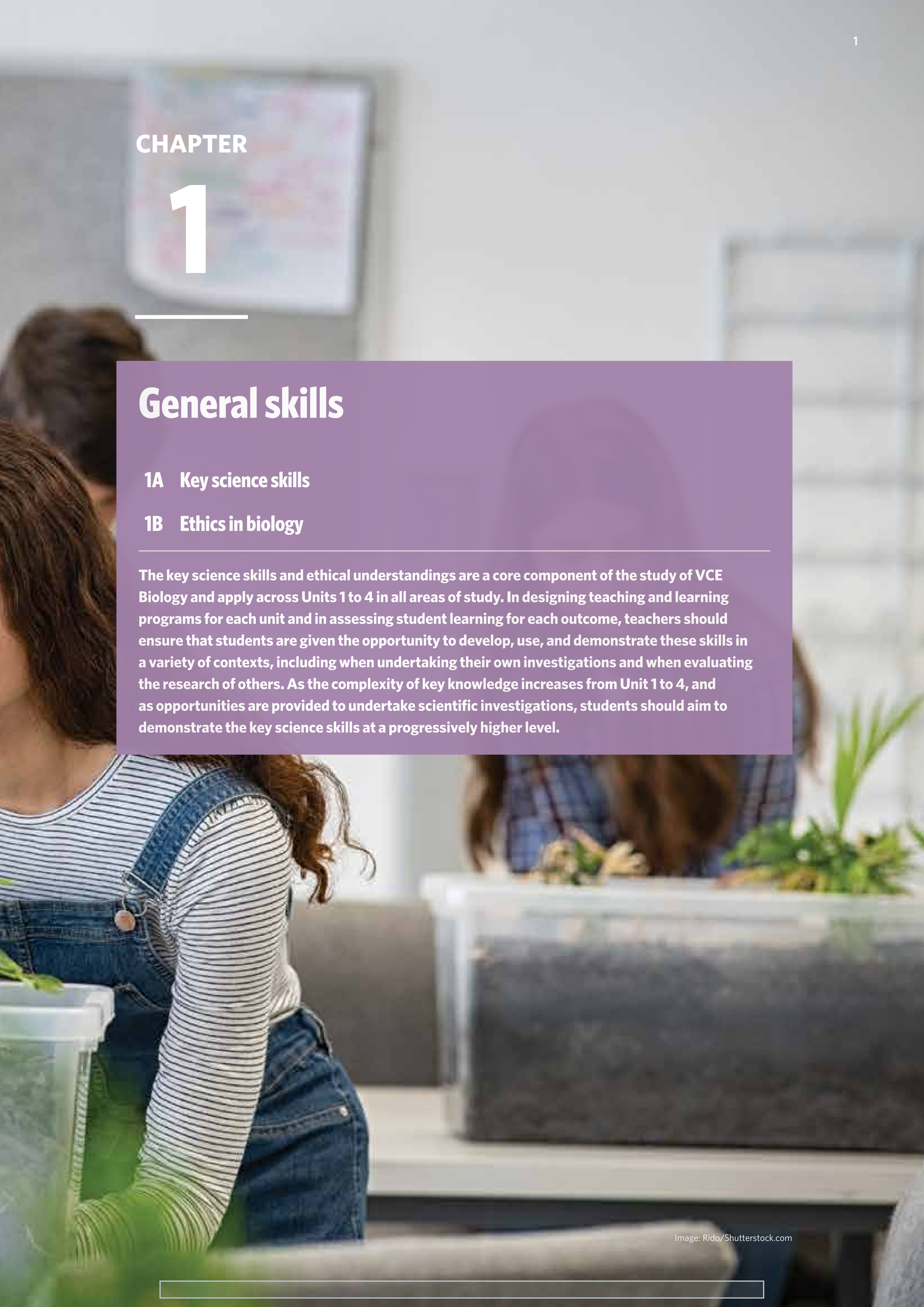


Image: Rido/Shutterstock.com

1A KEY SCIENCE SKILLS

If you were at school in Australia in Year 7 or 8, at some stage you would have found yourself in a line of students waiting to receive a vaccination for the human papillomavirus (HPV). How did you feel about this? Happy that you got to miss a bit of class? Or did you have to blink back tears of anxiety?

HPV can cause genital warts and a number of cervical and anal cancers. The HPV vaccine is taken in two doses six months apart and became free for school students in 2007 as part of the National HPV Vaccination Program. Before this program was introduced, four out of every five people contracted HPV at some stage in their life. Now, as a result of the vaccine:

- *cases of genital warts have decreased by 90% in people under 21*
- *90% of cervical cancers and 96% of anal cancers will be prevented*
- *Australia is set to be the first country in the world to eliminate cervical cancer.*

So how did the scientists make this powerful vaccine? Did they mix random concoctions of chemicals together with the hope they might destroy the virus? Did they hold up beakers of coloured water to the light and peer seriously at them like some mad scientist? Or were they following an age-old, systematic process of discovery?

This won't hurt a bit...

Image: Embrace of Beauty/Shutterstock.com

Lesson 1A

In this lesson you will learn the key science skills (KSSs) required to plan, conduct, analyse, and present the results of scientific investigations.

◀ *Prerequisite knowledge*

Future applications ▶

Years 7–10

You've followed the scientific method, written practical reports, and identified variables before. Now, you need to build on those foundations to broaden and deepen your science skills.

Year 11

In Year 11, you were first introduced to these key science skills and applied this knowledge to concepts such as the plasma membrane, homeostasis, and body systems.

Lesson 1B

None of the skills in this lesson can be used if your investigation is unethical – in lesson 1B, you'll learn how to identify and analyse bioethical issues.

Year 12

The skills taught in this lesson are applicable across the VCE Biology course, and will be assessed in many of your SACs and exams.

Study design dot points

- develop aims and questions, formulate hypotheses, and make predictions
- plan and conduct investigations
- comply with safety and ethical guidelines
- generate, collate, and record data
- analyse and evaluate data and investigation methods
- construct evidence-based arguments and draw conclusions
- analyse, evaluate, and communicate scientific ideas

Key knowledge units

What are key science skills?	0.0.0.10
Designing and planning investigations	0.0.0.11
Conducting investigations	0.0.0.12
Analysing and presenting results	0.0.0.13

What are key science skills? 0.0.0.10

OVERVIEW

Key science skills are the capabilities students demonstrate when designing, conducting, analysing, and presenting scientific investigations.

THEORY DETAILS

What are key science skills and why are they important?

Key science skills (KSSs) are a set of capabilities that VCE Biology students are expected to learn over Units 1–4 (listed on pages 7 and 8 of your study design). You can use KSSs in all realms of life, however, and not just in the Biology exam. This is because, at its most fundamental level, science is about discovering the truth in the world around us – which is clearly something we should all be doing!

key science skills (KSSs) the set of capabilities that VCE Biology students must learn to design, conduct, analyse, and report valid experiments

You demonstrate KSSs when you ask questions like:

- do I believe this? Why?
- what evidence supports this conclusion?
- is this evidence trustworthy?
- is it weak or strong evidence?
- is there evidence that undermines this conclusion, or supports another position?

When your friend gossips to you about their neighbour, or your grandad complains that 'kids these days are spoilt', or you read a tweet from your favourite celebrity – you can ask these questions to decide for yourself what to think.

You will use KSSs more rigorously and methodically in your VCE science subjects. In these classes, you will learn to distinguish between weak (e.g. an **opinion**) and strong (e.g. data from a well-designed **controlled experiment**) evidence. You will also collect, analyse, and draw conclusions by:

- designing your own investigation/s, or
- examining someone else's investigation/s.

Less formal evidence, such as anecdotes and expert opinions, can be helpful to consider when drawing conclusions. However, data gathered from investigations that are guided by KSSs are broadly considered more 'trustworthy' and **reliable**. This is because KSSs help you to reduce **bias**, minimise the effects of **errors**, and ensure results are not due to chance.

opinion the personal belief or viewpoint of an individual which typically has not been verified as fact

controlled experiment an investigation into the effect of an independent variable on a dependent variable, while keeping all other factors constant

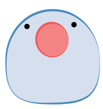
reliable describes an experiment, tool, or measurement that produces similar results when repeated and reproduced

bias an inclination to favour a particular position or outcome

error differences between observed values and the true value

The rest of this lesson will walk you through the KSSs you can use to design and examine scientific investigations. Whilst there are many different types of scientific investigations, we'll mostly focus on controlled experiments, which allow scientists to manipulate specific variables and control their studies to a high degree. You can be asked to demonstrate KSSs in SACs and on exams, so we have included KSS questions at the end of every lesson in this book.

> **Example**
>
> **ACING VCE BIOLOGY**
>
> Let's say you want to use your newly developed KSSs to answer an age old question – how do you ace VCE Biology? How does one even use KSSs to answer this? Some scientific investigations you could undertake to answer this question include:
>
> - surveying top-performing VCE Biology students from the previous year, collecting data on study habits and lifestyle
> - analysing the research of other scientists and coming to your own conclusions based on the strengths and weaknesses of their investigations
> - setting up an experiment where one group of students tries one study technique, and another does not try it, then comparing the marks they get on a test.



Theory in context

FRAMEWORKS FOR KNOWING WHAT IS 'TRUE'

Using KSSs to arrive at knowledge is often tied to ideas around the 'scientific method', which has characterised how many cultures around the world have approached natural science since the 17th century. However, the stringent adherence to KSSs is only one particular means of determining what is 'true'.

Other ways of seeking the truth can provide a more holistic approach to knowledge. For example, Indigenous Australians have a much longer history of developing knowledge which is often focused on the interconnections between individuals, habitats, and ecosystems. An example of this holistic, or 'big picture' knowledge of Indigenous Australians is fire management. According to Koori Country Firesticks (2017), Aboriginal fire management removes ground vegetation using cool burns that move slowly over small areas, taking place up to several times a year. This:

- reduces the fuel load
- protects the canopy of trees (so fruits and seeds are preserved; insects, birds, and climbing mammals have a place to hide; and shade is maintained after the fire)
- doesn't burn hollow logs (maintaining habitat)
- moves slowly so animals can escape
- manages weeds
- results in quicker return of native plants to the area.

Furthermore, the practice allows easier access to **Country**, cleans up important pathways, maintains cultural responsibility, and is part of ceremonies. In contrast, European 'hazard reduction burns' tend to involve hotter and less frequent fires that have the single goal of reducing fuel load.

Many people are calling for the integration of KSSs and Indigenous knowledge. These people point out that Indigenous ways of knowing share many characteristics with KSSs. Both place importance on observation, questioning, **hypothesis** testing, experimentation, and application. Indigenous ways of knowing have scientific rigour through thousands of years of repetition, but can also change if new evidence arises. These methods of scientific inquiry enabled Australia's first peoples to thrive on this continent for many tens of thousands of years, in good health and in a sustainable way.

Want to learn more about the intersection between Indigenous knowledge and KSSs? Here are some places to start:

Watch – this 10 minute video by the ABC about cool burns youtube.com/watch?v=RM72NtXxyLs&feature=youtu.be

Listen – to this podcast about Indigenous knowledge and science audioboom.com/posts/5380644-why-western-science-urgently-needs-aboriginal-holistic-knowledge-to-tackle-21st-century-issues

Read – this article about flaws in research into hazard reduction burns theconversation.com/the-burn-legacy-why-the-science-on-hazard-reduction-is-contested-132083

Country an area that is traditionally owned and looked after by an Aboriginal language group or community, or by certain people within that group. The term may indicate more than simply a geographical area – it is also a concept that can encompass the spiritual meaning and feelings of deep connection and attachment associated with that area

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

Designing and planning investigations 0.0.0.11

OVERVIEW

Designing a scientific investigation involves: constructing a research question and aim; identifying your independent, dependent, and controlled variables; formulating a hypothesis; selecting a methodology; designing a repeatable, reproducible, and valid method; following ethical and safety guidelines.

THEORY DETAILS

Constructing a research question and aim

Most scientists start investigations by noticing something unusual, or a pattern, in the world around them. They might notice that a particular plant has useful properties, students perform poorly on tests when hungry, or that birds fly around the MCG lights at 11 pm. Then, scientists need to narrow the scope of their inquiry down to one question that they wish to answer. Table 1 outlines the requirements for a **research question**.

research question a testable, achievable, and specific question that an investigation sets out to answer

Table 1 Elements of a research question

Research question must be	Explanation	Bad example	Good example
Testable	You must be able to measure the factors you are interested in.	'How do sea monkeys grow?	'What is the effect of salinity on the life cycle of sea monkeys?'
Achievable	The scientist must have the funding, ethical approval, and resources available to answer the question.	'What happens to test scores if we prevent all school students from eating on the day of a test?'	'What is the average test score for students at this particular school if they have fasted for 0, 4, 8, or 12 hours?'
Specific	Only particular individuals will be sampled at particular times and locations.	'Is bird behaviour affected by light pollution?'	'Is silver gull (*Chroicocephalus novaehollandiae*) nighttime behaviour affected by light pollution in Melbourne from June to September?'

Sometimes you need to do a bit more background research to settle on a final research question. You may even go through a few draft questions as you refine it to become more testable, achievable, and specific. From the research question, it is usually pretty easy to develop an **aim**. The aim is the objective of the investigation and typically starts with the word 'To'. For the research questions above, the aims would be:

- to determine if the salinity of water affects the duration of life cycle stages in developing sea monkeys
- to determine if fasting before tests affects student performance
- to determine if silver gull (*Chroicocephalus novaehollandiae*) nighttime behaviour is different in light-polluted Melbourne compared to non-light-polluted areas.

Note that, where required, we include scientific names for species in research questions and aims.

aim the objective of an investigation or experiment

Image: fishmonger/Shutterstock.com

Figure 1 Indigenous knowledge has made significant contributions to science, including the identification of potential new materials from native plants like spinifex grasses.

Example

HOW POWERFUL IS A POWER NAP?

If you're studying VCE Biology, you're probably quite keen to investigate if there is something you can do to improve your results on assessments. You might have lots of friends who swear by the 'cram' method before exams, where they try to fit as much information in their head in the minutes, hours, and days prior. Your mum, meanwhile, always tells you that 'if you have a problem, sleep on it' and that this will help you understand and solve it. Is there anything to either of these two learning strategies? Can either of them improve your memory and performance on tests?

Considering this, we devised a first version of a research question to investigate:

'Is cramming or napping a better study method?'

We realised pretty quickly that this research question has some problems:

- It's not testable – how do you measure if something is a 'better' study method?
- It's not specific – who is participating? What does cramming look like? How long do participants nap for?

From here, we worked on a second draft of a research question:

'Do Year 11 Biology students at this school remember more if they cram or nap for one hour after a class?'

This question was much more testable, given that a test can be administered to measure how much our research participants actually remember. It was also much more specific, given that the people being studied are identified as Year 11 Biology students from a certain school. We've also made the research question more achievable by making the duration of the experiment one hour and using easily accessible participants (rather than, for example, all VCE students in Victoria).

Using this information, devise an aim for the investigation:

Aim: ____

____

Suggested answer

Aim: To determine if cramming or napping improves the memory of Year 11 Biology students at this school.

Identify independent, dependent, and controlled variables

Notice that creating a testable, achievable, and specific research question means that investigations tend to end up measuring the effect of one variable on another variable. The variable that is being affected is the **dependent variable (DV)**, while the variable that is being manipulated is the **independent variable (IV)**. We can identify the IVs and DVs in the research questions we looked at previously:

- DV – duration of life cycle stages; IV – water salinity
- DV – test score; IV – time spent fasting prior to test
- DV – seagull nighttime behaviour; IV – light pollution or no light pollution.

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 this factor influencing the DV. To identify variables you need to control in your investigation, consider other factors that might cause your DV to change. For example, when testing the effect of activity level (IV) on occurrence of heart disease (DV), you would want to make sure that each participant was of a similar age. If this factor wasn't constant, it would be an **uncontrolled variable** that could potentially affect the results, making the experiment inaccurate and invalid (Figure 2).

dependent variable (DV) the factor/s measured in the experiment that are changed when the IV is manipulated

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

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**

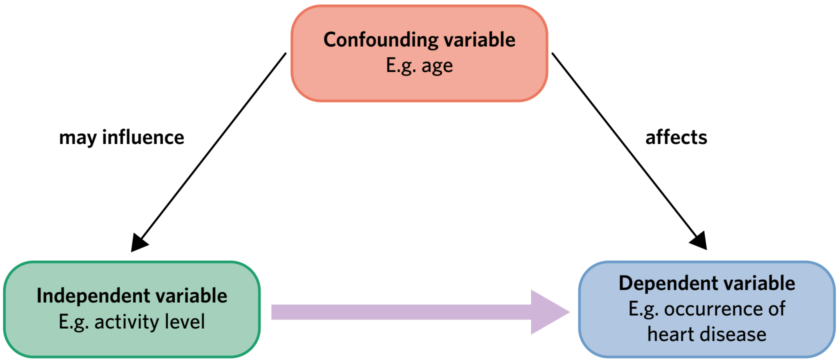


Figure 2 In this experiment, scientists are interested in determining if activity levels directly impact a person's likelihood of developing heart disease. Age is another variable in this experiment since it could influence a person's activity level and a person's likelihood of developing heart disease (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 an uncontrolled 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).

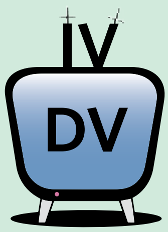


Figure 3 The IV-DV-TV

Example

HOW POWERFUL IS A POWER NAP?

Given the research question 'Do Year 11 Biology students at this school remember more if they cram or nap for one hour after a class?', use the template 'If [change in IV], then [change in DV]' to generate a hypothesis.

Note that sometimes you are also required to include an explanation that explains why you've made the prediction. In this case, your hypothesis template could be 'If [change in IV], then [change in DV] because [existing evidence]'.

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Suggested answer

There are two IVs – napping and cramming – so we could write two hypotheses: 1) 'if students nap after learning, then they will get increased test scores'; or 2) 'if students cram after learning, then they will get increased test scores.' Or, we could write a single hypothesis that includes both IVs: 'if students nap or cram after class, then they will get increased test scores.' You could also hypothesise that the interventions do not increase test scores.

Formulate a hypothesis

From your aim, question, and variables, you can then build a hypothesis. A hypothesis is more than 'what you expect to happen' during your experiment. It should:

- be a testable statement
- describe how you think your IV will affect your DV, including the direction of change (increase/decrease etc).

Your hypothesis will either be supported or refuted by your results. A simple hypothesis format is 'If [change in IV], then [change in DV].'

Select a scientific investigation methodology

Now that you've got your research question, it's time to figure out how to actually get to the answer by conducting a scientific investigation!

Scientific investigations can be undertaken in a variety of ways depending on your research question and aim. We call these broad frameworks for inquiry the scientific investigation **methodologies**, and they help guide how you will design your specific **methods** (the actual steps in your experiment). For instance, if you want to learn what species of bacteria live on human skin, it might make sense to use a classification and identification methodology. But, if you want to understand cause and effect, you'd want to perform a controlled experiment (where you test the effect of an IV on a DV, while controlling all other variables). Controlled experiments are often difficult to set up properly, however they can provide very reliable results, and most of the KSSs you will learn in this lesson relate directly to controlled experiments. The methodologies you can use to answer research questions are outlined in Table 2.

methodology the strategy or overarching framework followed in a scientific investigation

method the steps followed in a scientific investigation

Table 2 The nine scientific methodologies prescribed by the VCAA

Methodology	Description	Example
Case study	An investigation of an event or problem that involves a real or hypothetical situation. Case studies can take many forms including historical analysis, role-play of an imagined situation, or designing a solution to a real-world problem.	Researching a bioethical dilemma such as the de-extinction of woolly mammoths, then preparing a debate or essay presenting your analysis and conclusions
Classification and identification	Classification is the arrangement of individuals or objects into logical, manageable sets. We use identification to recognise where new individuals or objects belong in these sets.	Creating a classification tree or phylogeny showing how Australian marsupials are related
Controlled experiment	An investigation into the impact of an IV on a DV, controlling for all other variables.	Testing if introducing a new gene into tomatoes protects the plants from pests
Correlational study	Observing and recording events that have not been manipulated or controlled to understand associations that exist between variables. Typically still measures the effect of an IV (or multiple IVs) on a DV, but the IV is not manipulated by the experimenter and some conditions may be less controlled than in a laboratory experiment.	Recording how environmental conditions such as day length and temperature affect timing of leaf fall in different deciduous plant species
Fieldwork	A correlational study or controlled experiment set up outside a controlled environment (e.g. the classroom), usually in a selected ecosystem. Typically still measures the effect of an IV on a DV, however, conditions may be less controlled than in a laboratory experiment.	Measuring the distribution of sea snails across the intertidal region
Literature review	The collation and analysis of other people's scientific findings or viewpoints concerning a particular topic. Consideration of the reliability of sources and methods is important in literature reviews. They are used to provide background information on a topic of interest and/or identify potential areas of research.	A report summarising past research about Indigenous Australian agriculture and aquaculture
Modelling	The construction of a model or representation that approximates an object or event. This could be a drawing, a 3D structure, an equation, a moving structure, etc., and can be used to describe systems or make predictions.	A flow chart showing the biochemical reactions that take place during photosynthesis
Product, process, or system development	Design of an object, process, or system to meet a human need.	Designing a pot that delivers different water levels to indoor plants depending on the plants' needs
Simulation	The process of using a model to observe and predict what may happen in a real or theoretical system.	Using masking tape to make a large-scale map of the body's osmoregulatory system in your classroom, then have students act out what happens to different hormone levels in different conditions

Example

HOW POWERFUL IS A POWER NAP?

There are a couple of methodologies we could use to figure out if cramming or napping improves memory:

- a case study of exemplary students, where we survey and record what those students did over Years 11 and 12
- a literature review of studies that investigate what helps students perform well in high school.

However, these investigations may provide weaker evidence than a controlled experiment:

- case studies only look at a very small group of people, and the information we get from it might not be accurate (former students might, for example, overreport the amount of napping they did)
- a literature review may not include studies specific to the region or subject we're interested in, so the results may not be relevant.

Given that we are interested in a cause-effect relationship and have identified a DV, an IV, and several variables to keep constant, we can design a controlled experiment that gives us reliable and meaningful results.

Design a repeatable, reproducible, and valid investigation

For controlled experiments, there are some broad rules around what needs to be included in your experimental design. These rules also help ensure that your experiment is:

- **repeatable** – you can repeat your experiment and get the same results over and over again
- **reproducible** – other scientists could follow your method and get the same results over and over again
- **valid** – your experiment actually measures what it claims to be measuring.

If your experiment is not repeatable, reproducible, or valid, then the results are typically not going to be useful, reliable, or meaningful. To ensure you can trust your results, you need to design a strong method. Here are some tips for ensuring your methods are repeatable, reproducible, and valid:

Identify your experimental group/s and control group/s

The **experimental group** has individuals exposed to your IV treatment or intervention. There may be different levels of your experimental group. For instance, if you are testing the effect of a new pesticide on crop yield, your experimental groups could be three groups of crops exposed to either low, medium, or high levels of pesticide.

Control groups are used as a comparison with experimental groups and every controlled experiment should include at least one control group. Control groups can be samples that are not exposed to any level of the IV, which means we do not expect it to produce any results. These are known as negative controls. Alternatively, controls can be groups where you would expect to see a result. Scientists apply a treatment to this group which induces a well-understood effect on the DV which can be compared against the effects of other IVs. These are known as positive controls.

Negative controls are the most common and should be present in all controlled experiments. If they do produce results, we know that something other than the IV (an uncontrolled variable) may be causing the change in the DV and our method is flawed. In our pesticide and crop yield experiment, a negative control group would be a field not exposed to the pesticide at all, while 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.

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

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

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

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

Examiners' tip

Be careful not to mix up control groups and control variables. Controlled variables are factors that must be kept constant during your experiment whereas a control group is a sample that is not exposed to the independent variable.

Theory in context

MIND OVER MATTER

Placebo groups are often used as a type of control group, especially when testing medicines. Placebos are medicines/procedures that seem identical to the treatment medicine/procedure, 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 treatment group or the placebo group. So, if a treatment involves giving participants a pill, the placebo group would be given a pill that looks like the drug, but has no active ingredients (e.g. a sugar pill). A standard negative control, meanwhile, would just be a group of participants who receive no pill (so they know they aren't receiving treatment).

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). Scientists have even figured out how to boost the placebo effect to make a medicine more effective. For example, they've learned that antidepressant pills that are yellow are more effective than the same pill of a different colour.

placebo a substance that has no active ingredients or side effects

Table 3 Examples of research questions alongside potential experimental and control groups

Research question	Experimental group	Control groups
Does the drug we have developed kill bacteria?	Bacteria in a Petri dish exposed to the drug	Bacteria in a Petri dish not exposed to the drug
Are humans injected with our newly developed vaccine protected from the influenza virus?	Humans injected with the vaccine	Humans injected with a vaccine that is already widely used to provide immunity against influenza
Does gene X make banana plants produce more fruit?	Banana plants with gene X	Banana plants without gene X

Example

HOW POWERFUL IS A POWER NAP?

What would the experimental group/s and control group/s be for our experiment on cramming and napping?

Well, we obviously need to get one group to nap after learning, and one group to cram after learning:

- Experimental group #1 – cramming
- Experimental group #2 – napping

We also need a control group, where the treatments of cramming and napping are not applied, but everything else remains constant. Perhaps the best control group would involve participants 'taking a break' at the same time as the experimental groups experience the cramming or napping intervention. It would be important that the control participants are awake and do not revise during this time.

- Control group – awake break

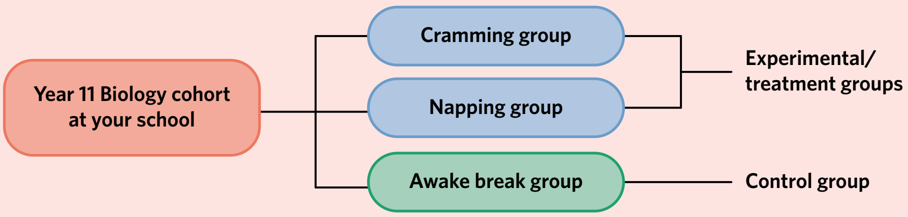

Figure 4 Diagram showing how the Year 11 Biology cohort is divided into experimental and control groups

Is the 'awake break' group an example of a negative or positive control group? What will the results from this group tell us?

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Suggested answer

This is a negative control group, unexposed to any treatment so that we can compare the results of this group to the experimental groups. Having a negative control group will tell us if applying the intervention alters student memory of the lesson.

When you are thinking about your experimental and control groups, you also need to think practically about how each will be treated. This means asking questions like:

- what tools will I use to take measurements of each group?
- how often will I take measurements of each group?
- how long will the experiment run for?

Example

HOW POWERFUL IS A POWER NAP?

Let's make sure we know the details of how we're going to treat each of the groups over the course of the experiment.

- What tools will I use to take measurements?

We need to test if students have remembered what they learned in the class prior to the intervention (or awake break). This can be measured using a 30-minute test on the material covered.

- How often will I take measurements?

Given that memory can be both short-term and long-term, it would be prudent to test students immediately after the intervention, but also one week later. Therefore, we'll give them two tests – Test 1, immediately post-intervention, and Test 2, one week later. The tests will cover the same content but have different questions. As we need enough questions for 2 × 30-minute tests, the pre-intervention lesson should be quite long – perhaps 2 hours.

- How long will the experiment run for?

In total, the experiment will run for one week. Learning and Test 1 will take place on day 1, and Test 2 will take place on day 8.

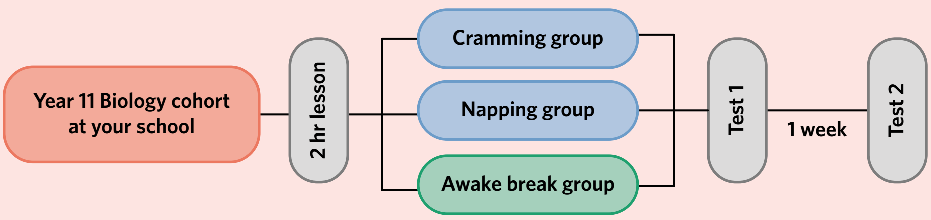


Figure 5 The design of the napping and cramming experiment

Replicate your experimental and control groups

Replication involves having multiple experimental and control groups. Using our crop and pesticide example, instead of having four different fields exposed to either no pesticide, low, medium, or high levels of pesticide, a replicated experiment would ensure there were two or more fields exposed to each treatment.

replication the process of running your test/experiment multiple times

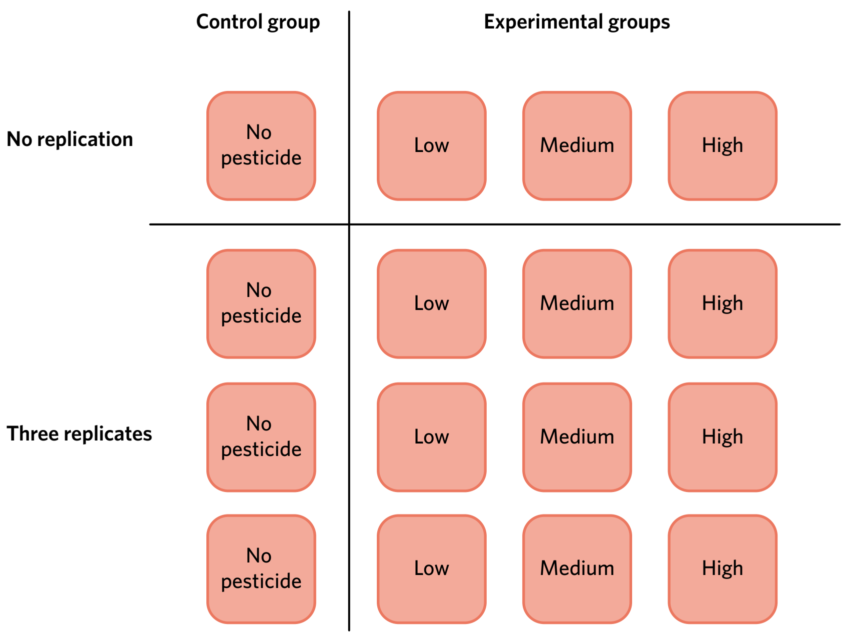


Figure 6 An example of replicated and unreplicated experimental designs testing the effect of pesticides on crop yield

Increasing replication is good scientific practice because:

- You can find out if your results are **precise**
  - Precise results indicate that your method is valid and reliable, and that you may be able to assume the same results would be found in a larger sample
  - If you get a wide spread of values across **replicates**, then results are imprecise
  - If replicates get similar results, your results are precise.
- You can take the average of your results
  - This reduces the impact of **outliers** and **random error**
  - This might make your results more **accurate**, as it may bring your final values closer to the **true value**.

Sometimes there is not enough funding, time, or resources to replicate an experiment many times. Nevertheless, you must design treatment groups with at least two replicates if you want to be able to trust your results. Depending on the field of Biology, it may be standard practice to replicate treatments hundreds or even thousands of times.

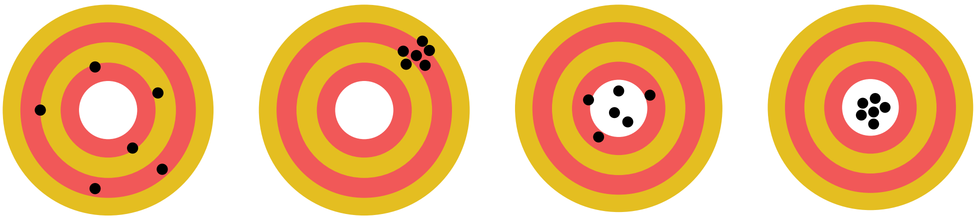


Figure 7 Accurate results are close to the true value, whereas precise results have very little spread around the mean value.

Example

HOW POWERFUL IS A POWER NAP?

To replicate our sleep study, we need to make sure that there is more than one person in each of the experimental and control groups. Ideally, we also have equal numbers of people in each group.
So, if we have 90 Year 11 VCE Biology students participating in the study, there would be 30 students in experimental group #1, 30 students in experimental group #2, and 30 students in the control group. This means that the experiment has 30 replicates.

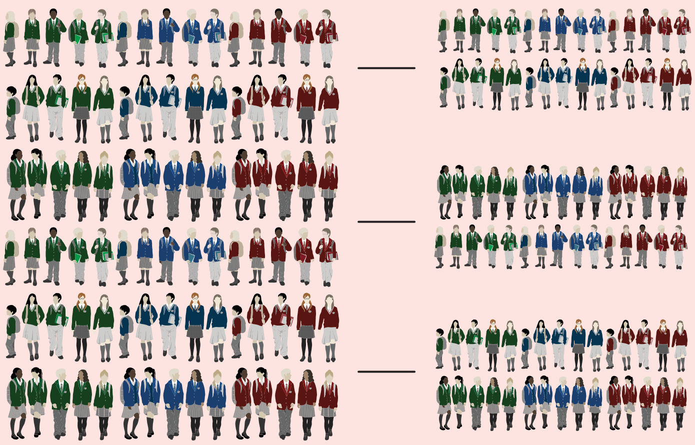


Image: Katrine Glazkova/Shutterstock.com

Figure 8 Diagram showing that there are 30 replicates in each group.

precise two or more measurements that closely align with each other

replicates multiple measurements that are exposed to the same level of the IV, are very close in value, and are close to the 'true' value of the quantity being measured

outlier a reading that varies drastically from other results

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

accurate how close a measurement is to the true value

true value the value that would be obtained by a perfect measurement without the influence of errors

Examiners' tip

It is important to note, however, that calculating the average of your results after replicating the experiment only brings your final values closer to the true value if the range of your data (maximum value-minimum value) isn't too large. In other words, if your data has a large range and you calculate the average, your final results will actually be further away from the true value.

Decide how to sample your groups

It is hard to take measurements of every single individual in a **population**, so scientists tend to collect data on only a small subset of that population called a **sample**. However, because sampling only looks at a subset of a population, scientists need to be careful that their samples are:

- **representative** – accurately reflects the characteristics of the entire population
- **unbiased** – unaffected by prejudice or an inclination towards finding a specific result.

It is a good idea to get as large a sample size as possible, as this will increase the likelihood that you have collected representative and unbiased data. A larger sample size also means that you will have a better understanding of the precision of your data and can take averages to reach a final value that should be more accurate than if you only took a smaller sample. To help ensure samples are representative and unbiased, scientists can use sampling techniques like those outlined in Table 4.

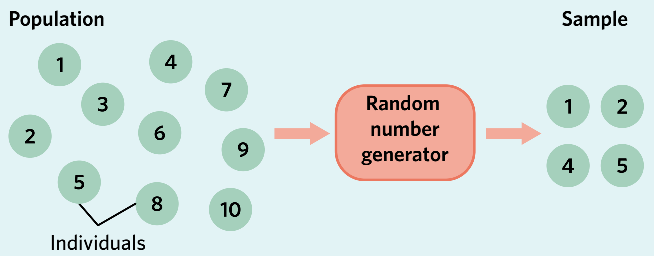
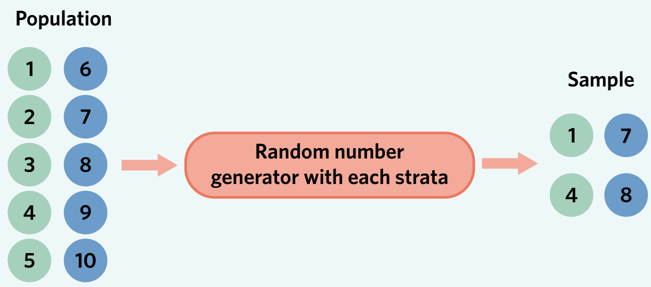
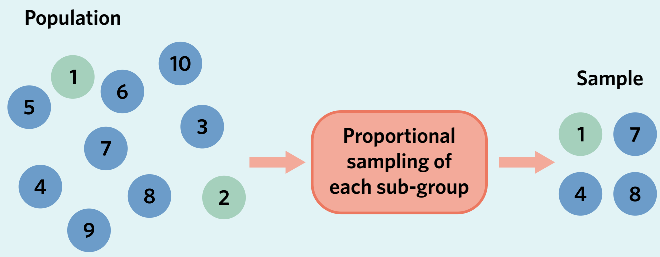
population a set of similar objects or individuals that are studied in a scientific investigation

sample a subset of the larger population being studied

representative a sample that accurately reflects the characteristics of the larger population

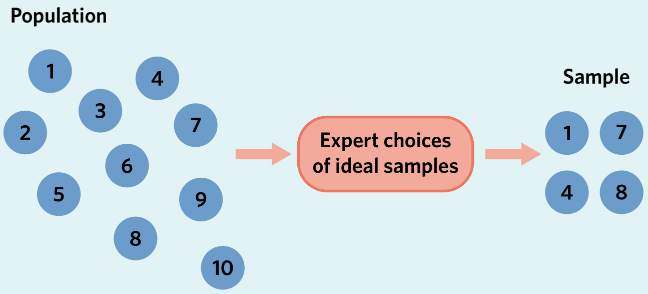
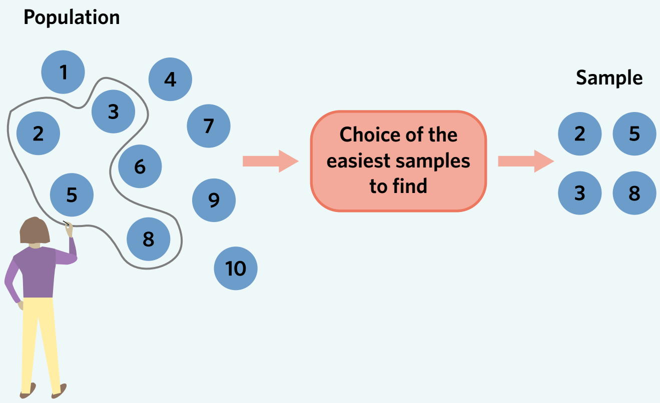
unbiased a sample or measurement that is unaffected by a scientist's expectations

Table 4 Different sampling techniques

<table>
<tr><th>Sampling technique</th><th>Definition</th></tr>
<tr><td>Random sampling</td><td>Random sampling ensures each member of the population is equally likely to be included.

</td></tr>
<tr><td>Systematic sampling</td><td>Systematic sampling involves taking samples at regular intervals along an environmental gradient (such as depth, soil type, rainfall, altitude, or temperature).

</td></tr>
<tr><td>Stratified sampling</td><td>When a population has clearly defined zones or characteristics, and you wish to sample proportionately from each zone, you may wish to use stratified sampling.


cont'd</td></tr>
</table>

Table 4 Continued

Sampling technique	Definition
Judgement sampling	Also known as selective sampling, the researcher chooses which individuals (or asks an expert's advice) to sample according to their needs. Judgement sampling can be biased and lead to unrepresentative data, so should only be used when necessary. 
Convenience sampling	This type of sample is taken from a group of individuals who are easy to reach. Convenience sampling can lead to biased and unrepresentative samples that make results unreliable, so should be avoided where possible. 

Example

HOW POWERFUL IS A POWER NAP?

Sampling technique

In this experiment, the 90 Year 11 VCE Biology students (we can say n = 90 to explain that the sample size is 90) at your school are a sample of all Year 11 VCE Biology students that exist. We chose these students using convenience sampling – they are the students who we know and are easily available to participate.

To strengthen the experiment, we can ensure that the sample of 90 students are randomly allocated into the experimental and control groups. For example, we could assign each student a number from 1–90, then use a random number generator to determine which intervention they receive: the first 30 cram (n = 30), the next 30 nap, and so on. This is important as it minimises the risk of all 'high-achieving' students being accidentally placed into the same group, which would make that treatment appear really successful.

Of course, there is a strong possibility that students at our sample school are not representative of VCE Biology students in general. For example, your school may be more linguistically diverse than the average Victorian school. You'll need to decide how this affects your results in your discussion.

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Example

HOW POWERFUL IS A POWER NAP? –CONTINUED

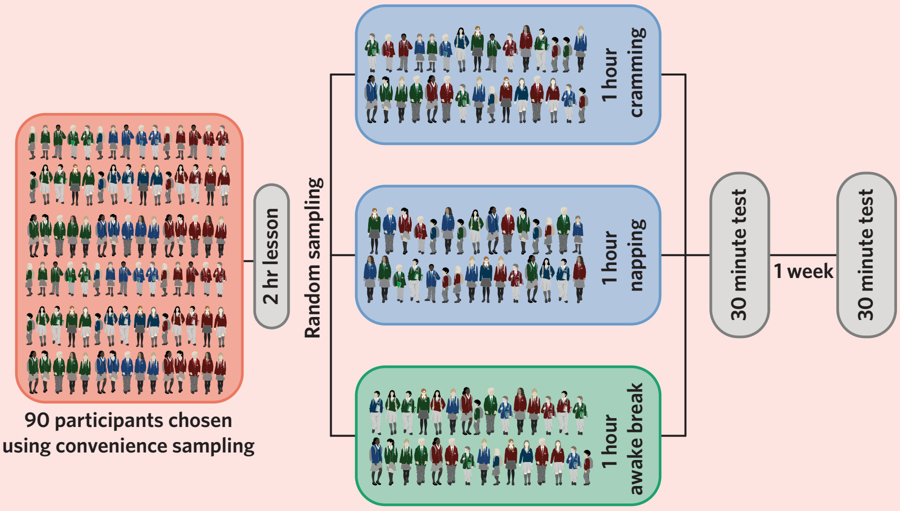

Image: Katrine Glazkova/Shutterstock.com

Figure 9 Experimental design to measure if cramming or napping improves student memory

Can you think of any other reasons why your school may not be representative of VCE Biology students?

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Suggested answer
The postcode a school is in, access to resources, the diversity of its culture, the influence of teachers and parents, and many other factors may mean that the sample school is far from 'average'.

Minimise the potential for error throughout the method

There are three main types of errors that you should plan to avoid during your experiment, outlined in Table 5. When you are designing your method, you should make sure you choose appropriate equipment to use for measurement, calibrate equipment where needed, and build in a sufficient number of replicates to minimise error. It is also important to identify parts of the method where errors may occur (e.g. during delicate or complex processes), then either find ways to reduce the risk of error or practice the process prior to conducting the experiment.

Table 5 The error types you need to know for VCE Biology

Error type	Description	How to avoid
Personal	Mistakes or miscalculations made by the experimenter. Counting incorrectly, rounding to the wrong decimal place, or labelling samples incorrectly are all examples of personal errors.	Repeat the experiment again. For measurements relying on human accuracy (e.g. counting plant numbers), you can get two or three people to make the same measurement.
Systematic	Errors which cause results to differ from the true value by a consistent amount each time, typically due to faulty equipment or calibration. They affect the accuracy of the experiment, and cannot be minimised through replication.	Re-calibrate your instruments, or use more reliable equipment.
Random	Errors which are caused by unpredictable variations in the measurement process and result in a spread of readings. For example, when a quantity is estimated by reading between the lines on a measuring cylinder – is it 5.6 mL or 5.7 mL? Perhaps we'll just say 5.65 mL. Random errors reduce precision.	Replicate the experiment, increase the sample size, refine the measurement process, or use more precise measuring equipment.

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

systematic error errors which cause results to differ by a consistent amount each time, typically due to faulty equipment or calibration, resulting in a less accurate result. Can be reduced by calibrating and maintaining instruments

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

Theory in context

QUANTIFYING UNCERTAINTY

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 10, the uncertainty is ± 1 mm. However, when you don't need to set the instrument up before measuring (e.g. a measuring cylinder, or a thermometer), then the uncertainty is half of the smallest measurement. In the measuring cylinder shown in Figure 11 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 of a second due to human reaction time.

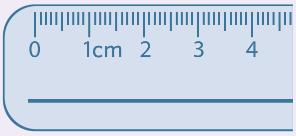

Figure 10 A section of a ruler that has an uncertainty of ± 1 mm

Image: oFFsoRRy/Shutterstock.com

Figure 11 A measuring cylinder that has an uncertainty of ± 0.5 mL

Write your method out clearly

Once you know your treatment groups, replication number, sampling method, and have identified any methodological stages which may introduce error, you should write the steps of your experiment out clearly. Remember that anyone should be able to follow your method exactly – other scientists won't be able to reproduce your results if they can't follow your method.

Memory device

You can think of the characteristics of a good controlled experiment as a checklist (RICHES):

- Replication
- Independent variable/ dependent variable
- Control group
- Hypothesis
- Errors are minimised
- Sample is large and randomly collected.

Follow ethical and safety guidelines

Before starting your experiment, you need to ensure that your method is **ethical**. Ethical conduct is valued so highly in modern day science that, at universities and research facilities, experimental procedures must be presented to an ethics board before being permitted to proceed.

To check if your experiment is ethically sound before starting, you should ask yourself the following questions:

- Is my method designed to avoid harming living things or ecosystems as much as possible?
- Has this research considered the beliefs, perceptions, customs, and cultural heritage of those involved in, or affected by, the experiment?
- Are all participants aware of the risks associated with this research and have they provided their consent?
- If I make a great discovery, will there be equal access to, and fair distribution of, any benefits that have arisen from this research?

ethics a field of knowledge that helps individuals exercise moral judgment and determine what is right and wrong

- Will I acknowledge all sources of funding and help for this research?
- Will I be transparent about any errors with the data or methods?
- Is the identity of participants protected?

If you answered 'No' to any of these questions, your experiment may not be ethical and you may need to revise your method. You will learn more about ethical decision making in lesson 1B.

Example

HOW POWERFUL IS A POWER NAP?

There may be some ethical issues with our experiment on napping and cramming. For example:

- Have participants provided fully informed consent to be a part of the experiment?
- As the test is being undertaken on minors, do we need to get consent from their parents as well?
- Are there language, gender, or cultural differences that may influence student experience of the experiment?

Can you think of any other ethical questions to consider for this investigation? List them below.

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It's important to have reasonable answers to these questions, and others, before starting the experiment.

Suggested answer

- If we use a test to measure student memory, will the score on their test affect their school results?
- Is there a safe place for students to nap?
- Will we share the results with the participants?
- Will participating in the experiment cause undue stress or anxiety for students?
- Do any of the students have a pre-existing sleep condition which means that they should avoid napping during the day?
- Can students leave the study if they wish?

Comply with safety guidelines

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 involves writing down all potential risks in an experiment, keeping in mind any contextual factors that may affect the safety of the experiment, and identifying ways to minimise these risks (Table 6).

Table 6 Examples of potential risks, contextual factors, and risk minimisation strategies during scientific investigations

Aspect of risk assessment	Examples
Possible risks	• Sharp objects • Flammable material • Hazardous chemicals • Open flames • Culturing of microorganisms
Contextual factors	• The experience of staff and students with the procedure • The behaviour of the class • Allergies of students and staff • Facilities available
Strategies to minimise risk	• Wearing personal protective equipment like gloves, lab coats, and enclosed footwear • Using fume hoods and other safety equipment where needed • Tying back long hair • Following instructions from the teacher and lab technicians • Washing hands after lab work • Keeping lab benches and equipment **sterile** • Conducting experiments in isolation • Conducting experiments in negative pressure rooms

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

You can undertake a risk assessment online (e.g. riskassess.com.au) or use a printed template provided by your school. The online risk assessments are helpful because they typically outline standard handling procedures for all equipment and safety data sheets for chemicals.

Example

HOW POWERFUL IS A POWER NAP?

Identify one possible risk that would need to be in this experiment's risk assessment.

____

____

Suggested answer
Acceptable responses include: stress from having to cram, stress from having to sit tests, stress from using up valuable VCE study time, and stress from potential disruptions to the sleep cycle.

Conducting investigations 0.0.0.12

OVERVIEW

During your investigation, you should focus on collecting unbiased, accurate, and precise raw data. In addition, you need to work cooperatively with classmates, teachers, and lab technicians to achieve the most reliable results.

THEORY DETAILS

Specific, answerable research question? Check. Appropriate research methodology? Check. Now it's time to start getting some data to actually answer your question!

Generate and collate data

If you're collecting your own data, we say you're collecting **primary data**. As you write results down in your logbook, the data is considered **raw**. Once you start graphing it or presenting it in tables, we describe that data as **transformed**. If you're getting results from someone else (e.g. a previous class, online data banks, or scientific papers) we say you're collecting **secondary data**.

When collecting primary data, it's important that you note down any observations from the experiment. In particular, write down any potential errors that may have occurred while conducting the experiment. Some examples of observations to collect during the experiment include:

- potential moments of contamination
- any personal errors, including spills or breakages
- general observations such as scents or colour changes
- any inconsistent treatment of experiment and control groups
- potential uncontrolled variables that may be affecting results.

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

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 comprehensible format that is easier to analyse

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

Example

HOW POWERFUL IS A POWER NAP?

Here is an example of the raw data we collected for our cramming and napping memory experiment. Notice that we have:

- tried to keep it neat and organised by using a computer rather than handwriting
- used clear headings so that anyone can interpret the data
- included a column for observations so that we can track any potential uncontrolled factors.

Student #	Group	Test 1 score	Test 2 score	Observations
1	Cram	90	88	
2	Nap	80	82	Loud noise may have disturbed nap
3	Break	42	33	
4	Break	54	52	May have dozed off during break
5	Break	70	53	
6	Cram	82	84	Only read notes, did not write anything down or highlight

Figure 12 An example of what raw data might look like

Lesson link

By writing down any potential errors that occur during the experiment and then discussing them in your report, you are communicating your results with integrity – a key ethical concept discussed in ***lesson 1B***. In doing so, you are basically saying 'my results say X, which is significant because Y, but make sure you're aware that Z happened during the experiment and that could make the results a bit dodgy'. This gives readers full autonomy to draw their own conclusions with all the required knowledge at their fingertips.

Analysing and presenting results 0.0.0.13

OVERVIEW

Once you've finished conducting your experiment, you need to interpret and present your results. This typically involves transforming your data into a graph or table, determining any potential sources of error, drawing conclusions from your data, and then communicating your findings to a specific audience.

THEORY DETAILS

After your investigation, you need to start thinking about what your results mean and how to communicate them. There are four steps to follow in order to do this (Figure 13), which we'll go through in more detail below.

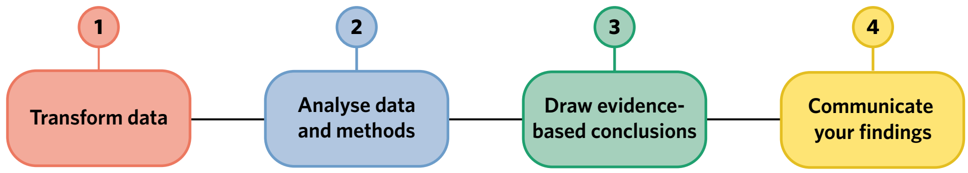


Figure 13 Steps to presenting and communicating results

1. Transform your data

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 (and, frankly, sometimes a bit boring!). 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.

The type of graph you choose depends on the type of data that you have collected. Table 7 outlines the different types of data you may collect, and how you can represent that type of data.

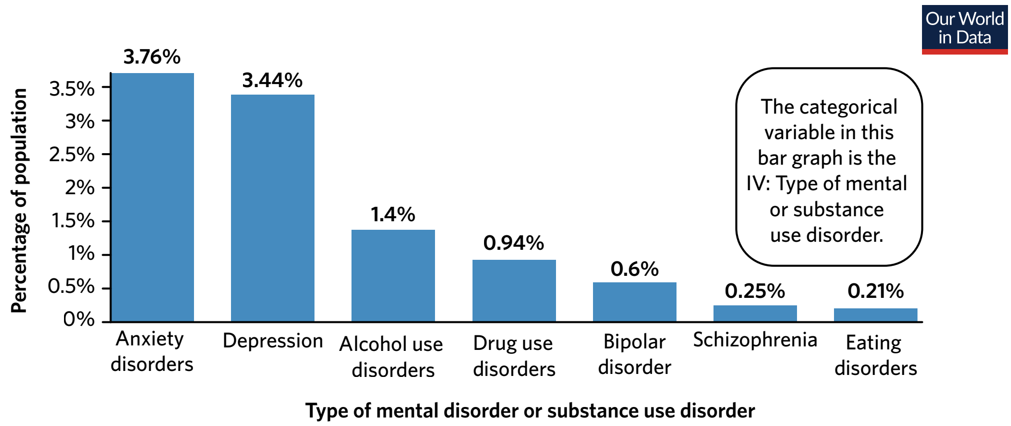
Table 7 Types of data you may collect about variables and how they are best graphed

Type of variable		Explanation	Typically graphed using
Numerical	Continuous	Data that can take any value between a set of real numbers. In other words, continuous data can include decimals and fractions e.g. height (178.87 cm), age (16 years 2 months 4 days…), mass (65.87 kg)	Line graph or scatter plot
	Discrete	Data that can be counted and takes a particular value. Discrete data cannot take a fraction of that value e.g. count of individuals (1, 2, 3)	Bar graph
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 (male, female, nonbinary, other), nationality (Australian, Chinese, South African, Egyptian), hair colour (brown, black, blonde, red)	

numerical variable a factor that is measured as a number such as height, count of population, and age

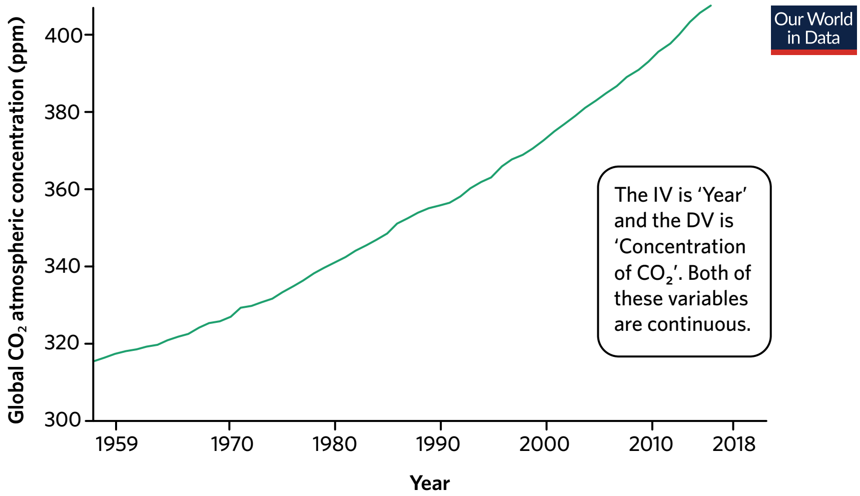
categorical variable a factor that is qualitative, typically describing a characteristic such as gender, birth order (1st, 2nd, 3rd), or nationality

Bar graphs (Figure 14) are typically used to display categorical and discrete data, whereas line graphs (Figure 15) and scatter plots (Figure 16) display continuous data. Scatter plots are particularly useful if you wish to visualise the relationship between two continuous variables (e.g. amount of rainfall and number of species in an ecosystem). If one variable is categorical but the other is continuous numerical, bar graphs usually work well. Note that, typically, the IV is presented on the x-axis and the DV is presented on the y-axis.



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

Figure 14 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 15 Line graph showing the change in global carbon dioxide atmospheric concentration over the past 60 years

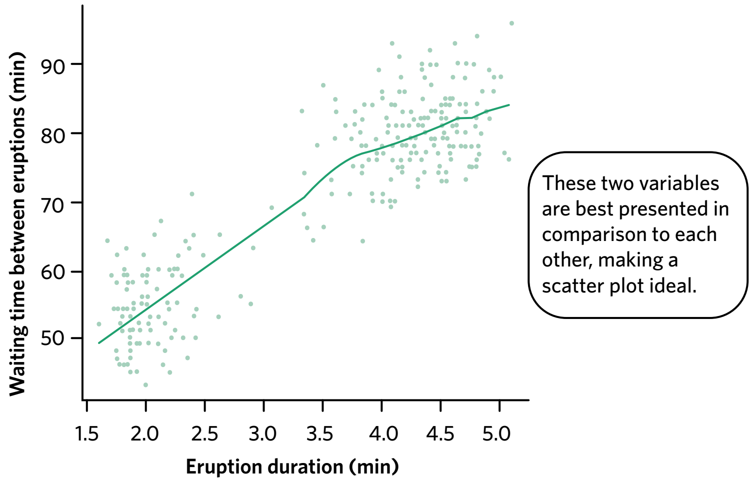


Figure 16 Scatter plot showing that the longer the wait time between eruptions of the geyser Old Faithful, the longer the duration of the next eruption.

During experiments, you may record continuous data enabling you to create a scatter plot. For example, you may record the oxygen concentration in a sealed jar with a plant inside every five minutes. Because both variables are continuous you can make the scatter plot a line graph by drawing a **trendline** also known as a line of best fit. The trendline will help readers determine if the relationship between the two variables is positive, negative, or non-existent. A line of best fit may pass through all the points, some of the points, or none of the points (Figure 17). 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.

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**

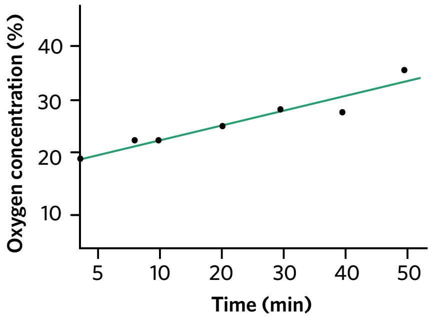


Figure 17 The line of best fit showing the general trend between two variables on a scatter plot

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 easy to 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 caption underneath
- each table should have a table number and title above
- tables should have units written in the column or row headings only, and not in the cells within the table
- the results section also includes text. The text should summarise the key findings for each graph in 1–2 sentences, including if the result supports the hypothesis.

Example

HOW POWERFUL IS A POWER NAP?

In our experiment, the DV was memory, as measured by a score on a test. The IV was study technique – cramming or napping. Classify the DV and IV as categorical or numerical, and continuous, discrete, ordinal, or nominal.

Suggested answer

Score on test = numerical, discrete (because you either get the mark or don't get the mark)

Study technique = categorical, nominal

Example

HOW POWERFUL IS A POWER NAP?

There are so many ways to present the data on test scores. Here, we'll walk through how you could transform the data you collect on study technique and memory.

If you turn our raw data point (Figure 12) into a graph, you'll see what score each student received in each week (Figure 18).

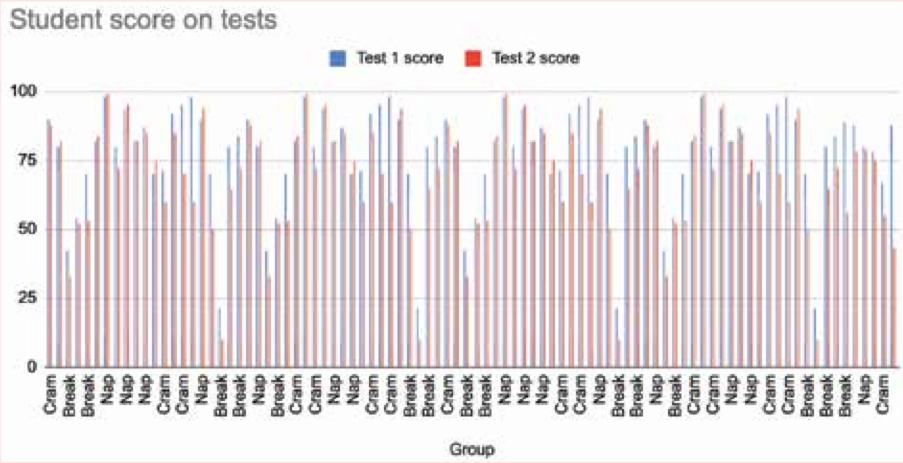


Figure 18 Raw data represented on a bar graph

Figure 18 is easier to read than a table, but is still a little confusing: you can see that the students performed differently, but you can't see if there is a difference between groups that used different study techniques. In essence, the graph is not telling a story yet. Ultimately, we want our graph to clearly answer our research question 'Do Year 11 Biology students at this school remember more if they cram or nap for one hour after a class?'. To do this, we need to figure out the mean score each group achieved on the tests. You can calculate this by summing up all the test scores within a group, then dividing that number by 30 (the number of participants).

Group	Test 1 mean score	Test 2 mean score
Break	62.03	49.13
Nap	85.40	86.73
Cram	86.23	72.47

Figure 19 The mean test scores for the students who breaked, napped, and crammed after learning.

We can then use the means to create a graph that shows our results clearly. Look at the graphs in Figure 20. Which do you think is most appropriate for representing our data, (a) or (b)? Why?

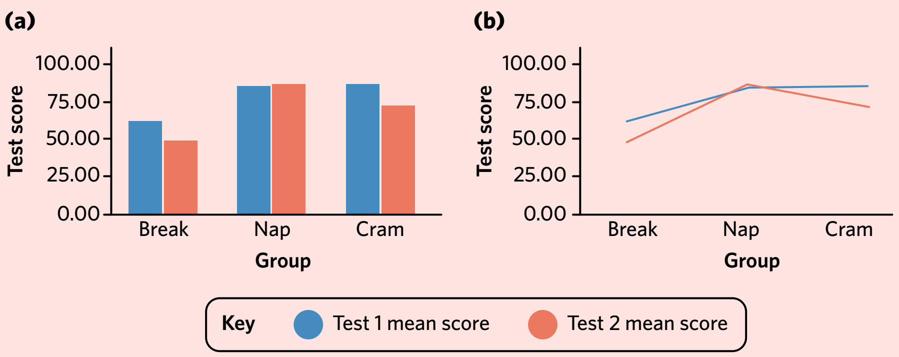


Figure 20 **(a)** A bar graph showing the average score on tests 1 and 2 using different study techniques and **(b)** a line graph showing the average score on tests 1 and 2 using different study techniques

Suggested answer

Graph A represents the data best because neither the IV nor the DV is continuous. In particular, using a line graph for (b) implies that there are values between 'Break', 'Nap', and 'Cram' (e.g. half break-half nap), which is not the nature of these nominal variables.

2. Analyse your data and method

Once you visualise your results clearly, you can:

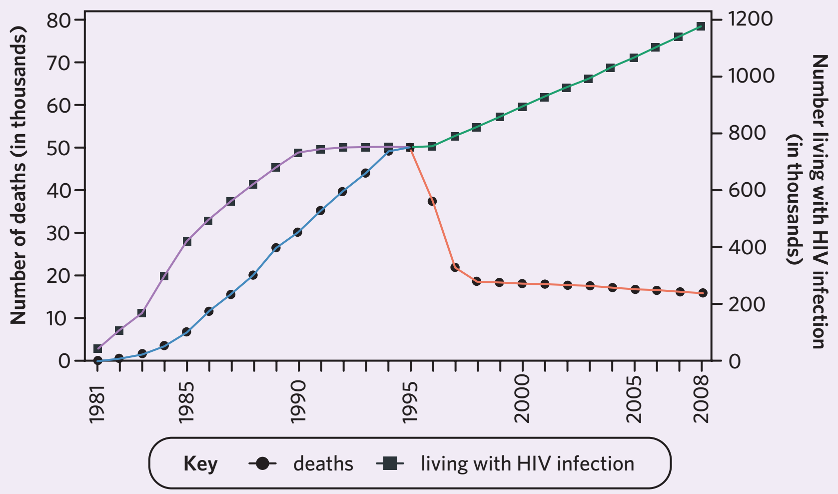
- determine if your hypothesis is supported or rejected
- reflect on your data and method to decide if your experiment is valid and reliable.

It is usually pretty easy to tell if the data support your initial hypothesis – you simply check if the data follow the pattern you expect, or if it does not. Often, you may find that the hypothesis is partially supported by your results. This is always really interesting, as your next step is to think of reasons why the pattern was not consistent. It may be due to an error in your method, or due to an unknown uncontrolled variable.

Theory in context

During exams, you may be asked to describe data before you explain it. A good plan of attack to describe the 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 different colours over particular sections of the data which makes it easier to interpret the line graph in sections.



Source: adapted from NIDA (2020)

Figure 21 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. This number stayed at approximately 800 000 for five years before increasing linearly to 1 200 000 by 2008.

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

Once you know what your results mean for your hypothesis, you can then dig deeper into the data and evaluate your method. Some questions you may wish to consider include:

- Method
  - Did anything happen during the experiment that might mean you can't trust a data point, or multiple data points?
  - Identify any personal, systematic, or random errors that may affect the accuracy and precision of your results.
- Data
  - Precision – are the results within replicate treatments similar or different? If there is a wide spread of results this could mean your instruments or processes were not valid and did not measure what you wanted to measure.
  - Accuracy – if you know what the true value should be, are the values you recorded similar or different? If they are different, this could mean an uncontrolled variable was affecting your results, your instruments were faulty, or that you were not collecting data carefully enough.
  - Outliers – are there any data points that stand out or do not follow the pattern? If so, did something happen when you collected that sample that could explain the anomaly? There may be a good reason to exclude outliers from your results, but make sure you report in your discussion that you did this and why.

The answers to these questions, and any others that may be relevant, should be brought up in the discussion section of a report, article, or poster.

3. Draw evidence-based conclusions

One of the beautiful and frustrating 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 instantly accept this 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.

Theory in context

SHIFTING PARADIGMS IN BIOLOGY

Biological models and theories change when more evidence is gathered. For example, 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.

The strongest evidence is derived from controlled experiments that use random sampling methods and have been reviewed and reproduced by colleagues in the scientific community. Other scientific investigations can provide evidence to draw conclusions from, but it may not be as reliable, as the methods used are typically not as reproducible, repeatable, and valid. Conclusions may also be drawn from **anecdotes** or opinions, though these are not considered reliable sources of evidence as they are subject to no or low replicability and large amounts of bias.

Drawing conclusions from evidence isn't always easy. There are two common mistakes that students make when drawing conclusions: assuming that 1) **correlation** means **causation** and 2) the same pattern will exist beyond the data you measured.

anecdote evidence involving a personal account or report of a previous experience that may provide a certain level of support for a position

correlation when there is a relationship between two variables

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

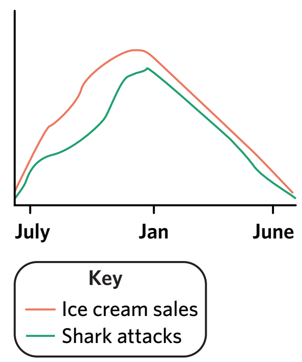


Figure 22 The number of ice cream sales and shark attacks are correlated, but one does not cause the other. It's more likely that an uncontrolled variable – for example, hot weather – explains the relationship (i.e. when it's hot, people are both more likely to eat ice cream and go to the beach, the latter likely increasing the number of shark attacks).

Correlation does not mean causation

Not all experiments will reveal a correlation between two variables – in fact you may find that the DV and the IV are unrelated. Furthermore, even if your data indicate that your IV is related to 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.

Data may not follow the same trend outside of the range you measure

In Figure 23, scientists measured the height of a seedling for ten days. Although a positive trend exists – indicating that seedlings get taller with time – we cannot assume that the growth will continue after day ten. Therefore, it is not correct to state that 'it will take the seedlings 20 more days to reach 9 cm'. One could, however, say that 'if the rate of growth continues in the same manner, then it will take the seedlings 20 more days to reach 9 cm'.

Similarly, the scientists did not collect data on day zero. So, when drawing a line of best fit, it is important not to force your line through zero. 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 (green line).

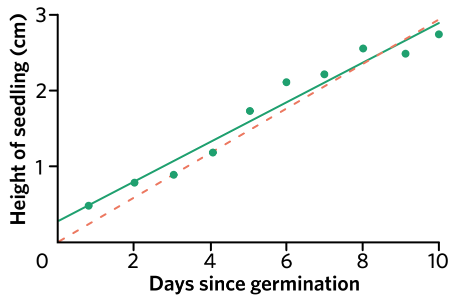


Figure 23 When drawing a trendline, avoid forcing your data through zero (red dotted line) as you end up with a different slope that doesn't accurately represent the data you collected (green).

Example

HOW POWERFUL IS A POWER NAP?

Let's see if we can draw some conclusions from our data on power napping and cramming. Here is our data:

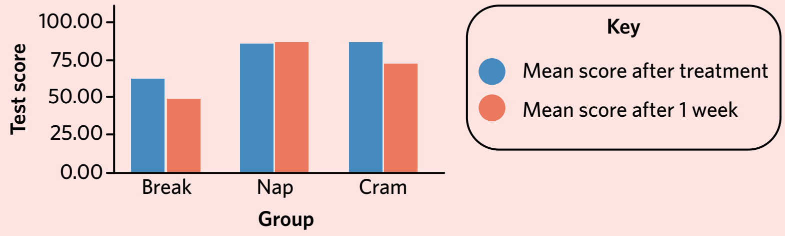


Figure 24 Transformed data showing that napping and cramming after learning improves student performance on tests more than taking a break, and that napping is better than cramming for long term memory formation

From these results, we can tell that both napping and cramming for one hour after a lesson are better study techniques than just taking a break – average students in these groups scored more than 20 points higher than control participants. After one week, students in the cramming group had forgotten more of the lesson than students in the napping group. In fact, the average test score for students in the napping group actually increased slightly. This tells us that for long term retention of knowledge, it is best to take a nap after studying. For short-term retention, you can either nap or study – both will help you achieve better scores than doing nothing.

Ok, so that's what our data tell us. Are there any reasons why this data might not be reliable? How could we address these limitations? Here are a few points that could be worth exploring:

Table 8 Limitations and potential solutions for the experiment 'how powerful is a power nap?'

Limitation	How to address
We used convenience sampling, so we can't assume the same pattern would exist in a different student population.	Collect a larger, random sample of students from lots of different schools. Or you could explain that it doesn't matter that you used convenience sampling, as you wish to determine the best study technique for you, and Biology students at your school are probably more similar to you than Biology students at a different school.
We never dictated in our methods what students should do in the week between tests – if some students studied and others didn't this would impact the results.	Ensure that all students do not study the test preparation material over the next week.
There were a number of variables that we did not control for in this investigation. For instance, did any individuals take medication, drink coffee, or have unusual sleeping routines? Were there any external life events that could have affected individual or group performance? If these variables were similar across groups, they shouldn't affect our results. But if one group is more affected than another, then our results may not be accurate.	Design a more controlled study, where participants are only included if they agree not to consume food or medicines that are stimulants or depressants. Alternatively, we could ask participants to track what they eat and how much they sleep during the study then retrospectively try to see if there are potential issues.
We haven't designed an investigation that helps us understand why napping cements learning.	To be sure that napping is the true underlying cause of improved memory, further investigations into the mechanism behind memory formation need to be undertaken.
There is a possibility that the napping group ended up with lots of high achieving students, and the awake break group was mostly composed of unmotivated students.	Ensure that the groups are composed of academically diverse students by using stratified sampling.

4. Communicate your findings

As we face global challenges like climate change, pandemics, and pollution, it is crucial that all citizens have basic scientific literacy. However, approximately forty per cent of Australians report being uninterested in, and disengaged from, science (Cormick, 2014). One of the major barriers to improving scientific literacy is that scientists often use complex, technical words and high levels of detail which can make science seem boring or difficult.

Professional science communicators emphasise that the best way to communicate your findings depends on your audience. For instance, to communicate your results to your teacher or supervisors, a formal laboratory report written according to standard scientific practice would be most appropriate. However, if you are trying to teach your siblings or parents about something you learned at school, you should avoid jargon and perhaps use drawings and examples to support your communication.

In this book, you'll find more information on specific communication techniques for assessments in Unit 4 Outcome 3 in the section called 'How to conduct a practical investigation '. In addition to these assessments, your teacher may ask you to complete practical reports on scientific investigations you conduct. To help you communicate your findings clearly, Table 9 outlines the typical conventions and formats for each section.

Lesson link

Check out the ***How to conduct a practical investigation*** guide which includes a visual example of a poster you might create for your SAC. This guide is found after Chapter 6.

Table 9 The components of a practical report, including the suggested length and tense of each section

Section	Section description	Suggested length	Suggested tense
Title	The title may be written as a question or statement that describes the main phenomenon you are trying to determine in your experiment. 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

Table 9 Continued

Section	Section description	Suggested length	Suggested tense
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. – Any gaps in knowledge, and how your experiment could fill that gap • The aim of the experiment • The variables that are being 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	Mostly present and future
Method	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, using short sentences and direct language. 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 trends, patterns, or relationships that exist. Each figure is accompanied by a brief (2–3 sentences) description of the key findings. 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
Discussion	The purpose of the discussion is to determine if the data obtained supports 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: • 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 *cont'd*

Table 9 Continued

Section	Section description	Suggested length	Suggested tense

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. For more information on how to reference, please refer to the Strategies for Success lessons included in this book.	Typically anywhere from 2–20 references (not included in word count)	N/A

Example

HOW POWERFUL IS A POWER NAP?

The investigation we've been stepping you through for this lesson is not made up – there is strong evidence that suggests daytime naps improve long term memory formation more than cramming. You can read the original research here: academic.oup.com/sleep/article/42/1/zsy207/5146032

This is how we'd reference the article in the Harvard style:

Cousins, J., Wong, K., Raghunath, B., Look, C., Chee, M. (2019). The long-term memory benefits of a daytime nap compared with cramming. Sleep, 42 (1).

Theory summary

KSSs are a set of capabilities that help build scientific thinking. There are opportunities to develop, demonstrate, and test your KSSs throughout VCE Biology. Figure 25 summarises the questions you should ask to demonstrate KSSs in scientific investigations.

1. Planning and designing

1 What is my research question and aim?
2 What are my IV, DV, and controlled variables?
3 What is my hypothesis?
4 What methodology is appropriate?
5 How do I design a reproducible, repeatable, and valid method that is both accurate and precise?
6 What ethical and safety guidelines should I follow?

2. Conducting

1 How do I collect data?
2 How do I record potential errors and observations?
3 How do I work best with my team?

3. Analysing and presenting

1 What is the best way to present my raw data?
2 What errors might there be with my methods and data that could invalidate my results?
3 What conclusions can I draw from these results?
4 How should I communicate my findings?

Figure 25 A summary of the questions to ask to demonstrate KSSs

The process of creating the HPV vaccine would have started with an observation about the nature of the virus – perhaps it is closely related to another virus, or it has a particular protein embedded in it's protective envelope. From there, the scientists would have constructed a research question, aim, and hypothesis about the nature of a HPV vaccine. They would have selected a methodology and developed a method for creating the vaccine, then tested it using random sampling, replication, and control and experimental groups, all the while attempting to minimise error.

To uphold ethical and safety guidelines, the vaccine would first be tested on cells and tissues, then animal subjects, and then, if it passed the previous trials, humans. The original HPV vaccine was tested on more than 20 000 females in 33 countries and 4 000 males in 18 countries before it was approved for general commercial use. Usually it takes more than 10 years to invent and approve a new drug, and only ~ 1 in 5 000 drugs that are 'invented' end up making it to market. What happens with the other 4 999? The results may not have supported the hypothesis that the drug would be effective, the method may have been unreproducible, the results may have been inaccurate or imprecise, the side effects may have made the drug unethical to sell – any number of things may have gone wrong. Luckily, rigorous testing using KSSs means that these ineffective or potentially dangerous drugs don't make it to pharmacies.

1A QUESTIONS

Theory review questions

Question 1

KSSs are

A the set of capabilities that people demonstrate when undertaking scientific investigations.

B biological theories and knowledge that must be memorised for the exam.

Question 2

An example of a testable, specific, and realistic research question is

A 'Does garlic inhibit the growth of the bacteria *Staphylococcus epidermis*?'

B 'How does garlic affect the growth of the bacteria *Staphylococcus epidermis*?'

Question 3

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 4

Control groups are important because they

A help us to make assumptions beyond the sample population.

B reveal if any factors besides the IV are influencing the results.

Question 5

Which of the following is true regarding replication? (*Select all that apply*)

I Replication decreases the influence of outliers on results, and proves that the same result can be achieved multiple times.

II Replication improves the reliability and validity of experiments, as it shows data are not due to random chance.

III Replication reduces the impact of random error, but cannot reduce systematic errors.

IV Replication, repeatability, and reproducibility are different words for the same thing.

V Replication always makes measurements more accurate and precise.

VI Replication never affects accuracy or precision.

Question 6

Fill in the blanks in the following sentences.

__________ errors decrease the precision of results. __________ errors decrease the accuracy of results. One way to increase __________ is to ensure all instruments are calibrated correctly. One way to increase __________ is to use appropriately sized measuring equipment.

Question 7

Which of the following is an example of a strategy to minimise risk in an experiment that involves growing plants?

A avoid using hazardous chemicals

B allergies of individuals in the class

C following Bunsen burner safety procedures

D sanitising equipment and benches after lab work

Question 8

Order the types of evidence from most to least reliable for drawing scientific conclusions.

I opinion

II anecdote

III primary data from a controlled experiment

IV primary data from an unreplicated case study

SAC skills questions

Scientific methodology comparison

Use the following information to answer Questions 9–15.

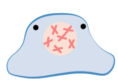
In 2020, the Victorian Government banned the use of mobile phones in schools in order to 'reduce distractions, tackle cyber-bullying, and improve learning outcomes'. In Term 1 2021, two groups of students wanted to find out if banning mobile phone use had actually improved student learning outcomes in their school. While having the same research question, the groups developed different methods:

Method 1

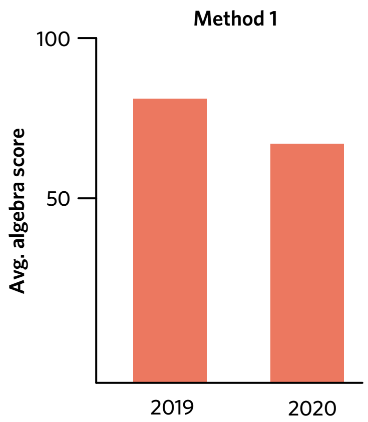
- Collect anonymised student grades for the algebra unit in Year 10 Maths from 2019 (n = 110) and 2020 (n = 110)
- Compare the average score of a student for this unit in 2019 and 2020

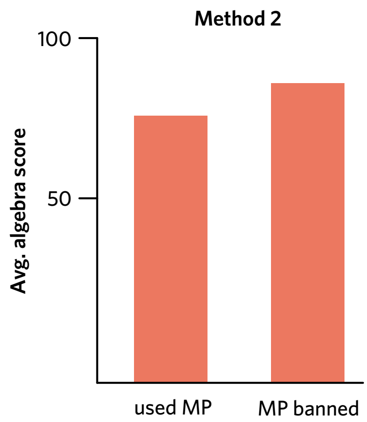
Method 2

- Randomly divide all Year 10 students in 2021 into two groups
- Both groups are taught the algebra unit by the same teacher
- One group (n = 55) is permitted access to mobile phones, the other group (n = 55) has mobile phone use banned
- Compare the average score of a student for this unit with or without mobile phone use



The student groups each undertook their experiment, and their results are shown:





Question 9

Which of the following is the best research question the students could have posed?

A 'Does banning mobile phones at our school improve algebra performance in Year 10 students?'

B 'Is mobile phone use affected by Year 10 student algebra performance?'

C 'Does banning mobile phones improve student learning outcomes?'

Question 10

Identify the independent and dependent variables in the investigation.

A IV – mobile phones banned or not banned; DV – average score on algebra test

B IV – average score on algebra test; DV – mobile phones banned or not banned

Question 11

A bar graph was used to depict the results instead of a line graph because

A the dependent variable is numerical.

B the independent variable is categorical.

Question 12

A strength of Method 1 is that it would

A have a larger sample size than Method 2.

B provide insight into the intelligence of students from two different cohorts.

Question 13

A strength of Method 2 is that it would

A be more highly replicated than Method 1.

B have less uncontrolled factors than Method 1.

Question 14

Which of the following conclusions can be drawn from the results collected by both groups?

A The results from both groups contradict the hypothesis that banning mobile phones improves student learning outcomes.

B The results from both groups support the hypothesis that banning mobile phones improves student learning outcomes.

C The two groups have collected contradictory evidence.

Question 15

Which of the following is not a possible explanation for the results derived from Method 1?

A The Maths teacher in 2019 may have been more experienced than the teacher in 2020.

B One cohort may be intrinsically better at algebra than the other cohort.

C Mobile phone use does not impair student learning outcomes.

D Students used the same textbook in both years.

Exam-style questions

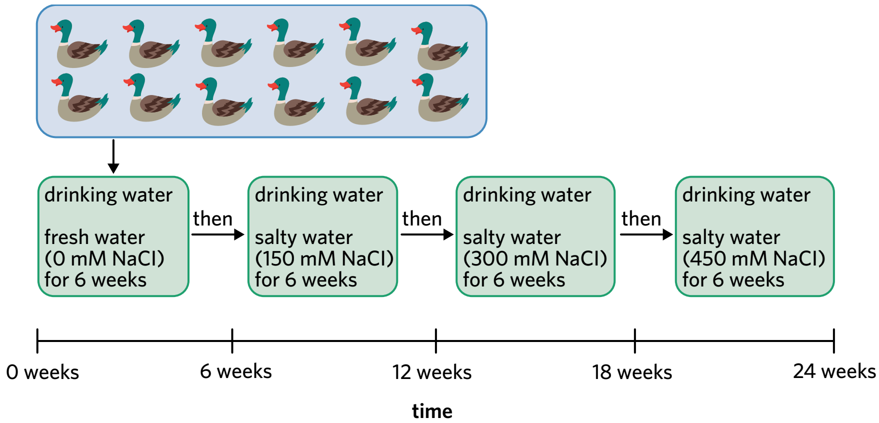
Within lesson

Use the following information to answer Questions 16–21.

Biologists investigating the regulation of body water in Pekin ducks, *Anas domesticus*, put forward the hypothesis that Pekin 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 Pekin ducks, males and females, were available and two experimental designs were suggested.

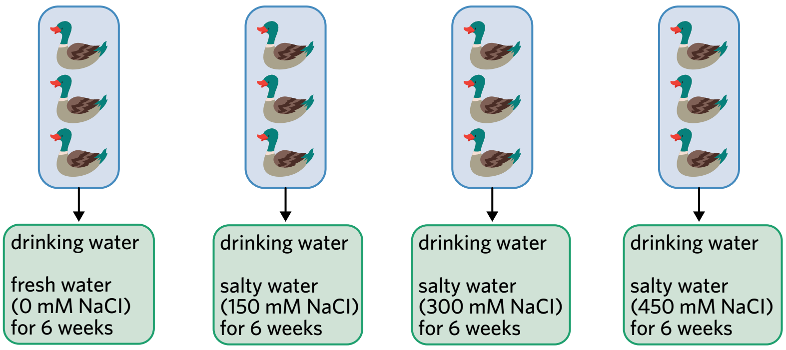
Design 1

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.



Adapted from VCAA 2004 Exam 1 Section A Q17

Question 16 (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.

Question 17 (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 18 (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 19 (1 MARK)

An uncontrolled variable in Design 1 is

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

Question 20 (1 MARK)

One strength of Design 1 is that it better accounts for

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

Question 21 (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.

Use the following information to answer Questions 22 and 23.

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 experiment.

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 22 (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.

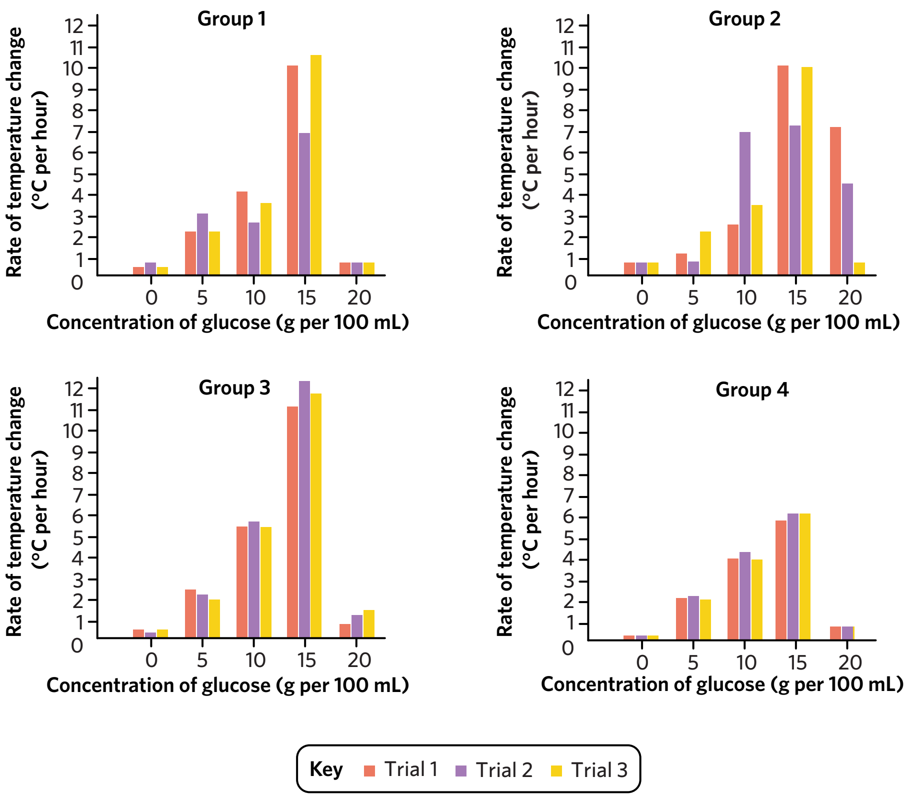
C Group 4's measurements are the least accurate and the least precise.

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

Adapted from VCAA 2018 Section A Q11

Question 23 (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.



Which one of the following conclusions can be drawn about the experiment's results?

A All the groups have invalid results because they didn't replicate their method.

B Group 2 experienced systematic errors during their experiment.

C Group 4's results are less precise than the other groups'.

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

Adapted from VCAA 2018 Section A Q12

Question 24 (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 a controlled experiment, using mice, to test the effectiveness of a drug that targets viruses. (3 MARKS)

b Identify two ethical considerations the scientists should consider 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)

Question 25 (8 MARKS)

An experiment was carried out by students to test the effect of temperature on the growth of bacteria. Bacterial cells were spread onto plates of nutrient agar that were then kept at three different temperatures: –10 °C, 15 °C, and 25 °C. All other variables were kept constant. The experiment was carried out over four days. The nutrient agar was observed every day at the same time and the percentage of nutrient agar covered by bacteria was recorded. At the conclusion of the experiment, the results were recorded in a table.

Time (days)	Percentage of nutrient agar covered by bacteria at three different temperatures (%)		
	–10 °C	**15 °C**	**25 °C**
0	0	0	0
1	0	5	10
2	0	10	20
3	0	15	40
0	0	20	60

Adapted from VCAA 2019 Section A Q7

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

b State a hypothesis that is supported by these results. (1 MARK)

c Suggest two variables that would have to be kept constant in this experiment. (2 MARKS)

d Two of the students, Mimi and Diego, wanted to reduce the chance of personal errors influencing the results. Mimi said that they could do this by getting multiple students to estimate the percentage of nutrient agar covered by bacteria, then taking the average. Diego thought it would be better to include a control group. Name the student who is correct, and explain your choice. (3 MARKS)

1B ETHICS IN BIOLOGY

Have you ever heard of The Fountain of Youth? It is an old, mythical story about a magic spring of water that can restore our youth. People have been writing about it for thousands of years but, until now, the idea of escaping death was squarely science fiction.

In the last twenty years, scientists have learned more about the specific genes involved in the aging process, and claim to be getting closer to unlocking the secrets of their regulation and control. Not only to slow the aging process, but also to increase our health and make us live longer as young, healthy adults. Some scientists have said we could live as long as 1 000 years and could be playing sports and running around for a lot of that. The focus now is on developing a safe and reliable medication to control the regulation of these anti-aging genes, a feat which some scientists from leading universities around the world suggest is as little as ten years away!

But the question is: how should we feel about all this? Should we meddle with the natural biology of our cells, or is living longer not all it's cracked up to be? How can we even begin to make a decision here, and feel confident that we're acting in the right way?

Lesson 1B

In this lesson you will be learning about the relevance of ethics in biology, including what defines an ethical issue and how to exercise judgement in real-life ethical dilemmas.

◀ *Prerequisite knowledge* | *Future applications* ▶

Years 7–10
You would have started thinking about ethics, especially when performing practical investigations using live organisms.

Year 11
You would have been introduced to the approaches to bioethics and bioethical concepts and applied this to the knowledge you learned, especially for concepts such as stem cell research or genetic testing.

Year 12
You are required to apply ethical frameworks when designing experiments, conducting your own investigations, analysing data, and identifying issues relating to the application of scientific knowledge. You will also get to practice evaluating and analysing ethical concepts in the question section of every lesson in this textbook, as well as a number of ethical deep dives at the end of chapter SAC practices.

Study design dot point

Over the course of your assessments and exam, you will be required to employ ethics when answering questions and approaching problems. For this reason, each lesson in this book includes questions that pertain to the KSSs you learned about in lesson 1A, and require you to apply the bioethical concepts and approaches you will learn about in this lesson. You can think of these as part of your bioethical 'toolkit' as a VCE Biology student.

Key knowledge units

Bioethical issues	0.0.0.14
Approaches to bioethics	0.0.0.15
Ethical concepts	0.0.0.16

Bioethical issues 0.0.0.14

OVERVIEW

Ethics is a way of thinking about right and wrong that helps guide our actions and decision-making. In the world of science, ethics is taught and developed to allow scientists to make informed judgements about how best to act in the interests of others.

THEORY DETAILS

What is ethics and why is it important?

Ethics is a field of knowledge that deals with our personal understanding of right and wrong. At its simplest, ethics can be thought of as a working system of moral principles that help us question our actions and those of others while defending our own values, beliefs, and principles.

Applied ethics is important in helping us bridge the gap between abstract theories we might learn in the classroom and concrete situations we might face in the world. It is an attempt to implement ethical theories and moral principles to guide decision making in particular contexts and problems. The ethical situations we are faced with often arise when different stakeholders (e.g. scientists, organisations) have different opinions on what is right or wrong and must choose between alternative points of view when deciding how to act.

ethics a field of knowledge that helps individuals exercise moral judgment and determine what is right and wrong

applied ethics the application of ethical theories to real-life moral problems and contexts

Why is ethics important in biology?

Science is rarely an individual endeavour. Instead, it involves constant interactions with others, whether that be colleagues, employers, or the public. An important part of 'doing science' is not just the theories and concepts you learn, but also how you apply that knowledge in a way that maximises ethical outcomes. This requires scientists to engage in **metathinking** – that is, thinking about the way they think – to ensure that they are aware of the outcomes of their actions and employ different strategies for reaching important decisions.

metathinking the practice of reflecting upon and evaluating the way we think, including the different strategies and tools for problem-solving and learning

It may be easy to assume that this ability to think critically and act ethically becomes part of a scientist's 'toolkit' incidentally through natural means such as their upbringing, education, and community involvement. However, this 'incidental learning' is not enough. Instead, ethics is deeply embedded and integrated within scientific education, and involves active learning and practice on the part of the developing scientist. Scientists use these ethical frameworks they learn to help guide their decision-making process and justify their actions. As such, the application of ethical understanding is an important feature that runs throughout the entirety of the VCE Biology course.

What is a bioethical issue?

Biologists frequently use **bioethics** in their work across interdisciplinary fields, including biotechnology, environmental conservation, and healthcare research. In the course of this work, biologists are often confronted with **bioethical issue**s, which are specific ethical dilemmas pertaining to biology (Figure 1).

bioethics the study of ethical issues pertaining to biology and medicine

bioethical issue an ethical dilemma pertaining to biology that typically involves a decision-making process between two or more choices or options for an action

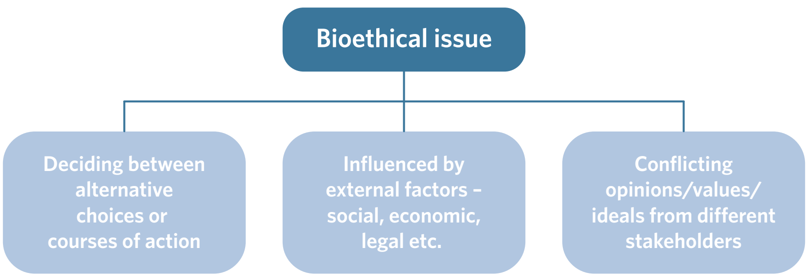


Figure 1 Some of the common features of a bioethical issue

We can recognise a bioethical issue because it will typically involve a decision-making process between two or more options for action, each of which will require some form of ethical justification – 'I should do X in this scenario, as it means that Y will occur'. The options available in these scenarios are usually in conflict with one another and can be evaluated using different **approaches to bioethics** and **ethical concepts**. The approaches and concepts help the individual consider the social, economic, legal, and political factors that might be relevant when deciding what is right (ethical) and wrong (unethical) (Table 1).

bioethical approach a decision-making framework that helps guide ethical behaviour

ethical concept a specific perspective or lens used to consider multiple angles of an ethical dilemma

Table 1 Some current areas of research that raise bioethical questions. Note that for each of these issues, multiple different ethical justifications can be identified. For example: 'we should use artificial intelligence in biology as it allows us to better track disease spreading patterns' vs 'we should not use artificial intelligence for disease-tracking as we are still not capable of containing its scope'.

Biological discipline	Bioethical issue
Biotechnology	• The use of artificial intelligence in biology, including disease-tracking software and facial recognition • The use of bioengineering in biology, such as the creation of synthetic vaccines, or replacement organs • The potential applications of stem cell research, including disease management and human enhancement
Healthcare	• The use of human embryos to research new therapies for diseases • The implications of prenatal testing for genetic defects during pregnancy • Whether or not organ donation ought to be voluntary, or if it should be state-imposed • How best to care for individuals at the end of their life, including the availability of euthanasia • The correct allocation of medical resources, including the dedication of physician time to hospital patients • The privacy of medical data, including the extent to which personal health data is shared with governments and insurers
Environmental conservation	• The potential of 'de-extinction' processes to bring back extinct species like mammoths • The potential for ecosystem management, and the best way to maintain the health of endangered species • How best to tackle climate change, including funding for research and changes to the way energy companies operate • How to balance the impact of industry and agriculture on natural environments, including laws that aim to control deforestation and habitat removal

Theory in context

ARE PATENTS HARMING BIOMEDICAL RESEARCH AND DEVELOPMENT?

A patent is a legally enforceable right to an invention that gives its owner the ability to exclude others from making, using, or selling that discovery. In the world of science and medicine, patents are useful in protecting the innovation of manufacturers by assigning them legal ownership of their developments, such as vaccines and medical equipment.

Nonetheless, it is unclear whether patents stimulate and promote important research and development, or whether they hinder it. Manufacturers argue that the protection of a patent provides an incentive to invest time and resources into further development, and allows for increased financial returns to improve resourcing and help progress further research. On the other hand, some critics argue that patents stifle free research by preventing others from accessing patented equipment or methods that might be helpful in their studies. This can lead to skyrocketing costs for the general public, as pharmaceutical companies might decide to heavily inflate the cost of their own prescription medications.

Approaches to bioethics 0.0.0.15

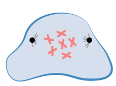
OVERVIEW

There are many different approaches that can be used when exploring bioethical issues. In VCE Biology, you are required to use three approaches in particular: consequences-based, duty/rule-based, and virtues-based. These approaches act as frameworks for addressing bioethical concerns and serve many purposes, including identification, exploration, consideration, decision-making, and reflection.

THEORY DETAILS

What is an approach to bioethics?

Because bioethics is often 'applied', scientists need specific tools to help them make informed ethical decisions. One type of tool scientists can use are approaches to bioethics, which are decision-making frameworks that help guide ethical behaviour. There are three specific approaches to bioethics that you need to be aware of in VCE Biology (Figure 2). Depending on the bioethical issue being considered, you may be able to use one or more of the following approaches to help inform your decision-making process.



Approaches to bioethics

Consequences-based

The individual should be driven by consideration for the consequences that are likely to result. The aim of this approach is to maximise positive outcomes while minimising negative effects.

A **consequences-based approach** often emphasises the surrounding circumstances of an action, and may sometimes allow an individual to break the rules in order to achieve the greatest good for the greatest number of stakeholders.

Key terms: outcomes, benefits, consequences, effects

Duty/rule-based

The individual should be driven by a fundamental duty to act in a certain way. The aim is to follow set rules and responsibilities, with less regard for the consequences that may result.

A **duty/rule-based approach** oftenargues that an action can't be justified just because it produces good consequences. Instead, some actions must be followed because they are the responsibility of the individual, regardless of the consequences that may result.

Key terms: obligation, duty, responsibility, commitment

Virtues-based

The individual should be driven by their character, rather than by any fundamental rules or consequences. The aim is to emphasise the moral nature of the individual, and provide guidance as to the behaviours a morally good person would hope to achieve.

A **virtues-based approach** often argues that an action can be justified simply because it is charitable, or caring, or good (virtues). Here, emphasis is given to the 'virtues' involved in making a decision, rather than following a rule or being driven by consequence.

Key terms: any reference to virtues, such as good, honest, caring

Figure 2 The three major approaches to resolving bioethical issues. Notice that each approach has a different main focus – consequences, responsibility, and virtues. It can be helpful to use key 'buzz' terms when discussing each approach, as this demonstrates to your examiner that you can effectively separate the approaches in your mind and discuss their individual focuses.

consequences-based approach an approach to bioethics that aims to maximise positive outcomes while minimising negative outcomes

duty- and/or rule-based approach an approach to bioethics that promotes the responsibility of the agent above all else, and places importance on the duty of each individual

virtues-based approach an approach to bioethics that emphasises the individual goodness of the agent, and promotes acting in accordance with the values of a 'moral' person, such as honesty and compassion

Theory in context

CORONAVIRUS 2020 – THE APPROACHES IN ACTION

To consider these approaches in action, let us examine a bioethical issue during the early parts of the coronavirus pandemic, where Italian hospitals were faced with the ethical decision of who to treat and who to turn away. In such a situation, different ethical approaches may point to different courses of action.

As of March 1 2020, Italy had a total number of 1 701 cases of coronavirus nationwide. However, within the space of only 30 days, the number had sky-rocketed to 110 574 cases. This dramatic increase meant that hospitals and doctors could not treat everyone, leaving them with an incredibly hard decision: 'who do we treat first and how do we decide who to turn away?'

The ethical ramifications of such a decision were immense, as people who were denied treatment were sometimes at an increased risk of dying. Denying patients' access to treatment seems to stand in direct opposition to 'professional ethics' and therefore requires ethically trained professionals to try and develop the most moral course of action in the extraordinary circumstances.

As such, the Italian College of Anesthesia, Analgesia, Resuscitation, and Intensive Care (SIAARTI) published guidelines that doctors and nurses were asked to follow. The guidelines were rigorously examined against a range of bioethical considerations, including a consequences-based approach, which sought to maximise favourable outcomes for the largest number of people. This involved allocating care to patients with the highest chance of survival, specifically prioritizing young and otherwise healthy individuals while turning away older patients. How else might the SIAARTI have acted, and how might each approach point to a different course of action?

cont'd

Theory in context

CORONAVIRUS 2020 – CONTINUED

A consequences-based approach might argue that each hospital should aim to maximise good for the most number of people. If it turned out, as was the case for most Italian hospitals, that the demand for care outweighed their resources, then maximising good outcomes might mean focusing those resources on patients who are likely to best recover and respond to treatment. In this case, that means focusing treatment on young and otherwise healthy individuals, and less so on older patients who are perhaps less likely to survive.

A duty/rule-based approach might argue that as doctors and healthcare providers, each individual has a moral obligation to provide treatment to whoever is in need. Perhaps this would mean focusing resources in a first-come-first-serve manner, where care is distributed sequentially based on when a patient arrives at the hospital. A duty/rule-based approach might suggest that this is the fairest means of distributing care, and that hospitals have a duty to act indiscriminately rather than turning away patients based on their age.

A virtues-based approach might argue that doctors ought to follow the moral guidance of their own value judgements as to who is most in need. That is, the distribution of care should be left to the moral virtues of a good doctor – such as kindness, fairness, and good judgement. In this case, a hospital would not follow a certain rule (such as first-come-first-serve), nor focus on maximising consequences (though this may well be an outcome). Instead, each doctor is seen as their own moral agent deciding how best to distribute resources.

Figure 3 The approaches in action

In this case, the recommendations of the SIAARTI and the response of Italian hospitals most closely aligned with a consequences-based approach. However, it is important to understand that the three approaches rarely act in isolation. That is, it is rare for the approaches to sit distinctly in their own box. Instead, each approach will often act in conjunction with others to inform an individual as to the best or most ethical course of action in the circumstances.

Memory device

It is helpful to think of bioethical approaches as tools in a toolbox. Sometimes, a single hammer will be enough for a job, such as hammering a nail. Other times, however, the job might be more complex and require not only a hammer but also a saw and a wrench. The same is true of the three approaches. We are required to consider each in our quest to make ethical decisions and judgements.

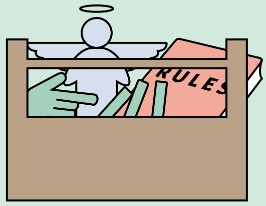
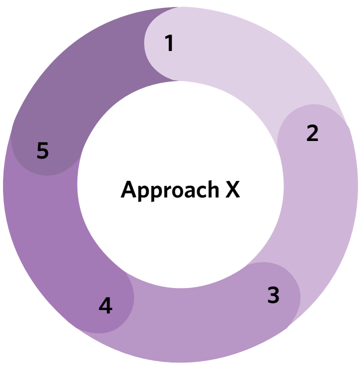


Figure 4 Bioethical approaches are like tools in a toolbox.

Why are approaches to bioethics important?

The three approaches we have looked at serve as broad frameworks for considering a bioethical issue and help guide us when considering the potential of different outcomes. Figure 5 represents some of the ways a bioethical approach might be useful when considering a bioethical issue. Ultimately, each approach can serve a range of important functions, and they provide the individual with useful guidelines when approaching a particular dilemma or issue.



1 **Identifying the issue**
Why is this an important bioethical concern?
Why are we considering this?

2 **Exploring the issue in context**
What situational factors surround the issue?
What do we need to be aware of?

3 **Considering different perspectives**
Who are the stakeholders involved in this issue?
What do they think and how might this affect them?

4 **Deciding on a position or course of action**
What is the most ethical way to proceed?
What position am I going to take on this issue?

5 **Reflecting on chosen course of action**
How did my position or course of action affect stakeholders?
What was the impact of my judgement?
Do I need to revise my position?

Figure 5 The role of a bioethical approach – identification, exploration, consideration, decision-making, and reflection. Note that we should be using all three approaches in conjunction wherever possible. Often this comes between steps 3 and 4, when it comes time to analyse the strength of different perspectives and come to a position or course of action.

Ethical concepts 0.0.0.16

OVERVIEW

There are five ethical concepts that are often used in conjunction with the three overarching approaches to bioethics. These concepts – integrity, justice, beneficence, non–maleficence, and respect – help inform the approaches spoken about in the previous section.

THEORY DETAILS

What are ethical concepts and why are they important?

As well as the three overarching approaches to bioethics, there are also a variety of ethical concepts which may be used in the exploration of bioethical issues. Each concept serves as a unique perspective or lens for considering different angles of an ethical dilemma and may be used either in isolation or in conjunction with each other alongside the three approaches we spoke about in the previous section.

There are five specific bioethical concepts that you need to be aware of in VCE Biology. Depending on the bioethical issue being considered, you may use one or more of the following concepts to help you analyse a bioethical issue:

- **Integrity** – the commitment to knowledge. This concept encourages individuals to act honestly and truthfully, especially when presenting their findings or results. Integrity prioritises an accurate understanding and representation of the facts, whether favourable or unfavourable to an individual's personal position, and encourages scrutiny and criticism.
- **Justice** – the commitment to fairness. This concept encourages consideration of different people's opinions and positions, especially those directly affected or marginalised by a course of action. Justice prioritises the fair distribution of resources, as well as equal access to the benefits of an action, policy, investigation, or research.
- **Beneficence** – the commitment to maximising benefits. This concept encourages individuals to act in a way that benefits others. Beneficence promotes the personal wellbeing and good of other persons, particularly direct stakeholders such as patients and research subjects.
- **Non–maleficence** – the commitment to minimising harm. This concept encourages individuals to act in ways that remove as much harm as possible. Indeed, while actions may always involve some degree of possible harm, non–maleficence prioritises minimising this harm, sometimes to the detriment of people's freedom of choice and autonomy.
- **Respect** – the commitment to consideration. This concept encourages individuals to consider the value of others, including their personal welfare, beliefs, freedom, and autonomy. Respect prioritises the freedom of others to make their own decisions and be protected from persecution or exploitation.

The concepts in action

Here at Edrolo Lab, our team is developing a new vaccine that can help cure a terrible new disease known as 'Biologitis'. Throughout our research and trial stages, we were sure to act ethically and were informed at different times by the three approaches to bioethics. Now, it is time to release our vaccine and make it available to the public. To ensure we continue to behave ethically, we have considered the relevance of each of the five bioethical concepts (Figure 7).

integrity an ethical concept that encourages a full commitment to knowledge and understanding as well as the honest reporting of all sources of information and results

justice an ethical concept that encourages fair consideration of competing claims, and ensures that there is no unfair burden on a particular group from an action

beneficence an ethical concept that seeks to maximise benefits when taking a particular position or course of action

non–maleficence an ethical concept that discourages causing harm – or when harm is unavoidable, ensuring that the harm is not disproportionate to the benefits from any position or course of action

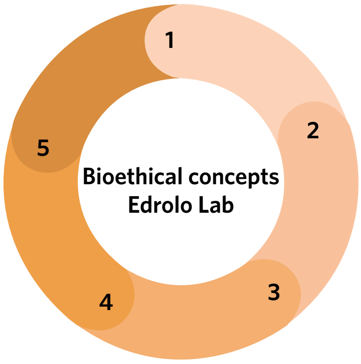
respect an ethical concept that encourages the acknowledgment of the intrinsic value of living things, and considers the welfare, beliefs, customs, and cultural heritage of both the individual and the collective

Memory device

When using the five concepts to help evaluate a bioethical issue, it may be helpful to use the mnemonic memory device:

I **J**oke **B**ut **N**o-one **R**eacts

Figure 6 It's 'not funny' to forget the concepts



1 Integrity
Edrolo Lab decided to publicly release the research and results that went into developing the vaccine to allow for public scrutiny.

2 Justice
Edrolo Lab decided to provide free access to their vaccine for people in low socioeconomic communities.

3 Beneficence
Edrolo Lab decided to produce excess vaccines for storage in all hospitals in Victoria.

4 Non-maleficence
Edrolo Lab was sure to minimise unnecessary harm and distress of the animals used during the testing phase of their vaccine.

5 Respect
During human trials to check for vaccine efficiency, Edrolo Lab was sure to gain informed consent from all of their research participants.

Figure 7 The bioethical concepts in action. Can you identify other ways that each concept might be used to inform the actions of Edrolo Lab?

Theory in context

THE ISSUE OF GENETICALLY MODIFIED ORGANISMS (GMO)

A genetically modified organism (GMO) is an organism whose DNA has been altered using genetic engineering techniques. This often occurs in a laboratory, or in agriculture, and is typically used to favour the expression of some trait, such as pest/pesticide/disease/drought tolerance, higher yields, larger size, greater nutritional content, longer shelf lives, or brighter colour.

The use of GMOs for human and animal food is a bioethical issue. Some of the most common pros and cons associated with GMOs are summarised in Table 2.

Table 2 Common pros and cons associated with the GMO debate

Pros	Cons
• GM crops typically 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 • GM foods can be made to have improved nutritional content, improving the health of individuals • GM crops can sometimes grow in more adverse conditions (e.g. drought-tolerant corn), protecting against famine and improving food security • Increased crop yields result in larger profits for farmers, while herbicide-tolerant crops reduce labour demands as farmers don't need to pull weeds by hand	• 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 GM genes to spread accidentally • Some people consider GMOs to be unnatural, or like we are 'playing God' • Some people believe that genetically modifying animals for human benefit is inhumane – many anti-animal GMO arguments apply to animal agriculture in general • GM animals can have health issues

How might the bioethical concepts be used to inform this debate?

- **Integrity** – manufacturers might need to clearly label their products as GMOs, allowing consumers to be better informed.
- **Justice** – GMOs might create inequity between larger agricultural companies who have the resources to genetically alter their crops versus a small family farm that does not.
- **Beneficence** – there are positive health outcomes for people who consume GM foods that have been nutritionally enhanced.
- **Non-maleficence** – GMOs might cause unintended disruptions to the food web, such as insect-resistant crops that may alter population levels of different pests.
- **Respect** – it is important to promote the right of individuals to freely choose whether or not they use GMOs, and be provided with equal representation of alternatives.

By weighing up the considerations raised by each of the ethical concepts, scientists can figure out the best or most ethical course of action.

Theory summary

Ethics is a system of knowledge that deals with our personal understanding of right and wrong. In VCE Biology, we need to be aware of different strategies and tools to help us think and behave ethically. These include three bioethical approaches, and five bioethical concepts (Figure 8).

Each approach serves as an overarching framework for tackling a bioethical issue. The bioethical concepts may be used in conjunction with these frameworks, or indeed as standalone means for evaluating a position or course of action.

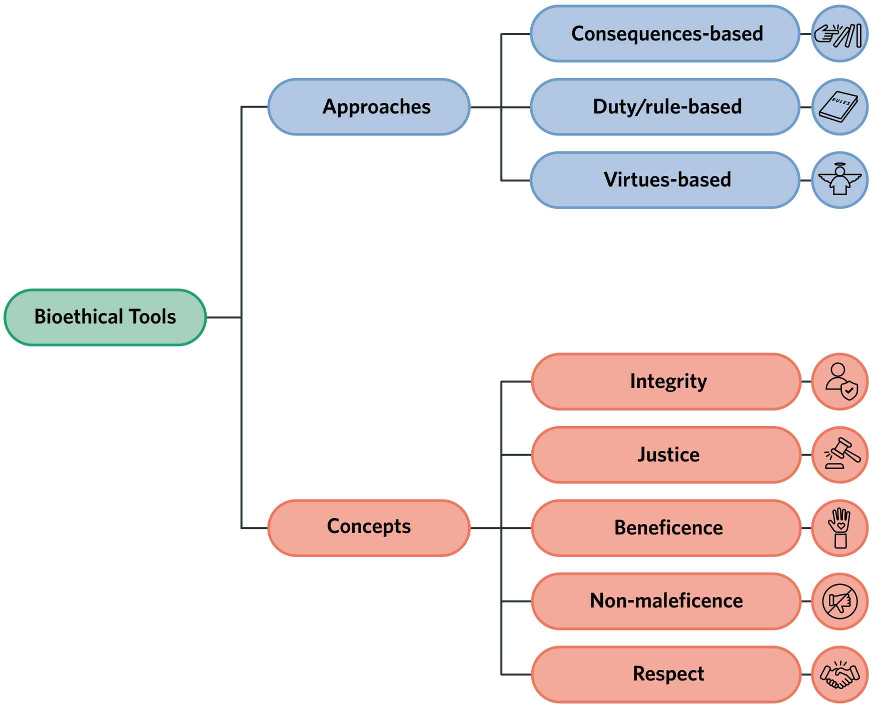


Figure 8 A summary of the bioethical toolkit

The prospect of an anti–aging pill that helps us live healthily for hundreds of years sounds like a no–brainer. But as with any biological research, we must remain in tune with the ethics and implications of all our decisions. For example, some people might argue that scientists have a duty/obligation to extend human life however possible, while others might point to unforeseen consequences on population levels, quality of life, corruption etc. Similarly, we must respect the sanctity of human life, but does that mean extending it by working against our inherent biology, or does it mean deferring to the power and autonomy of our cells? Who knows the right answer... but the approaches and concepts of bioethics can help us get closer to understanding all sides of the issue!

1B QUESTIONS

Theory review questions

Question 1

Match the term to its definition.

Term	Definition
• ethics	**I** __________ the use of ethical theories in guiding decision-making
• bioethics	**II** __________ the study of ethical questions relating to biology and medicine
• metathinking	**III** __________ the practice of reflecting on how we think and make decisions
• applied ethics	**IV** __________ a working system of knowledge that helps us evaluate our actions, values, and beliefs

Question 2

Which of the following most accurately describes the role of ethics in biology?

A Working in science involves making decisions that may impact a range of people. Ethics serves as a way of evaluating and exercising sound judgement.

B Working in science involves justifying your ideas and thoughts. Ethics is a means of evaluating these ideas in terms of their likely accuracy and validity.

Question 3

The approaches to bioethics provide a framework for ethical thinking. Categorise the following statements as **consequences-based**, **duty/rule-based**, or **virtues-based**.

I 'We should release the vaccine at a reduced price for people in low socioeconomic areas, as this is the kindest and most charitable thing to do.' __________

II 'We should skip the final round of trials and release the vaccine to the public now. That way more people can be cured quickly and we can minimise the rate of infection.' __________

III 'We should make sure the vaccine goes through all rounds of trials before releasing it to the public. Regardless of the rate of infection, it is our responsibility to ensure that the vaccine is safe.' __________

IV 'We should release the vaccine at the same price for all people, regardless of their geographic location or socioeconomic status. We have a responsibility to our shareholders to make as much profit as possible.' __________

Question 4

Assume someone is in danger and in need of help. Which of the following responses best distinguishes a virtues-based approach from a duty/rule-based approach?

A A duty/rule-based approach suggests that to help the person is your responsibility, whereas a virtues-based approach argues that to help them is to act with kindness and benevolence.

B A duty/rule-based approach suggests that to help the person is your responsibility, whereas a virtues-based approach argues that to help them is to save their life and maximise well-being.

Question 5

Match the bioethical concept to its description

Concept	Description
• justice	**I** __________ scientists should act with honesty and in the interest of progressing scientific knowledge
• integrity	**II** __________ scientists should consider the fair application of and access to their research, including the positions of marginalised groups
• respect	**III** __________ scientists should act in the best interest of others, and aim to promote benefits to all who are involved in or impacted by their research
• beneficence	**IV** __________ scientists should consider the intrinsic value of others as living beings, and give due consideration to their personal beliefs and values
• non-maleficence	**V** __________ scientists should ensure that they are removing as much harm as possible, and only risking harm to others if it is absolutely necessary

SAC skills questions

Bioethical deep dive

Use the following information to answer Questions 6–11.

Current technology allows doctors to test an individual's DNA and determine their susceptibility to particular genetic diseases, such as cystic fibrosis. This can be really helpful for patients and families to better understand a disease that runs in their family, 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 (testing during pregnancy) involves taking a small sample of foetal cells from the amniotic fluid or tissue surrounding the foetus and identifying any potential abnormalities before a child is born. This early identification can allow families to learn about and plan for 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. In some instances, genetic screening may also help parents understand the facts and make an informed choice on whether to continue a pregnancy.

Prenatal genetic screening carries a very small risk of losing the pregnancy. For this reason, the procedure is not compulsory, and individuals can choose to have the test based on their personal beliefs. Many people argue that prenatal testing should be avoided in cases where:

- the disease does not begin showing symptoms until later into adulthood, or
- there are no preventative treatments or cures for the disease being tested for.

Further, prenatal genetic screening is only used in Australia for a limited number of genetic diseases, however, it is likely to be recommended by a doctor if:

- the mother is over 35
- there is a family history of genetic diseases
- the mother has a history of abnormal pregnancies
- the mother has undergone previous testing which indicates an increase in disease risk.

Question 6

According to the information provided, which of the following is not a benefit associated with prenatal screening?

A helping to prepare and inform families of a genetic disease
B helping to cure a genetic disease prior to birth by removing harmful genes
C helping the early identification of a disease and establishing treatment options
D helping parents make an informed decision on whether to continue a pregnancy

Question 7

Which of the following statements is supported by the information provided?

A Testing for susceptibility to genetic diseases is only possible before birth.

B Prenatal screening is widely used in Australia, and is recommended for all pregnancies.

C Prenatal testing is an invasive practise that obtains a cell sample directly from the foetus.

D Prenatal testing will only be used to test for a limited number of genetic diseases in Australia.

Question 8

Which of the following statements from the extract best supports the concept of beneficence?

A 'the procedure is not compulsory and will only be used in Australia for a limited number of genetic diseases'

B 'genetic screening may also help parents understand the facts and make an informed choice on whether to continue a pregnancy'

C 'early identification can allow planning for or the treatment of genetic diseases, which can significantly improve outcomes for patients'

Question 9

Which of the following statements from the extract best supports the concept of respect?

A 'the procedure is not compulsory and allows individuals to choose based on their personal beliefs'

B 'genetic screening may also help parents understand the facts and make an informed choice on whether to continue a pregnancy'

C 'early identification can allow planning for or the treatment of genetic diseases, which can significantly improve outcomes for patients'

Question 10

Which of the following objections to prenatal testing best demonstrates the concept of non-maleficence?

A The decision to conduct prenatal testing for conditions with no known cure or treatment should be left to the discretion of the parents, as it is ultimately their decision.

B Prenatal testing should still be promoted in cases where the disease has no cure or treatment, as this provides parents with time to prepare and learn about disease management strategies.

C There is little point in risking the health of the foetus by testing for conditions for which there is no treatment available. The diagnosis will not result in medical benefit for the child, and is exposing the child to harm for little more than the parent's peace of mind.

Question 11

Which of the following objections to prenatal testing best demonstrates the concept of respect?

A Testing for conditions that do not show symptoms until later in life is typically only used by the affluent, and is rarely available to all.

B The burden of being made aware of a genetic disorder before its onset can be difficult for an individual, and should be avoided so as to reduce unnecessary stress and anxiety.

C The decision to undergo genetic testing, especially for conditions with later onset, should be left to the individual themselves, when they are old enough to make their own autonomous decisions.

Exam-style questions

Within lesson

Question 12 (6 MARKS)

In Victoria, a terminally ill patient may seek euthanasia, which is the practice of voluntarily ending their own life to relieve them from severe pain and suffering. Current laws are the first of their kind in Australia, and come with a range of stringent requirements, including (but not limited to):

- the patient having less than six months to live
- the patient making three separate requests to end their life
- two separate doctors agreeing to the procedure after individual assessments.

a Suggest one reason as to how Victoria's voluntary euthanasia laws might uphold the bioethical concept of respect. (1 MARK)

b Suggest how having two separate doctors individually assess the patient might uphold the bioethical concept of integrity. (1 MARK)

c Some people oppose these new laws, arguing that allowing voluntary euthanasia opens the door for unethical applications, such as involuntary euthanasia whereby some patients may not be able to provide informed consent.

i Explain the aim of a consequences-based approach to bioethics. (2 MARKS)

ii How might this argument be informed by a consequences-based approach to bioethics? (2 MARKS)

Question 13 (4 MARKS)

He Jiankui was sentenced to three years in prison after participating in the genetic alteration of human babies in 2018. As a result of his study, twin baby girls were born with altered copies of a particular gene known as *CCR5*, which He believed would make them immune to the human immunodeficiency virus (HIV). It was later found that He had "forged ethical review documents and misled doctors into unknowingly implanting gene-edited embryos into two women" (Normile, 2019).

a Which bioethical concept has He failed to uphold by forging documents and misleading doctors? Justify your answer. (2 MARKS)

b It was not sufficiently proven that the girls are immune to HIV. Instead, they were given a totally novel version of the *CCR5* gene that is likely not found in any other human genome. These artificial genes are also heritable.

i Outline what is meant by the term heritable. (1 MARK)

ii Identify a potential bioethical issue in relation to this novel version of the *CCR5*. (1 MARK)

Question 14 (5 MARKS)

Mark is a 32-year-old patient who suffered major head trauma and brain injury in a car accident. After 4 weeks in intensive care, Mark has yet to regain consciousness. The prognosis for 'meaningful recovery' is less than 1%. The decision is made to withdraw Mark from life support. Hearing of this, the nurse on call notifies the hospital's organ procurement team to assess Mark's potential as an organ donor. When the team arrives, they find that Mark's driver's license indicates that he was an organ donor, but that he had not signed up for the online registry and that there were no directives on his file. What's more, the crash had scuffed the back of Mark's driver's license so that his signature and the date could no longer be made out.

a Identify a bioethical issue in relation to Mark's organ donation. (1 MARK)

b The organ procurement team spoke to Mark's family, asking whether Mark had ever discussed organ donation with them. The family became distressed and asked the procurement team to leave them alone: 'we do not want to talk about this. Mark has been injured enough from the crash, we do not consent to his organs being donated'.

With reference to the bioethical concept of respect, how should the procurement team respond to the family's wishes? (2 MARKS)

c To test Mark's potential as an organ donor, the procurement team explains that they need to undergo tissue testing and examine the medical record. They say that this could take a few hours, and ask the family and nurses on call to keep his life support for a couple of hours longer despite the family asking for it to be turned off due to their belief that Mark is suffering a great deal by being kept alive artificially.

Assume you are part of the procurement team. Using a duty/rule-based approach to bioethics, how would you justify keeping the life support on? (2 MARKS)

CHAPTER 1 SUMMARY

In science, I must make sure my experiment is:

Reproducible

Different scientists can get the same results when they follow the same method as the original scientists.

Repeatable

The original scientists can get the same results when they replicate the experiment.

Valid

The experiment measures what it claims to be measuring.

I can ensure this by designing an experiment that:

1 Tests the effect of **independent variable(s)** on **dependent variable(s)**.

The IV is the factor you control or change. The DV is the factor you measure. You want to test if/how your IV affects your DV. Both variables should be mentioned in your hypothesis, which should predict how the IV influences the DV.

The groups that have the IV applied to them are known as the experimental groups.

2 Has a **control** group.

A control group is a group 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 may be attributed to the IV (provided all potential uncontrolled variables are controlled against).

3 Has **replicates** of each experimental and control group.

Replication means you have multiple groups under the same conditions. This suggests that your results are less likely to be outliers or due to chance, and allows you to take the mean average of your replicates for each experimental group. If your experiment is well-designed, the values for different replicates of the same treatment should be similar.

4 Minimises potential for **uncontrolled variables** and sources of **error**.

Personal errors are mistakes or miscalculations made by the experimenter. They can affect accuracy, precision, validity, and/or reliability.

Systematic errors cause readings to differ from the true value by a consistent amount each time. They affect the accuracy of the experiment.

Random errors are unpredictable variations in the measurement process that result in a spread of readings. They affect the precision of the experiment.

Uncontrolled variables 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.

5 Is informed by **bioethical** approaches and concepts.

Your experiment must follow the bioethical concepts of **integrity**, **justice**, **beneficence**, **non-maleficence**, and **respect**.

When analysing a bioethical issue, it is important to consider the three approaches to bioethics: **consequences-based**, **virtues-based**, and **duty/rule-based**.

6 Collects data that is **reliable**.

To collect reliable data: get a large, unbiased sample, be **accurate**, be **precise**, and minimise uncertainty in measurements.

An accurate measurement is one that is close to what is considered to be the 'true' value. Accuracy can be increased by reducing measurement/systematic error.

Precision refers to how closely multiple measurements are to one another. Precision can be increased by having a larger sample size and calibrating your equipment properly when taking measurements.

7 Is **communicated** clearly, so other scientists can **peer-review** my work.

This means you need to present data in a meaningful way with tables and graphs that follow scientific conventions, give a clear method section so your work can be reproduced, and consider the appropriate safety and bioethical factors.

Rotate page

CHAPTER 1 SAC PRACTICE

SAC skills covered in this section:

✓ Case study analysis ✓ Scientific methodology comparison ✓ Bioethical investigation

THE PLACEBO PROBLEM IN CLINICAL TRIALS FOR PSYCHIATRIC DISORDERS (20 MARKS)

To study the efficacy of a specific treatment for a particular psychiatric disorder, researchers will often employ a double-blind, placebo-controlled experiment. A double-blind study means that neither the participants nor the researchers know which participants are receiving the placebo, and which participants are receiving the treatment. These studies are designed to compare the results of the introduced treatment with that of a placebo on two groups of randomly selected patients.

In the field of psychiatric drug development – also known as psychopharmacological drug development – placebo studies pose a significant problem in that they often result in negative findings. These are trials in which researchers have failed to demonstrate the superiority of the treatment over the placebo condition, and therefore pose a range of issues surrounding the validity of clinical drug development trials. The larger the placebo response, the more difficult it is to prove that an experimental treatment is effective.

1 Define the term placebo. (1 MARK)

2 Describe what is meant by the term ‘placebo problem’ and explain how this can be problematic for psychopharmacological drug developers. (2 MARKS)

3 Negative trials are often less likely to be published in academic journals. With reference to the bioethical concept of integrity, explain the potential impact of this on the understanding of certain psychiatric treatments or medications. (2 MARKS)

Antidepressants and the placebo effect

Antidepressants are a group of medications that are prescribed to help manage symptoms of depression, anxiety, and a range of other related psychiatric illnesses. They work in a variety of ways, and typically increase active levels of serotonin in a patient’s brain. However, Kirsch (2019) of Harvard Medical School suggests that an extensive literature review of the clinical trial data shows that most of the benefits of antidepressants in the treatment of depression and anxiety are due to the placebo response. What’s more, Kirsch (2019) suggests that any differences in improvement between drug and placebo are not clinically meaningful and may often be due to research errors on the part of both the patients and clinicians.

In efforts to refute Kirsch’s findings, two groups of researchers designed separate research trials each aimed at testing the efficacy of a specific antidepressant (Drug X) on relieving symptoms of depression. Each of the methods are described.

Group 1

- Potential participants were first phone-screened by an in-house clinical psychologist and given a score from 1–10 based on the severity of their symptoms. A score above 7 indicates a diagnosis of clinical depression and gains admittance to the trial.
- A total of 30 participants were admitted and randomised to two study arms: one group was given sugar pills while the other was given Drug X. Both groups were instructed to take two pills a day for 12 weeks (morning and night). Each participant was made aware of the presence of the two groups, but not told which group they were assigned to. However, the scientists knew the group to which the participants were assigned.
- At the beginning of the trial (Week 0), participants were interviewed and administered a computerised cognitive test to measure their symptoms and determine a baseline that measured their memory and reaction times.
- Participants were then called via phone every two weeks and administered the same test as that given in Week 0. The test provides a total score based on their answers that measures the severity of their symptoms from a scale of 10–70, with higher scores indicating more severe symptoms.
- At the conclusion of Week 12, the participant’s scores were collated and analysed. The participant was also asked to complete the same computerised cognitive tests as at their baseline appointment, as well as a 1.5 hour debriefing session with the in-house clinical psychologist.
- At the conclusion of the twelve weeks, researchers collated and analysed the data.

Group 2

- Potential participants were chosen at random based on a collection of applications received by the researchers in response to an advertisement. Each participant's medical record was verified to ensure a diagnosis of clinical depression.
- A total of 60 participants were admitted and randomised equally into three study arms: group one was given sugar pills, group two was given Drug X, and group 3 was given Drug Y – a known antidepressant with proven efficacy.
- All three groups were instructed to take two pills a day for 12 weeks (morning and night). Each participant was made aware of the presence of the three groups, but not told which group they were assigned to. The researchers also did not know which group each participant was assigned to until the study was completed.
- Participants were asked to self-complete a test which requires them to report on their symptoms according to a number of separate measures. The test consisted of 20 questions and would result in a total score that indicates the severity of symptoms. Each participant submitted a test to researchers once a week.
- At the conclusion of the twelve weeks, researchers collated and analysed the data.

4 Identify the sampling technique employed by Group 1. (1 MARK)

5 Explain what is meant by the term control group. Identify the control group used by Group 2. (2 MARKS)

6 With reference to the information provided, identify which of the two groups had the highest level of replication. In your answer, be sure to state the number of replicates of each group. (1 MARK)

7 Identify one uncontrolled variable and explain how it could affect the validity of both groups' results. (2 MARKS)

8 Identify which of the two groups successfully designed a double-blind study. Justify your response. (2 MARKS)

9 Group 1 required participants to complete a set of computerised cognitive tests at both their baseline and week 12 appointments. Suggest how this decision might uphold the bioethical concept of non-maleficence with regards to future consumers of the drug. (2 MARKS)

Antidepressants and the game of trial and error

Due to the relationship between antidepressants and the placebo effect, it is difficult to associate with certainty any improvements in a patient's symptoms to the actual action of the treatment or medication. Recently, research has suggested that antidepressants may have both a pharmacological effect and a placebo effect, meaning that the placebo effect only enhances the effect of the drug itself. For instance, Cipriani et al. (2018) found that antidepressants do have a significant effect compared with placebo alone, while research from Sapirstein & Kirsch (1998) suggests that around 25% of the impact of antidepressants is due to placebo, 25% is due to unknown factors, and the remaining 50% is due to the actual pharmacological effects from the drugs. Since this research in the late 1990s, however, Kirsch has changed much of his assumptions and now questions the role of any pharmacological effects at all.

Ultimately, due to this uncertainty, it can take several trials with different medications before finding one that helps a particular patient. What's more, doctors have plenty of contributing factors to consider when prescribing the right antidepressant, including things like the age, medical history, family psychiatric history, and life circumstances of the patient. It is also important to consider the potential side effects of some antidepressants, which can range from insomnia, rashes, headaches, and joint pain to more serious problems associated with long-term usage such as reduced blood clotting capacity.

10 Based on the information provided in the second paragraph, identify the bioethical issue associated with the prescription of antidepressants. (1 MARK)

11 With reference to a consequences-based approach to bioethics, how might an opponent of antidepressants critique the current nature of trial and error prescriptions? (2 MARKS)

12 With reference to the bioethical concept of beneficence, how might a supporter of antidepressants promote the current trial and error method of antidepressant prescribing? (2 MARKS)

For more information regarding the treatments that are available for depression, see here: beyondblue.org.au/the-facts/depression/treatments-for-depression

CHAPTER 1 EXAM PRACTICE

30 min

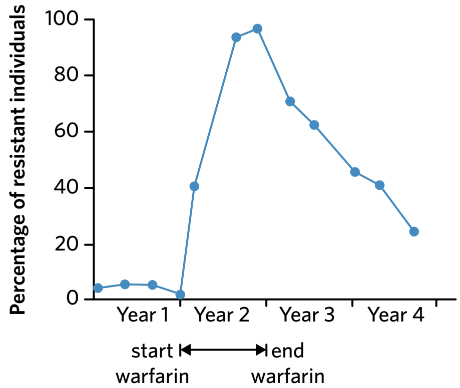
Section A (5 MARKS)

Use the following information to answer Questions 1 and 2.

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 four 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 the age of three months and can breed about every three weeks.

Adapted from VCAA 2002 Exam 2 Section B Q7a



Question 1 (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.

Question 2 (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.

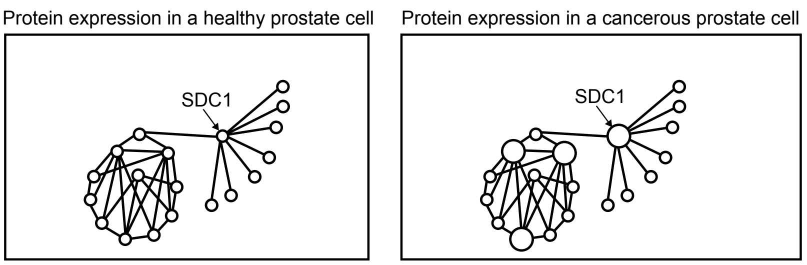
B the dependent variable is continuous but the independent variable is ordinal.

C both variables are continuous.

D both variables are categorical.

Question 3 (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. Note that the size of the circles is proportional to the level of protein expression.



Source: adapted from JR Heath, ME Davis and L Hood, 'Nanomedicine targets cancer', in *Scientific American*, 300(2), February 2009, pp. 44–51

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 is greater in cancerous prostate cells than in healthy prostate cells.

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

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

Use the following information to answer Questions 4 and 5.

Coeliac disease is an autoimmune disorder that results in a person's immune system reacting to gluten. In 2019, a possible coeliac disease treatment was developed using nanotechnology which introduces microscopic nanoparticles into a patient's body to train their immune system to not initiate an inflammatory response to gluten.

Data was taken from a randomised double-blind study with 28 research participants, half of whom were administered the treatment while the other half were given a placebo. The results showed that the treatment was effective in limiting inflammatory responses. However, the treatment has only recently been developed, and is yet to go to market. Researchers are aware that the results have not been reproduced, so cannot confirm that the treatment will work consistently from person to person.

Question 4 (1 MARK)

Based on the information provided, which of the following presents a potential weakness in the findings of the researchers?

A the lack of a control group

B the small sample size used by researchers

C the nanoparticle was artificially introduced into the patient's body

D the use of judgement sampling to select only patients with coeliac disease as participants

Question 5 (1 MARK)

Using a consequences-based approach, which of the following statements is most correct?

A While promising, the research has not been reproduced. The treatment should be withheld until full confidence is reached, as the danger of adverse side effects overrides the necessity to help patients in the short term.

B Researchers admit that the treatment will not be cheap in the first few years of its manufacturing. For this reason, the treatment will cost a lot to administer and should therefore be withheld until manufacturing costs are lowered.

C Sometimes there is not enough funding, time, or resources to reproduce an experiment many times. If it has been shown to work on patients in the lab, it should be made public for other people with the disease to choose by themselves.

D Researchers made sure to conduct a randomised double-blind study, which is sufficient to be confident in the efficacy of the treatment. The treatment should therefore be made public, allowing each patient with coeliac disease to decide for themselves whether to use it.

Section B (15 MARKS)

Question 6 (10 MARKS)

Ibrahim wanted to investigate the effectiveness of an antifungal medication against the common household 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. Then, using tweezers, collect 0.2 g of the *Aspergillus niger* spores from the culture and place them in the centre of the first agar plate.
4. Spread the spores over the agar plate with the spreader provided.
5. Place a drop of the antifungal in the centre of the agar plate.
6. Close the lid of the agar plate and tape the lid to the bottom of the agar plate with sticky tape.
7. 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.
8. Place the agar plates on the side bench and leave overnight.
9. 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

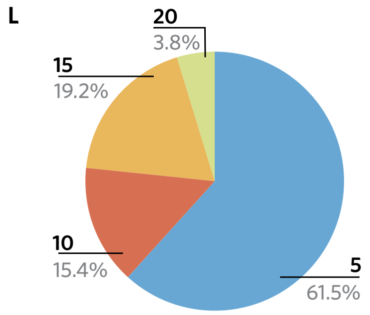
a Name the independent and dependent variables. (2 MARKS)

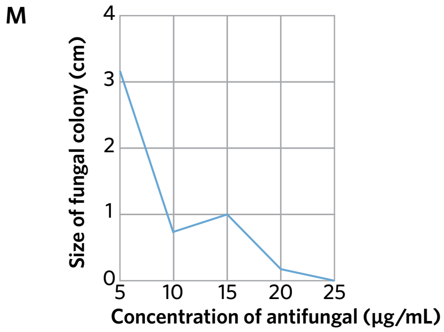
b Explain the importance of using sterile tools for the validity of the experiment. (2 MARKS)

c Explain whether Ibrahim has replicated his experiment. (1 MARK)

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

e Ibrahim tried manipulating his data in a number of ways, making the following graphs.





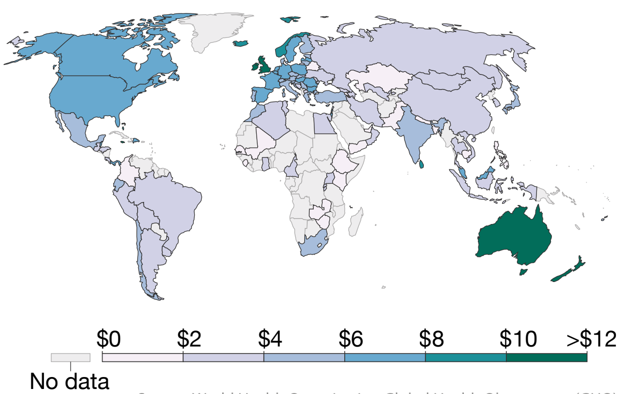
Which one of the graphs (L or M) is the best representation of Ibrahim's data? Justify your response. (2 MARKS)

Question 7 (5 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 Health Observatory (GHO)
Adapted from Roser and Ritchie 2019

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

b 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)

c Using a duty-based approach to bioethics, provide one argument in favour of Australian governments raising the prices of cigarettes. (2 MARKS)

UNIT 1

How do organisms regulate their functions?

In this unit, students examine the cell as the structural and functional unit of life, from the single-celled to the multicellular organism, including the requirements for sustaining cellular processes. Students focus on cell growth, replacement, and death and the role of stem cells in differentiation, specialisation, and renewal of cells. They explore how systems function through cell specialisation in vascular plants and animals, and consider the role homeostatic mechanisms play in maintaining an animal's internal environment.

Reproduced from VCAA VCE Biology Study Design 2022-2026

A student-adapted or student-designed scientific investigation is undertaken in Area of Study 3. The investigation involves the generation of primary data and is related to the function and/or the regulation of cells or systems. The investigation draws on the key science skills and key knowledge from Area of Study 1 and/or Area of Study 2.

UNIT 1

AOS1

How do cells function?

In this area of study, students examine the structure and functioning of prokaryotic and eukaryotic cells, and how the plasma membrane contributes to survival by controlling the movement of substances into and out of the cell. Students explore cellular growth, replacement, and death. They become familiar with the key events and regulation of the cell cycle and the processes for cell division, including disruptions to the cell cycle and deviant cell behaviour. Students consider the properties of stem cells and their role in differentiation, specialisation, and renewal of cells and tissues.

Outcome 1

On completion of this unit, the student should be able to explain and compare cellular structure and function and analyse the cell cycle and cell growth, death, and differentiation.

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CHAPTER

2

What are cells?

Key knowledge

- cells as the basic structural feature of life on Earth, including the distinction between prokaryotic and eukaryotic cells
- surface area to volume ratio as an important factor in the limitations of cell size and the need for internal compartments (organelles) with specific cellular functions
- the structure and specialisation of plant and animal cell organelles for distinct functions, including chloroplast and mitochondria

2A CELLS AS THE BASIS OF LIFE

It's the year 3058 and the zombie apocalypse is forcing humanity to the brink of extinction. You send your best friend out to scout the area and find some food. When they come back, you see teeth marks on their shoulder. Is it the world's biggest hickey, or have they been bitten by a zombie? Are they still living, or have they become one of the living dead? How do you figure out if they're still alive?

Image: Cryptographer/Shutterstock.com

Lesson 2A

In this lesson you will learn that all living things are made up of cells which can be either prokaryotic or eukaryotic.

Prerequisite knowledge

Years 7–10
Living things differ in appearance and function, and we can use these differences to classify cell types.

Future applications

Lesson 2B
Eukaryotic cells are composed of multiple compartmentalised sections called organelles.

Chapter 4
Prokaryotic and eukaryotic cells replicate by binary fission and mitosis, respectively.

Year 12
The human immune system responds to invading prokaryotic and eukaryotic organisms.

Study design dot point

- cells as the basic structural feature of life on Earth, including the distinction between prokaryotic and eukaryotic cells

Key knowledge units

What are living things?	1.1.1.1
Prokaryotes and eukaryotes	1.1.1.2

What are living things? 1.1.1.1

OVERVIEW

To evaluate whether something is living, it must fulfil the eight criteria of living things. In addition, cell theory is a fundamental concept of biology that describes the makeup of living things.

THEORY DETAILS

What it means to be alive

From our best friend to our pets, and even the bacteria in our gut, **living things** shape our lives. All living things must possess all of the following eight qualities:

living thing anything that can move, respire, sense, grow, reproduce, maintain equilibrium, excrete waste, and take up nutrients

1 Movement – all living things are capable of self-generated movement. Individual bacteria swimming, humans walking, and plants moving towards light are self-generated movements.

2 Respiration – all living things can extract energy from carbohydrates, fats, and proteins through the biochemical processes of aerobic or anaerobic cellular respiration.

3 Sensitivity – all living things sense and react to stimuli. Examples of this include plant tips growing towards a light source.

4 Growth – all living things grow and develop over time. An example is how infants grow into adults.

5 Reproduction – all living things can produce new living things. Examples include cell division and sexual reproduction.

6 Equilibrium – all living things can maintain a relatively stable internal environment unique to an individual species, which is known as maintaining **homeostasis**. This allows **organisms** to tolerate environmental changes such as varying temperatures or a lack of water availability.

7 Excretion – all living things produce wastes that must be removed. Urine or dead cells, if not removed, can become toxic.

8 Nutrition – all living things extract nutrients from the environment, which are used to produce cellular energy, grow and develop, and maintain equilibrium. Some organisms gain nutrition by consuming food (heterotrophs), whereas others produce their own essential nutrients from simple inorganic molecules (autotrophs).

To put this into practice, think about when you get sick. Bacteria and viruses are two different 'pathogens' that cause disease, however the way they are treated is very different. Antibiotics can be used to fight bacterial infections, however are ineffective to viral infections. This is partly because bacteria are living, whilst viruses are not. Viruses do not satisfy all the requirements of a living thing as they cannot independently respire, consume nutrients, maintain homeostasis, nor excrete wastes. They also rely on host cells to reproduce. Bacteria, meanwhile, fulfil all eight qualities of living things.

homeostasis the maintenance of a relatively stable internal environment in the body despite changes in the external environment

organism a living thing made up of one or more cells

Memory device

To remember the eight criteria for living things, remember MRS GREEN.

Movement
Respiration
Sensitivity

Growth
Reproduction
Equilibrium
Excretion
Nutrition

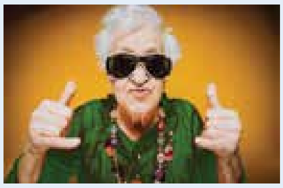


Image: oneinchpunch/Shutterstock.com

Figure 1 While MRS GREEN may be clinging to life, she certainly knows what it means to be alive!

Cell theory

In addition to the MRS GREEN requirements for life, all organisms also function according to **cell theory**. Cell theory states that:

1 all living things are made up of cells

2 cells are the smallest and most basic units of life

3 all cells come from pre-existing cells.

cell theory the idea that all living things are made of cells, cells are the smallest functional unit of living things, and all cells come from pre-existing cells

Figure 2 Cells from different kingdoms look different, but all of them follow the principles of cell theory. **(a)** The bacteria *Staphylococcus aureus* (400X magnification), **(b)** *Egeria* plant cells (400X magnification), and **(c)** *Paramecium*, a type of protist (400X magnification).

Theory in context

BEFORE CELL THEORY

The three parts of cell theory may seem really obvious, however it's important to remember that before modern microscopes were invented, people didn't know how cells worked.

For example, people had no idea that cells arise from pre-existing cells. Instead, the dominant theory used to be Aristotle's theory of 'spontaneous generation', which stated that organisms randomly arise from unrelated objects. For example, fleas were thought to be generated from dust, and maggots arose from dead flesh. Nowadays, this theory seems bizarre but it was not disproven until the 19th century, nearly 2 000 years after Aristotle, by showing that maggots only arose from dead flesh because flies had laid eggs in them. So, even though cell theory seems obvious, it was an important discovery that is core to understanding biological systems.

Prokaryotes and eukaryotes 1.1.1.2

OVERVIEW

Organisms are classified as either prokaryotic or eukaryotic based on the composition of their cells. From here, they can be further classified into six different kingdoms.

THEORY DETAILS

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

The cells of both prokaryotes and eukaryotes contain a **plasma membrane**, **cytosol**, **ribosomes**, and **DNA**. Eukaryotic cells contain many **membrane-bound organelles**, multiple linear **chromosomes** of DNA packed in a **nucleus**, and tend to be larger than prokaryotes. Prokaryotic cells lack a nucleus, have a single loop of circular DNA, and may contain some smaller circular units of DNA called **plasmids**.

Cell replication differs between prokaryotes and eukaryotes. Eukaryotic **somatic cells** usually duplicate through **mitosis**, and eukaryotic **germline cells** split into four individual **gametes** through **meiosis**. In contrast, prokaryotic cells replicate via a simpler process known as **binary fission**. These processes will be explained in chapters 4 and 7.

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 chromosome in a nucleus	One circular chromosome and additional plasmids
Organism nature	Can be unicellular or multicellular	Unicellular
Size	Larger (~ 10–100 μm)	Smaller (~ 0.1–5 μm)
Method of cell replication	Mitosis and meiosis	Binary fission

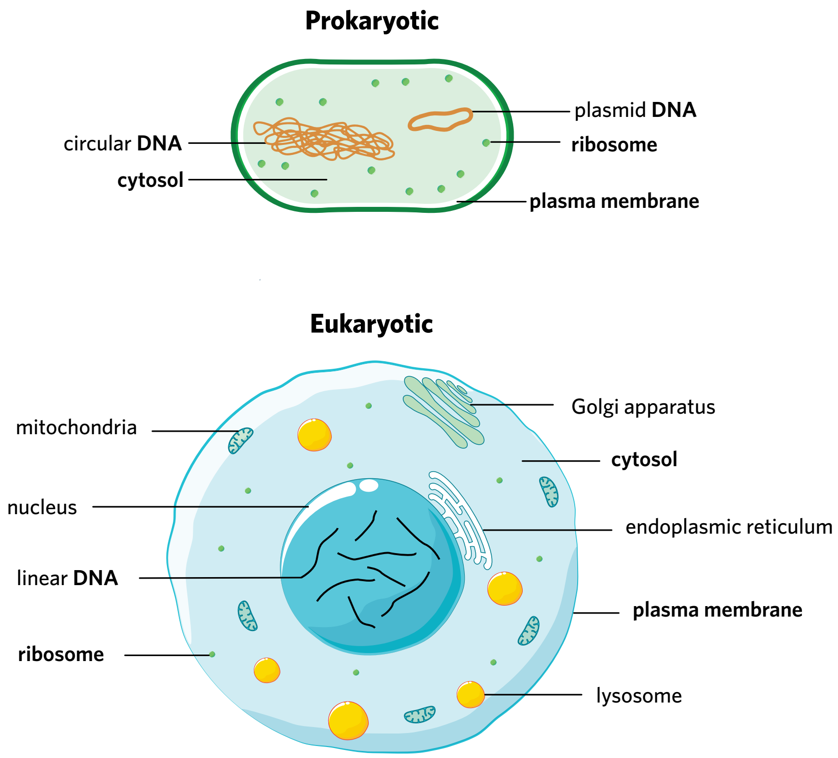


Image: Designua/Shutterstock.com

Figure 3 Comparison between a prokaryotic and eukaryotic cell, where similarities are highlighted in bold.

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

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

plasma membrane the phospholipid bilayer and embedded proteins which separate the intracellular environment from the extracellular environment. Also known as **cell membrane**

cytosol the aqueous fluid that surrounds the organelles inside a cell

ribosomes small RNA-protein structures that are the site of protein synthesis. They either float freely in the cytoplasm or are attached to the RER

DNA (deoxyribose nucleic 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

membrane-bound organelle structure within a cell that is enclosed by a phospholipid bilayer

chromosome the structure made of protein and nucleic acids that carries genetic information

nucleus a double membrane-bound organelle that protects and confines the genetic information (DNA) of a cell. Inside the nucleus is a smaller structure known as the nucleolus which is the site of ribosome production

plasmid a small, circular loop of DNA that is separate from a chromosome, typically found in bacteria

somatic cell any cell that is not a reproductive cell (such as sperm and egg cells). Somatic cells are diploid ($2n$), meaning they contain two sets of chromosomes – one inherited from each parent

mitosis the cell division phase which involves the complete separation of sister chromatids and nuclei

germline cells cells that are involved in the generation of gametes in eukaryotes

gametes reproductive cells that arise from germline cells that contain half the genetic material (n) of a somatic cell. In humans, gametes are sperm and eggs

Domains and kingdoms of life

All organisms fall into one of three domains: Archaea, Bacteria, and Eukarya. Archaea and Bacteria are both prokaryotic domains, whilst Eukarya are eukaryotic. Eukarya are divided into four kingdoms to further differentiate organisms. These are: Animalia, Fungi, Plantae, and Protista. Archaea and Bacteria are also known as kingdoms, which means there are a total of six kingdoms of life. The following table outlines some characteristics of each kingdom.

meiosis a specialised form of cell division used to produce gametes in sexually-reproducing organisms

binary fission the method of cell replication used by prokaryotes

micrometres (µm) unit of measurement where 1 mm = 1 000 µm

Lesson link

Don't worry about the function of membrane-bound organelles yet! In ***lesson 2B***, you will learn what these structures do and why we have them in our cells!

Table 2 Characteristics of each kingdom

	Type of organism	Organism nature	Examples
Animalia	Eukaryotic	Multicellular	coral, worms, insects, fish, humans
Archaea	Prokaryotic	Unicellular	*Aeropyrum pernix, Thermosphaera aggregans, Ignisphaera aggregans*
Bacteria	Prokaryotic	Unicellular	*Escherichia coli, Staphylococcus aureus, Wolbachia spp.*
Fungi	Eukaryotic	Unicellular or multicellular	yeast, mould, mushrooms
Plantae	Eukaryotic	Multicellular	moss, ferns, conifers, flowering plants
Protista	Eukaryotic	Unicellular or multicellular	algae, *Toxoplasma gondii, Plasmodium spp.*

Image: AofTimusz/Shutterstock.com

Figure 4 The six kingdoms of life

Theory summary

In order for an organism to be classified as living, it must satisfy the eight criteria of living things and be made of cells. Living things can be categorised as either eukaryotic or prokaryotic organisms, and further classified into domains and kingdoms.

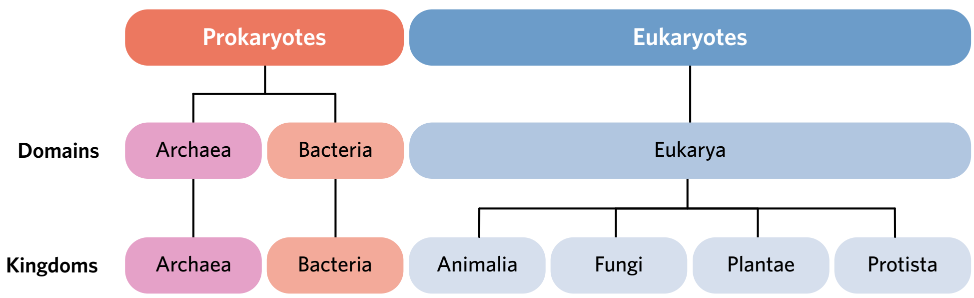


Figure 5 Branching diagram of the domains and kingdoms of life

IT WAS NOT A HICKEY! RUN! With the help of MRS GREEN, you determined your friend was not living because they weren't breathing, and therefore could not undertake cellular respiration!

Image: solar22/Shutterstock.com

2A QUESTIONS

Theory review questions

Question 1

Archaea are

A living things.

B non-living things.

Question 2

Which of the following qualities do living things not need to fulfil? *(Select all that apply)*

I maintain equilibrium

II move

III grow

IV excrete

V respire

VI oxygenate

VII sense

VIII reproduce

IX sunlight

X extract nutrients

Question 3

Cell theory applies to

A all living things.

B eukaryotic organisms only.

C prokaryotic organisms only.

Question 4

Fill in the blanks in the following sentence.

Cell theory states that all __________ are made up of cells, cells are the __________ and most basic unit of life, and all cells come from __________.

Question 5

Categorise the following as being found in **prokaryotic organisms**, **eukaryotic organisms**, or **both**.

I ribosomes __________

II membrane-bound organelles __________

III linear DNA __________

IV multicellular organisms __________

V binary fission __________

VI circular DNA __________

VII plasma membrane __________

VIII mitosis and meiosis __________

IX unicellular organisms __________

Question 6

Which kingdoms are eukaryotes? *(Select all that apply)*

I Animalia
II Archaea
III Bacteria
IV Fungi
V Plantae
VI Protista

SAC skills questions

Case study analysis

Use the following information to answer Questions 7–12.

According to western science, organisms are first classified by their domain, then using Linnaean taxonomy are further classified into: kingdom, phyla, class, order, family, genus, and finally species. For example, the complete classification for modern humans is: Animalia, Chordata, Mammalia, Primates, Hominidae, *Homo, sapiens*. Due to lengthiness, we often shorten organism scientific names down to the genus and species level, hence modern humans are also known as *Homo sapiens*.

The classification systems of First Nations' Australians take a very different approach to classifying organisms. Their system focuses on binary characteristics such as whether it is edible or inedible, or whether it is totemic (a sacred object) or non-totemic. In addition, it accounts for an organism's age, the stage in its life-cycle, sex, and how it can be used by people.

This grouping system contrasts with the Linnaean taxonomy which groups organisms by relatedness, which means there can be distinct differences in the way the Aboriginal and Torres Strait Islander peoples and western science describe an organism. For example, First Nations' Australians group turtles, barramundi, and dugongs together because they are aquatic organisms that have fins or flippers. Meanwhile, the Linnaean taxonomy classifies turtles as reptiles, barramundi as ray-finned fish, and dugongs as mammals.

Although these systems have distinct differences, it is important to note that Aboriginal and Torres Strait Islander people's deep understanding of plants and animals heavily assisted western science in developing their classification of native Australian organisms. (Australian Curriculum, n.d.)

Question 7

According to Linnaean taxonomy, what order does *Homo sapiens* belong to?

A Primates
B Mammalia

Question 8

Which of the following statements is true?

A The Linnaean taxonomy focuses on the physical structures of organisms.
B The Aboriginal and Torres Strait Islander people categorise organisms based on how they can be used by humans.

Question 9

Scientists collected a sample of cells from a dugong. Which of the following outlines some of the characteristics of these cells?

A absence of membrane-bound organelles, linear chromosomes, divide by binary fission
B presence of membrane-bound organelles, one circular chromosome, divide by binary fission
C presence of membrane-bound organelles, linear chromosomes, divide by mitosis and meiosis
D absence of membrane-bound organelles, one circular chromosome, divide by mitosis and meiosis

Question 10

Which of the following conclusions can be made about the way western science classifies organisms compared to Aboriginal and Torres Strait Islander people?

A There is no overlap between either classification system.
B Only western science classifies organisms into hierarchical groups.
C Aboriginal and Torres Strait Islander people classify organisms the same way as western science.
D Western science focuses on genetic relationships between organisms, whilst the Aboriginal and Torres Strait Islander people's system focuses on how organisms can be used by people.

Question 11

The Aboriginal and Torres Strait Islander people are likely to have classified kangaroos and wallabies in the same group of animals as they are both land animals that can be cooked and consumed. Which of the following conclusions is correct?

A The Linnaean system would not classify them in a similar grouping.

B The Linnaean system would also classify them in a similar grouping as they look similar.

C The Linnaean system would also classify them in a similar grouping because they are both marsupials.

Question 12

Which of the following is the most correct statement concerning classification systems?

A There is no single 'right' way to classify living things, as classification systems are human constructs and develop depending on what they are used for.

B The classification system of Australia's First Peoples' is the 'right' way to classify Australian organisms, as they were the original inhabitants.

C The Linnaean classification system is the 'right' way to classify living things because it groups organisms by relatedness.

Exam-style questions

Within lesson

Question 13 (1 MARK)

A typical prokaryotic cell does not have

A DNA.

B ribosomes.

C a plasma membrane.

D membrane-bound organelles.

Adapted from VCAA 2002 Exam 1 Section A Q1

Question 14 (1 MARK)

Which of the following kingdoms contain a circular molecule of DNA in their cells?

A Animalia

B Bacteria

C Plantae

D Fungi

Adapted from VCAA 2016 Section A Q12

Question 15 (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 circular chromosomes.

D linear chromosomes.

Adapted from VCAA 2012 Exam 2 Section A Q4

Question 16 (1 MARK)

Which of the following statements is correct?

A Prokaryotes and eukaryotes both have DNA.

B Prokaryotic and eukaryotic genetic material is stored within the nucleus.

C Prokaryotes and eukaryotes both store genetic material in the form of linear chromosomes.

D Prokaryotes and eukaryotes both store genetic material in the form of circular chromosomes.

Adapted from VCAA 2007 Exam 2 Section A Q3

Question 17 (5 MARKS)

Saccharomyces cerevisiae is a fungus.

a To determine whether *Saccharomyces cerevisiae* is a living thing, it must satisfy certain qualities. Describe two of these qualities. (2 MARKS)

b Cells can be classified as prokaryotic or eukaryotic. Identify which group fungal cells belong to. (1 MARK)

c Describe one feature which distinguishes prokaryotic organisms from eukaryotic organisms. (1 MARK)

d Prokaryotic and eukaryotic organisms are composed of cells. One of the fundamental concepts in biology is cell theory. State the three principles of cell theory. (1 MARK)

Adapted from VCAA 2003 Exam 1 Section B Q2

Key science skills and ethical understanding

Question 18 (7 MARKS)

In early 2016, there was an outbreak of food poisoning in Victoria linked to the consumption of prepackaged lettuce. In investigations carried out by the Department of Health and Human Services, several products tested positive for the prokaryote *Salmonella anatum*.

a *Salmonella anatum* is not a member of the kingdom Archaea. Identify which kingdom it must be part of. (1 MARK)

b *S. anatum* is not a common cause of food poisoning. Data have been collected and analysed for the occurrence of illness caused by this organism in Queensland over a five-year period. The graph displays the average monthly notification rate per 100 000 of the population for the illness caused by *S. anatum*.

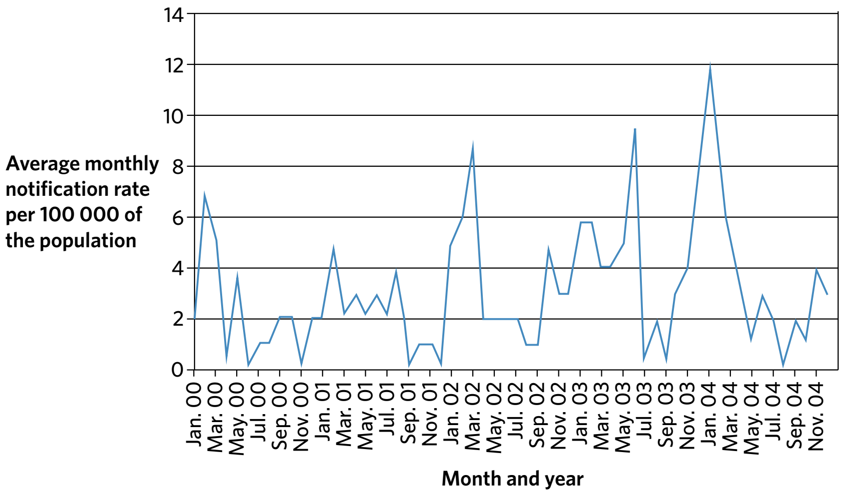


Image: The State of Queensland (Queensland Health) 1996–2016

i How often were recordings taken? (1 MARK)

ii State the average monthly notification rate per 100 000 of the population in November 2004. (1 MARK)

iii Describe the trend of the graph for the year 2001. (3 MARKS)

c A scientist attempted the same study again to see whether the results are different in the present time compared to 20 years ago. They hand-picked participants who had an inherent resistance to *S. anatum* infections but failed to describe this selection in their paper. Instead, the scientist reported that their studied population was 'chosen at random from the population'. Identify which ethical concept the scientist has ignored. (1 MARK)

Adapted from VCAA 2016 Section A Q22 and Q23

2B ORGANELLES

Eliud Kipchoge currently holds the world record for the fastest marathon run by a man, completing the 42.2 km run in almost two hours, which is less than three minutes per kilometre! Meanwhile, the average time for a non-elite athlete is almost double that of Eliud. Could there be a physiological difference in the contents of Eliud's cells compared to a non-elite athlete?

Lesson 2B

In this lesson you will learn about different compartments of eukaryotic cells and the differences between plant and animal cells.

◀ *Prerequisite knowledge*

Years 7–10
Cells are the basic units of life.

Lesson 2A
Cells can be either prokaryotic or eukaryotic.

Future applications ▶

Chapter 3
This chapter focuses on the plasma membrane in detail and its importance in maintaining cell structure and function.

Year 12
Here you'll learn more about how organelles work together to perform specific functions like protein synthesis and transport, photosynthesis, and cellular respiration.

Study design dot points

- surface area to volume ratio as an important factor in explaining the limitations of cell size and the need for internal compartments (organelles) with specific cellular functions
- the structure and specialisation of plant and animal cell organelles for distinct functions, including chloroplast and mitochondria

Key knowledge units

Structure and function of organelles	1.1.3.1
Mitochondria and chloroplasts	1.1.3.2
Comparing plant and animal cells	1.1.3.3

Structure and function of organelles 1.1.3.1

OVERVIEW

A cell has many different-shaped organelles that perform specific roles to keep the cell functioning.

THEORY DETAILS

Cells are made up of many different structures that work together to increase the efficiency of the cell. These compartments are known as **organelles**, and all have different structures that help them perform their function.

Every cell is surrounded by a plasma membrane which controls what can and cannot enter the cell. Inside each cell is a fluid substance known as the **cytosol**, which contains the dissolved salts, nutrients, and molecules necessary for cell function. All the organelles (except the nucleus) and the cytosol in which they float make up the **cytoplasm**.

organelle a cellular structure that performs specific functions

cytosol the aqueous fluid that surrounds the organelles inside a cell

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

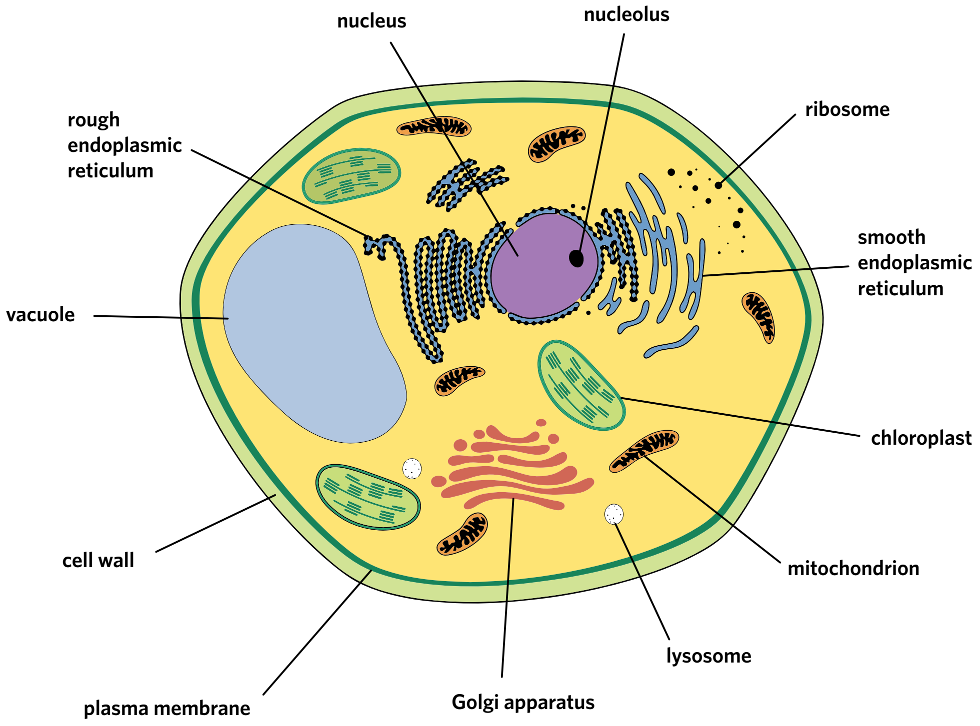


Image: Aldona Griskeviciene/Shutterstock.com

Figure 1 The organelles of a plant cell

Memory device

Think of the cell as your favourite soccer team. If everyone just ran after the ball with no plan, they would never win a game. But when people are assigned positions, the team performs much better as a whole.

A cell is like this soccer team. Each organelle performs a specific function, and when organelles work together, the cell can run efficiently and effectively.

Lesson link

In ***lesson 2A*** you learned that only eukaryotes have membrane-bound organelles. It is important to remember that prokaryotes still do have organelles, however, there are comparatively less and they are not membrane-bound. In this lesson, then, we're focusing solely on the organelles of eukaryotic cells.

Table 1 outlines the structures and functions of the organelles important in VCE Biology.

Table 1 A diagrammatic representation of different organelles and their structures and functions

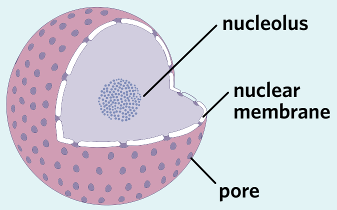
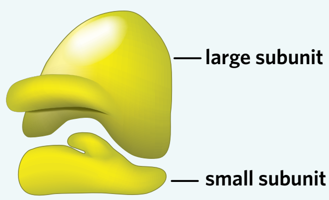
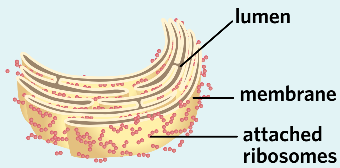
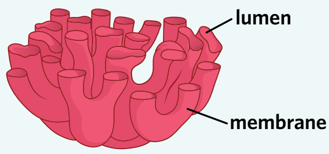
Organelle	Structure and function	Diagram
Nucleus	The nucleus is surrounded by a double membrane. Its role is to protect and confine the genetic information (DNA) of the cell. Inside the nucleus is a smaller structure known as the nucleolus which is the site of ribosome production.	 Image: Soleil Nordic/Shutterstock.com
Ribosomes	Ribosomes are tiny structures made of **ribosomal RNA** (rRNA) 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 the rough endoplasmic reticulum. Ribosomes assemble the building blocks to make proteins.	 Image: Designua/Shutterstock.com
Rough endoplasmic reticulum (RER)	A membranous chain of connected and flattened sacs which are coated with ribosomes. This allows the rough endoplasmic reticulum to synthesise and modify proteins. The rough endoplasmic reticulum 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. The smooth endoplasmic reticulum is responsible for the production of lipids in a cell.	 Image: Djordje Raca/Shutterstock.com

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Table 1 continued

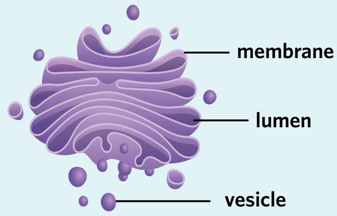
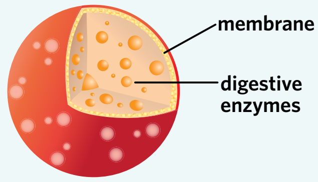
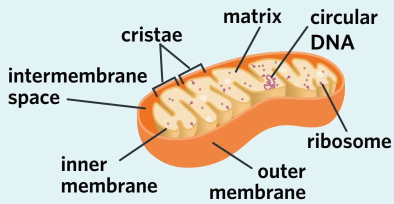
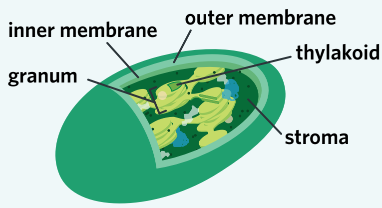
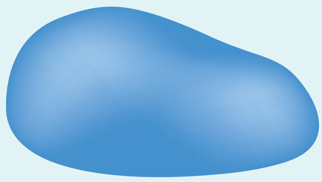
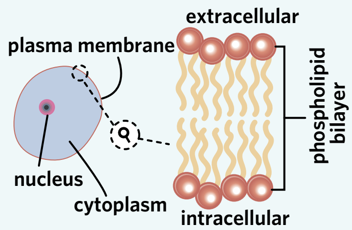
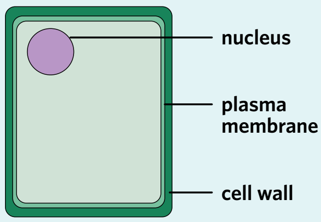
Organelle	Structure and function	Diagram
Golgi apparatus	Stacked flattened sacs that are the sites of protein sorting, packaging, and modification for use in the cell or export. Protein-filled vesicles often fuse with or bud off from the Golgi apparatus. Also known as the Golgi body.	 Image: LDarin/Shutterstock.com
Lysosome	A membrane-bound vesicle that contains digestive enzymes. It is responsible for breaking down cell waste and toxins, 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, a chemical reaction that 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 are the site of photosynthesis. Chloroplasts also contain their own DNA and ribosomes.	
Vacuole	A membrane-bound sac that is used for water and solute storage. Vacuoles can also play a role in maintaining plant cell structure.	 Image: Designincolorc/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.	

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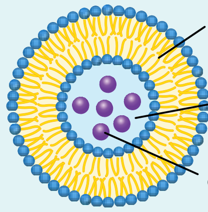
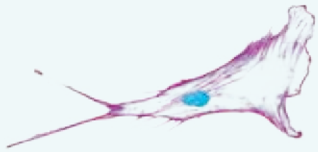
Table 1 continued

Organelle	Structure and function	Diagram
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 large network of protein filaments that start at the nucleus and reach out to the plasma membrane. The cytoskeleton is critical for maintaining shape and transporting vesicles around the cell. In the given fluorescence microscopy photo, the purple represents the cytoskeleton.	 Image: DrimaFilm/Shutterstock.com

While Table 1 is not a comprehensive list of every organelle, it covers most of the important ones in VCE Biology. Some of these organelles are **membrane-bound**. This means the organelles are surrounded by a membrane that controls what enters and exits the organelle. Table 2 outlines which organelles are membrane-bound and which organelles are not membrane-bound.

ribosomal RNA (rRNA) a type of nucleic acid that is a key structural component of ribosomes

lumen the space within a cavity which can act as a passage-way

membrane-bound organelle structure within a cell that is enclosed by a phospholipid bilayer

Table 2 Summary of which organelles are membrane-bound

Membrane-bound organelles	Not membrane-bound
• nucleus • rough endoplasmic reticulum • smooth endoplasmic reticulum • Golgi apparatus • lysosomes • mitochondria • chloroplasts • vacuoles • vesicles	• ribosomes • cell wall • cytoskeleton

Mitochondria and chloroplasts 1.1.3.2

OVERVIEW

Mitochondria are the sites of aerobic cellular respiration, which is a necessary process for all organisms to break down sugars into energy. Chloroplasts are the sites of photosynthesis in organisms that use sunlight to create sugars.

mitochondrion (pl. mitochondria) the primary site of energy production from aerobic cellular respiration

cellular respiration the biochemical process in all living things that converts glucose into ATP. Can be aerobic or anaerobic respiration

matrix the space inside the inner membrane of the mitochondria

crista (pl. cristae) the fold of the inner membrane of the mitochondria

THEORY DETAILS

The mitochondrion

Mitochondria contain an outer membrane surrounding a highly folded inner membrane. This creates a narrow, low-volume intermembrane space that facilitates some of the processes of **cellular respiration**. The space inside the inner membrane is known as the **mitochondrial matrix** and the folds of the inner membrane are known as the **cristae**.

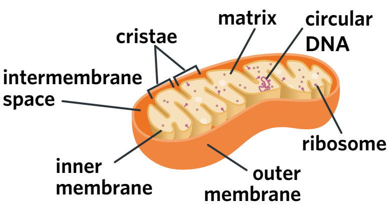


Figure 2 The structure of a mitochondrion

Cellular respiration is the cell's primary method of producing energy. It breaks down the simple carbohydrate known as glucose to produce energy. Cellular respiration can occur either **aerobically** or **anaerobically**, but mitochondria only play a role in the aerobic cellular respiration pathway. The formula for aerobic cellular respiration is shown in Figure 3.

aerobic requiring oxygen

anaerobic requiring no oxygen

> ### *Theory in action*
>
> Check out scientific investigations 2.1 and 2.2 to put this into action!

glucose + oxygen → carbon dioxide + water + energy

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O + 36\text{ ATP}$$

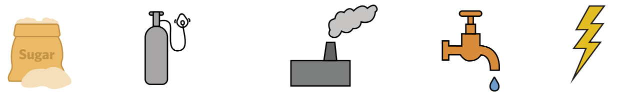


Figure 3 Equation for aerobic cellular respiration

> ### *Theory in action*
>
> **CAN YOU OBSERVE CELLULAR RESPIRATION IN ACTION?**
>
> **Materials**
>
> - 1 large sandwich bag
> - 10g of baker's yeast
> - ½ cup of white sugar
> - 1 cup of lukewarm water
>
> **Method**
>
> Combine the yeast, sugar, and water into the sandwich bag and seal the bag closed. Observe what happens to the bag.
>
> **Questions**
>
> 1 What did you observe? Why do you think this happened?
>
> 2 Explain why you required water and sugar for this reaction to occur.
>
> 3 Evaluate whether this practical is exploring aerobic and/or anaerobic cellular respiration.

The chloroplast

Chloroplasts can be found in plant and **algae** cells. They are made up of an inner and outer membrane which control what enters and exits the chloroplast. Inside the chloroplast, you will find **grana**, which are made up of a stack of flattened sacs known as **thylakoids**, and a fluid substance known as the **stroma**. These structures help plants and algae undergo **photosynthesis**.

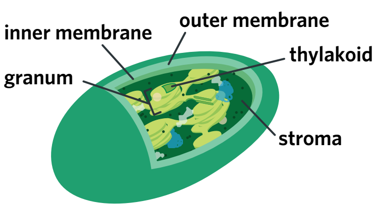


Figure 4 The structures of a chloroplast

Photosynthesis is the process which uses light energy from the sun, carbon dioxide, and water to produce glucose and oxygen. In order for photosynthesis to take place, the thylakoid membranes contain a green pigment known as **chlorophyll** which absorbs light to energise reactions. The glucose produced can then be used during cellular respiration, to build cell walls, and to carry out metabolic reactions. Excessive glucose can be stored in seeds as starch. The formula for photosynthesis is shown in Figure 5.

carbon dioxide + water $\xrightarrow[\text{chlorophyll}]{\text{sunlight}}$ glucose + oxygen

$$6\,CO_2 + 6\,H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6\,O_2$$

Figure 5 The net equation of photosynthesis

chloroplast a double membrane-bound organelle that contains flattened, fluid-filled sacs that are the site of photosynthesis. Chloroplasts also contain their own DNA and ribosomes

algae a large diverse group of photosynthetic protists found in aquatic environments

granum (pl. grana) a stack of thylakoids

thylakoid a flattened sac-like structure inside the chloroplast. Thylakoids stacked upon one another make up a granum

stroma the fluid substance that makes up the interior of chloroplasts

photosynthesis the process of converting light energy, carbon dioxide, and water into glucose and oxygen

chlorophyll a green pigment found in the thylakoids of chloroplasts. It is responsible for absorbing light energy in photosynthesis

Theory in action

HOW DOES LIGHT AFFECT THE RATE OF PHOTOSYNTHESIS?

Materials

- two plastic/paper cups
- alfalfa plants
- potting soil
- a window
- a dark place

Method

Pot the alfalfa into each of the two cups. Leave one cup on the window ledge and one cup in the dark place for three days.

Questions

1. Which plant grew more? Why do you think this happened?
2. What variables did we not account for in our experiment? Think about temperature, initial height of the alfalfa, water, and any others.

Theory in context

ORIGINS OF THE CHLOROPLAST AND MITOCHONDRIA

Strong evidence suggests that the ancestors of chloroplasts and mitochondria were both once free-living bacteria that existed billions of years ago, until they were engulfed by a larger organism to establish an **endosymbiotic** relationship (Figure 6). A symbiotic relationship occurs when two organisms have a close relationship with each other. An endosymbiotic relationship is when one organism lives inside the other, and typically results in both organisms gaining some benefits.

There are a few pieces of evidence that support the **endosymbiosis theory**:

- mitochondria and chloroplasts have a double membrane which can be explained if they were engulfed via endocytosis
- mitochondria and chloroplasts have their own ribosomes that share characteristics with bacterial ribosomes
- mitochondria and chloroplasts have their own DNA and ribosomes so they can produce specialised proteins independently from the rest of the cell
- mitochondria and chloroplasts have their own circular DNA which is not enclosed in a nuclear membrane (similar to bacteria), unlike eukaryotes that have linear DNA
- mitochondria, chloroplasts, and bacteria all replicate through binary fission. Plant, animal, fungi, and algae cells replicate through mitosis or meiosis
- the outer membrane of mitochondria and chloroplasts contain transport proteins called porins. The only other place porins are found is in the cell membrane of prokaryotes.

The origin of mitochondria and chloroplasts

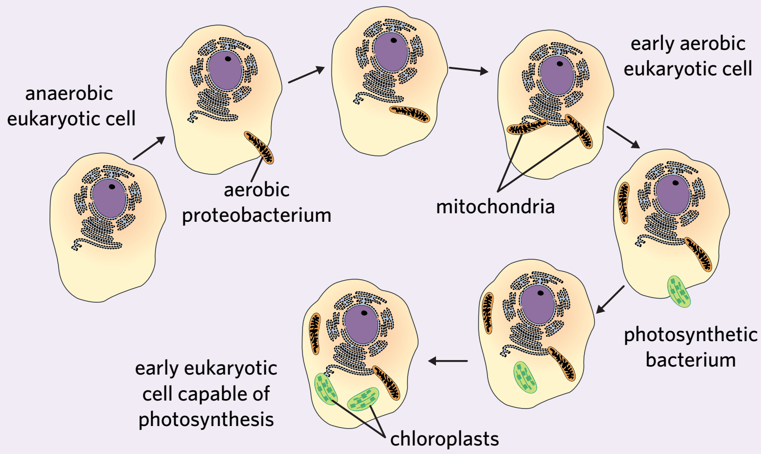


Image: J. Marini/Shutterstock.com

Figure 6 The process of endosymbiosis

endosymbiosis when one organism lives inside another in a mutually beneficial relationship

endosymbiosis theory a theory suggesting that chloroplasts and mitochondria were once free-living organisms before being engulfed by a larger cell

Comparing plant and animal cells 1.1.3.3

OVERVIEW

Animals and plants look and function very differently from each other. These differences can be traced back to differences in the way their cells are structured, and the effect this has on their function.

THEORY DETAILS

Eukaryotic cells can be classified as fungi, protist, animal, or plant, according to organelle composition and the overall organism structure. VCE Biology mostly focuses on animal and plant cells, so we will deep dive on them here.

Table 3 Differences between plant and animal cells

Key differences	Explanation
A cell wall made of cellulose is present in plant cells but not animal cells.	Unlike plants, most animals have evolved structures like skeletons that provide structural support for the organism. Plants rely on their strong cell walls to perform the same function.
Chloroplasts are present in plant cells but not animal cells.	Chloroplasts are found in plants as they are the site of photosynthesis, which is how plants source glucose for energy. Animals source their food through other methods.
Vacuoles in animal cells are small and there can be many or none, whereas plant cells tend to have one large vacuole.	Vacuoles in plants are used to provide further support for the organism; they must be full to prevent wilting. In animals, vacuoles are primarily involved in solute and water storage rather than structural support.

Lesson link

In ***lesson 2A*** you learned that all living things were either prokaryotic or eukaryotic. Here, we distinguish between two eukaryotes: plants and animals. However, remember that fungi and protists are also types of eukaryotes. Fungi have a chitin cell wall, can be unicellular or multicellular, and source energy from other organisms rather than from the sun through photosynthesis. Protists are usually unicellular (but can be multicellular) and they can get energy either through photosynthesis or by consuming other organisms.

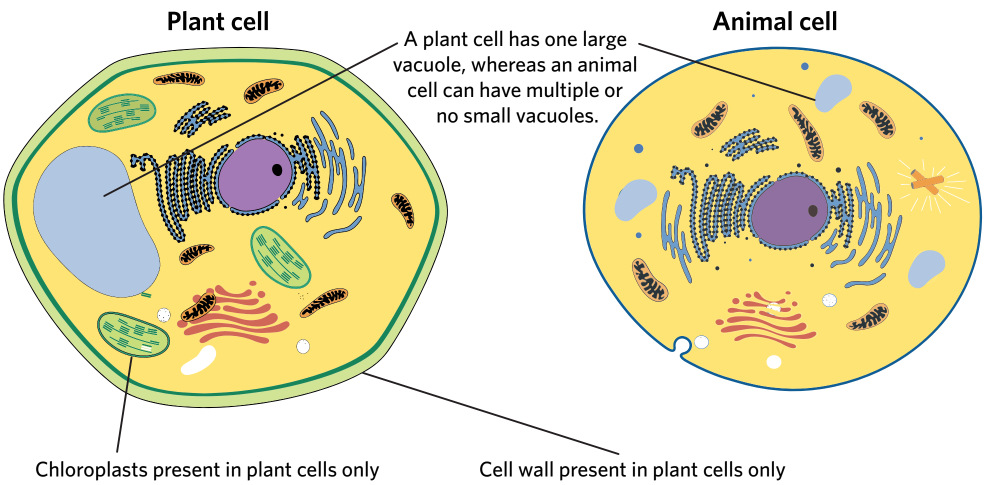


Image: Aldona Griskeviciene/Shutterstock.com

Figure 7 The differences between animal and plant cells

Theory summary

Table 4 Summary of the organelles in eukaryotes

Organelle	Is the organelle membrane-bound?	Eukaryotes	
		Plant?	Animal?
nucleus	✓	✓	✓
rough endoplasmic reticulum (RER)	✓	✓	✓
smooth endoplasmic reticulum (SER)	✓	✓	✓
ribosomes	✗	✓	✓
Golgi apparatus	✓	✓	✓
lysosome	✓	✓	✓
mitochondria	✓	✓	✓

cont'd

Table 4 Continued

Organelle	Is the organelle membrane-bound?	Eukaryotes	
		Plant?	Animal?
chloroplast	✓	✓	✗
vacuoles	✓	✓	✓
plasma membrane	✗	✓	✓
cell wall	✗	✓	✗
vesicle	✓	✓	✓
cytoskeleton	✗	✓	✓

It is believed that training helps elite athletes produce more mitochondria in their cells. This means they can produce more energy and work at higher intensities for longer periods, allowing them to complete a marathon in almost half the time of a non-elite athlete. So, what are you waiting for – pull on those runners, hit the track, and start making those mitochondria!

Image: Brizmaker/Shutterstock.com

2B QUESTIONS

Theory review questions

Question 1

An organelle is

A a cluster of cells.

B a system of organs working together.

C a structure of a cell with a specialised function.

Question 2

Fill in the blanks with the following terms.

- mitochondria
- chloroplasts
- nuclei
- cell walls
- vacuoles

__________ and __________ are found in plant cells but not animal cells. __________ and __________ are found in both plant and animal cells. In animal cells, there can be multiple __________ or they can be absent, however there is generally only one in each plant cell.

Question 3

Label the parts of the plant cell from the list of terms.

- rough endoplasmic reticulum
- mitochondrion
- chloroplast
- Golgi body
- ribosomes
- cell wall
- nucleus
- vacuole

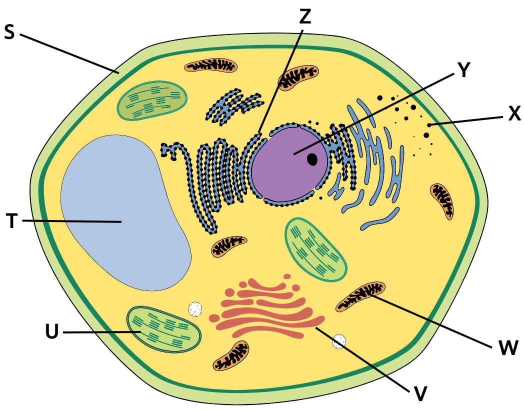


Image: Aldona Griskeviciene/Shutterstock.com

Question 4

Match the organelle to its function.

Organelle

- nucleus
- rough endoplasmic reticulum
- smooth endoplasmic reticulum
- ribosomes
- Golgi body
- mitochondrion
- chloroplasts
- plasma membrane
- lysosome

Function

I __________ site of protein synthesis
II __________ controls what enters and exits the cell
III __________ sorts, packages, and modifies proteins
IV __________ the control centre of the cell that holds nuclear information
V __________ site of aerobic cellular respiration
VI __________ the site where proteins are synthesised and modified and contains ribosomes on the surface
VII __________ contains molecules that digest waste products
VIII __________ site of lipid production in the cell
IX __________ site of photosynthesis

Question 5

Fill in the blanks in the following sentence.

The grana and stroma are structures of the __________ which facilitates the process of __________, whilst the cristae and matrix are structures of the __________ which facilitates the process of __________.

Question 6

The equation of photosynthesis is

A $\text{glucose} + \text{oxygen} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \text{carbon dioxide} + \text{water}$

B $\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \text{glucose} + \text{oxygen}$

SAC skills questions

Scientific methodology comparison

Use the following information to answer Questions 7–12.

Scientists discovered an unknown microorganism in Antarctic waters. They inspected it under a microscope and found that it had membrane-bound organelles, so it had to be eukaryotic. In addition, it was found that the cell can be part of more complex tissues or organs and therefore cannot be from a protist. This left scientists wondering whether it was an animal, plant, or fungus. Key characteristics of fungi cells are that they are surrounded by a chitin cell wall (unlike a plant's cellulose cell wall), and they do not contain chloroplasts. The scientists proposed two different methods to classify the organism.

Method 1: Cell wall staining

Staining is the method of creating contrast in the colours of different structures at a microscopic level. Scientists applied a dual-stain that contained trypan blue (which turns chitin red) and aniline blue (which turns cellulose yellow/green) to the recently discovered specimen. They also took a known sample of an animal, plant, and fungal tissue and applied the stain to these three samples. They planned to align the colour of the mystery cell with the matching colour shown in one of the three known samples.

Method 2: Photosynthesis testing

Scientists set up four sealed micro test tubes, each with a source of light, carbon dioxide, oxygen, and water. The levels of oxygen and carbon dioxide were initially recorded. In each test tube, either the unknown sample, or a known plant, animal, or fungal cell was added. After three hours, the concentrations of oxygen and carbon dioxide were recorded.

Question 7

The plant cell wall is made of

A a phospholipid bilayer.

B cellulose.

C chitin.

Question 8

It is expected that the fungal cells would be which colour after staining?

A red

B blue

C yellow

Question 9

Following method 1, which of the following results would support the hypothesis that the unknown organism was an animal?

A The cell wall was red in colour.

B The cell wall did not stain at all.

C The cell wall was blue in colour.

D The cell wall was yellow/green in colour.

Question 10

In method 2, scientists are testing for the presence of which organelle?

A chloroplasts

B Golgi body

C ribosomes

D nucleus

Question 11

In method 2, outline the purpose of the three known cell type samples.

A These were control groups to create a baseline in the results which can be compared to the unknown group.

B These were the uncontrolled groups which have a different independent variable, cell type.

Question 12

Identify which method is less valid for classifying the mystery organism.

A Method 1 as there were no control groups.

B Method 1 as if the stain is incorrectly performed, it would show no colour.

C Method 2 as the calibration of the oxygen and carbon dioxide detectors might be incorrect.

D Method 2 as it does not clearly distinguish the unknown sample from the three known samples.

Exam-style questions

Within lesson

Question 13 (1 MARK)

The membrane-bound organelle that packages proteins is the

A ribosome.

B lysosome.

C Golgi body.

D smooth endoplasmic reticulum.

Question 14 (1 MARK)

Which of the following organelles contains circular DNA within it?

A nucleus

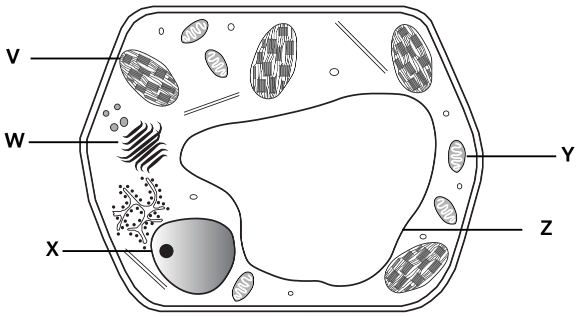
B ribosomes

C lysosomes

D mitochondria

Question 15 (7 MARKS)

The following diagram displays a eukaryotic cell.



a Identify structure X. (1 MARK)

b State whether the diagram shows an animal or a plant cell. Justify your response. (1 MARK)

c Identify which structure is the main site of aerobic cellular respiration. (1 MARK)

d What is the name and role of structure Z? (2 MARKS)

e Explain the difference between the cytosol and the cytoplasm. (2 MARKS)

Multiple lessons

Question 16 (1 MARK)

Plant and animal cells are examples of

A prokaryotic cells.

B eukaryotic cells.

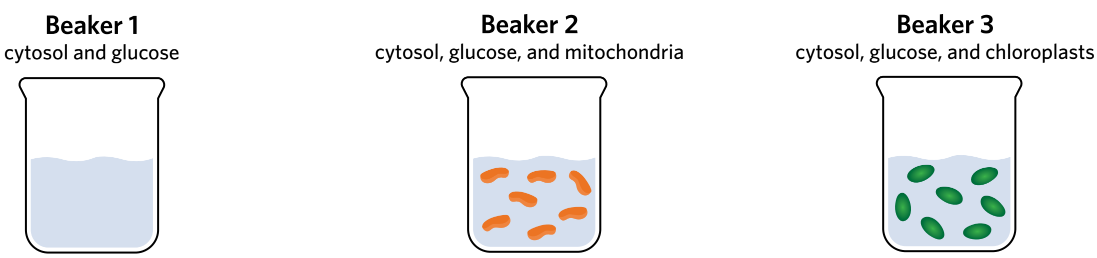
C bacterial cells.

D fungal cells.

Key science skills and ethical understanding

Question 17 (7 MARKS)

Cayden and Lacey were two university students performing an experiment to look at photosynthesis and cellular respiration. They set up three sealed beakers and measured the percentage of oxygen in the beaker over a three hour period.



a Predict the trend in the results for each beaker in the following table. Draw an arrow up (↑) for increase, arrow down (↓) for decrease, or a hyphen (-) for no change. (1 MARK)

	Beaker 1	Beaker 2	Beaker 3
Change in oxygen concentration			

b Their results can be shown in the given table.

	Beaker 1 **Cytosol and glucose**	**Beaker 2** **Cytosol, glucose, and mitochondria**	**Beaker 3** **Cytosol, glucose, and chloroplasts**
Initial average percentage of oxygen in beaker (%)	20	21	22
Average percentage of oxygen in beaker after one hour (%)	20	16	17
Average percentage of oxygen in beaker after two hours (%)	21	12	13
Average percentage of oxygen in beaker after three hours (%)	21	8	11

i In the second hour, Cayden misread the digital meter for the percentage of oxygen for one of his beakers. Identify what type of error this is. (1 MARK)

ii Identify the dependent variable in this experiment. (1 MARK)

iii Outline whether the results support or refute your predictions in part a. If they do not support your predictions, identify a potential experimental error that could have occurred to cause it. (3 MARKS)

iv Cayden suggests to his teacher that they should complete the experiment again with mitochondria from himself and each of his classmates and compare their efficiency. The teacher agrees but forgets to ask Cayden to get signed consent from the students and their parents. Which ethical concept are the teacher and Cayden not adhering to? (1 MARK)

2C CELL SIZE AND SHAPE

It's 8PM. You have been studying so hard and realised you haven't eaten since breakfast! You have all the ingredients to cook up an easy potato curry in a hurry, but potatoes take forever to cook. How can you speed up the cooking time of the potatoes?

Image: Monali.mishra/Shutterstock.com

Lesson 2C

In this lesson you will learn that cells are microscopic in size to create a large surface area to volume ratio.

◀ *Prerequisite knowledge*

Years 7–10
Cells are the smallest and most basic units of life.

Lesson 2A
Prokaryotic cells have a diameter of 0.1–5 μm, compared to 10–100 μm in eukaryotic cells.

Future applications ▶

Lesson 3B
This lesson focuses on how substances pass through the plasma membrane to enter the cell.

Lesson 5A
Small cells work together to create tissues, organs, and organ systems in animals.

Lesson 10A
Maintaining body temperature for some organisms relies heavily on their surface area to volume ratio.

Study design dot point

- surface area to volume ratio as an important factor in the limitations of cell size and the need for internal compartments (organelles) with specific cellular functions

Key knowledge units

Why are cells so small?	1.1.2.1
Surface area to volume ratio	1.1.2.2

Why are cells so small? 1.1.2.1

OVERVIEW

Instead of being one giant cell, an adult human is made up of an estimated 37.2 trillion cells. By having many small cells, as opposed to one big cell, it is more efficient to transport nutrients and remove wastes.

THEORY DETAILS

Cells drastically vary in shape and size. An **ovum**, or egg cell, is the only human cell that can be seen by the naked eye as it has a diameter of 0.1 mm and is an almost perfect sphere. In contrast, **red blood cells** are biconcave disks and have a diameter of approximately 7 μm or 0.007 mm. Both of these cells serve very different purposes, which is why they have different sizes and shapes. Ova are key to reproduction and contain genetic information, organelles, and the nutrients required to create an embryo, whereas red blood cells circulate oxygen around the body by squeezing through tiny capillaries.

ovum (pl. ova) a fully mature female egg cell which, when fertilised, can divide and give rise to an embryo

red blood cells cells that transport oxygen through the bloodstream and do not contain a nucleus

The benefits of having small cells are:

1 The exchange of materials with the extracellular environment (including importing nutrients and oxygen, and removing toxins) can occur efficiently and effectively due to a high surface area to volume ratio. This will be explained later in this lesson.

2 Distances to travel within the cell are smaller, so the intracellular transport of molecules is faster.

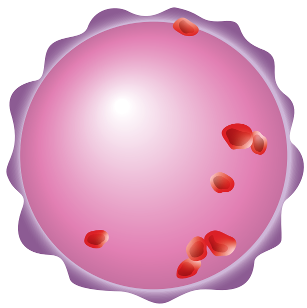


Figure 1 Comparison in size of an ovum to red blood cells

Surface area to volume ratio 1.1.2.2

OVERVIEW

A greater surface area and smaller volume, or high SA:V, can help a cell exchange materials efficiently with the environment.

THEORY DETAILS

What is volume?

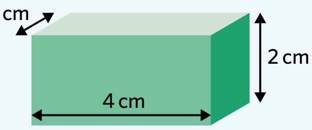
Volume is the space within an object. When thinking of volume, it is handy to know that 1 mL = 1 cm^3, which means if we find out that a jug has a volume of 1000 cm^3, this could hold 1 L of liquid. When calculating the volume of a cuboid, all you need is the length, width, and height of the cuboid (in the same units). You then substitute these values into the following formula: *volume = length × width × height*.

Memory device

Think of how long it would take you to run from the boundary line of your school oval all the way into the middle and then back out to the boundary (approximately 75 m each way). Compare this to how long it would take to run to the middle of the centre circle on a netball court (0.45 m each way). Molecules (like you) take longer to travel further distances.

volume the amount of space inside an object. Measured in (units of length)^3 (i.e. mm^3, cm^3, m^3)

Table 1 Worked example of calculating the volume of a rectangular prism

1 Measure each edge of the object	 length = 4 cm width = 1 cm height = 2 cm
2 Substitute values into the formula	volume = length × width × height volume = 4 cm × 1 cm × 2 cm volume = 8 cm^3

From the example given in Table 1, this object could contain 8 cm^3, or 8 mL, of liquid inside it.

What is surface area?

Surface area is the sum of the area of each of the faces of a three-dimensional object. This means that to work out the surface area of a prism, we must do the following steps:

1 Identify the length of each unique edge, and establish which side is your length, width, and height (doesn't really matter which you choose).

2 a If all edges are the same length (such as for a cube), calculate the area of any one face, and multiply the area of the one side by the number of faces in the shape

b If the edges vary in length, calculate the area of:

i face A – length × width

ii face B – length × height

iii face C – width × height.

Then multiply each face area by 2, and add them all together.

It is important to note that surface area is always measured in units^2 (so cm^2 or m^2).

surface area the sum of the area of all exposed sides of a three-dimensional shape. Measured in (units of length)^2 (i.e. mm^2, cm^2, m^2)

Table 2 Worked example of calculating the surface area for a shape where the edges are all the same length

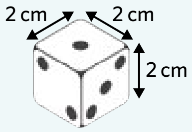
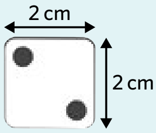
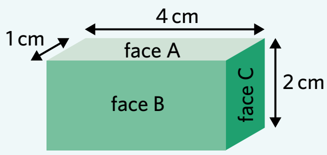
1 Measure each edge of the object	 length = 2 cm width = 2 cm height = 2 cm
2 Calculate the area of any one side	 area = length × width area = 2 cm × 2 cm area = 4 cm^2
3 Multiply the area of one side by the number of sides	area = 4 cm^2 number of sides = 6 surface area = area × number of sides surface area = 4 cm^2 × 6 surface area = 24 cm^2

Table 3 Worked example of calculating the surface area for a shape where each edge is a different length

1 Measure each edge of the object	 length = 4 cm width = 1 cm height = 2 cm
2 Calculate the area of: **a** face A – length × width **b** face B – length × height **c** face C – width × height	face A area = length × width face A area = 4 cm × 1 cm face A area = 4 cm^2 face B area = length × height face B area = 4 cm × 2 cm face B area = 8 cm^2 face C area = width × height face C area = 1 cm × 2 cm face C area = 2 cm^2
3 Multiply the area of each face by 2 and add them together	Surface area = (face A × 2) + (face B × 2) + (face C × 2) Surface area = (4 cm^2 × 2) + (8 cm^2 × 2) + (2 cm^2 × 2) Surface area = 8 cm^2 + 16 cm^2 + 4 cm^2 Surface area = 28 cm^2

What is surface area : volume ratio?

A **ratio** is a mathematical representation showing the relative proportions of two things. Ratios operate in a similar way to fractions in that we try to simplify them down as small as possible. For example, Granny Smith's fruit bowl has 10 apples and 2 oranges. We would write this ratio as 5 apples : 1 orange, not 10 apples : 2 oranges. This means for every one orange, there are five apples. We can also look at ratios in terms of the total, so the ratio of apples to the total fruit count in the bowl is 10 : 12, which can be simplified to 5 : 6. This reads as, for every six pieces of fruit, five of them are apples.

In terms of **surface area : volume ratio**, it works the same way. For every cm^3 of volume, how many cm^2 of surface area are there?

To calculate the SA:V of an object we must take the following steps:

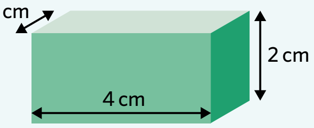
1. Calculate surface area
2. Calculate volume
3. Calculate (surface area)/(volume) to work out every unit of surface area per unit of volume
4. Convert into a ratio.

Let's do this calculation for the rectangular prism used in Table 1 and Table 3.

ratio a comparison between two things to show proportions

surface area : volume ratio (SA:V) a comparison of the amount of surface area per unit of volume. In Biology, SA:V influences temperature regulation, and a high SA:V leads to more effective transport into and out of cells

Table 4 Worked example of calculating the surface area to volume ratio of a rectangular prism

1 Calculate surface area	 surface area = 28 cm^2
2 Calculate volume	volume = 8 cm^3
3 Calculate (surface area)/(volume) to work out every unit of surface area per unit of volume	SA/V = 28 / 8 SA/V = 3.5
4 Convert into a ratio	SA:V = 3.5 : 1

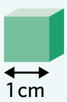
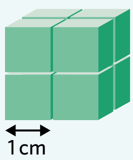
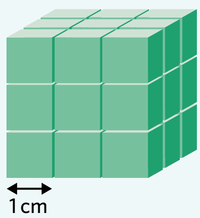
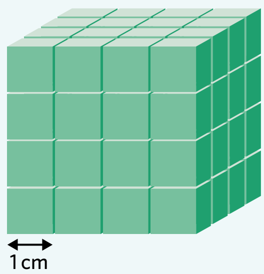
Theory in action

Check out scientific investigation 2.3 to put this into action!

Maximising surface area to volume ratio

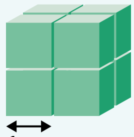
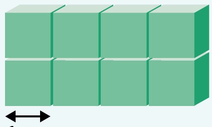
Smaller objects have larger surface area to volume ratios (Table 5).

Table 5 Influence of size on surface area to volume ratio

				
surface area	6 cm^2	24 cm^2	54 cm^2	96 cm^2
volume	1 cm^3	8 cm^3	27 cm^3	64 cm^3
SA:V	6 : 1	3 : 1	2 : 1	1.5 : 1

Size isn't the only influence on SA:V. The shape of an object also alters the SA:V (Table 6).

Table 6 Influence of shape on surface area to volume ratio

	 1 cm	 1 cm	 1 cm
surface area	24 cm^2	28 cm^2	34 cm^2
volume	8 cm^3	8 cm^3	8 cm^3
SA:V	3 : 1	3.5 : 1	4.25 : 1

From Table 6, we can see that objects with the same volume can have a different SA:V. The general trend is the more compact the object, the lower the SA:V. This means that objects with long lengths and short depths and widths are likely to have a higher SA:V.

Another way to figure out the surface area is to count how many squares you can see on the faces of each of the shapes in Table 6. Then double that number to account for all the faces on the other side of the shape. We can see 12 squares on the left shape, 14 squares on the middle shape, and 17 squares on the right shape, once we double to account for the hidden faces, we end up with 24, 28, and 34 respectively.

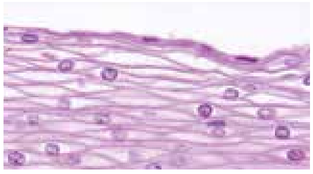


Image: Jose Luis Calvo/Shutterstock.com

Figure 2 Stratified squamous epithelium which are flat to maximise their surface area to volume ratio

Surfaces and cells with high SA:V

Surfaces, which are made up of many cells, are able to exchange substances with the environment most effectively if they have a high SA:V. Therefore, both surfaces and cells that need to transport lots of substances across their border tend to be small and elongated. For instance, in the small intestine, which is responsible for absorbing nutrients, cells lining the intestine arrange into 'finger-like' shapes called villi. Some of these cells even have smaller 'finger-like' shapes of their own on their surface called microvilli that fold in and out to increase their surface area. By having both villi and microvilli, the surface area of the lining inside the small intestine can be greatly increased, which leads to an increased SA:V (Figure 3).

Lesson link

In ***lesson 5C***, you will learn more about how the digestive system functions to absorb nutrients from our food and how a high surface area to volume ratio facilitates the process.

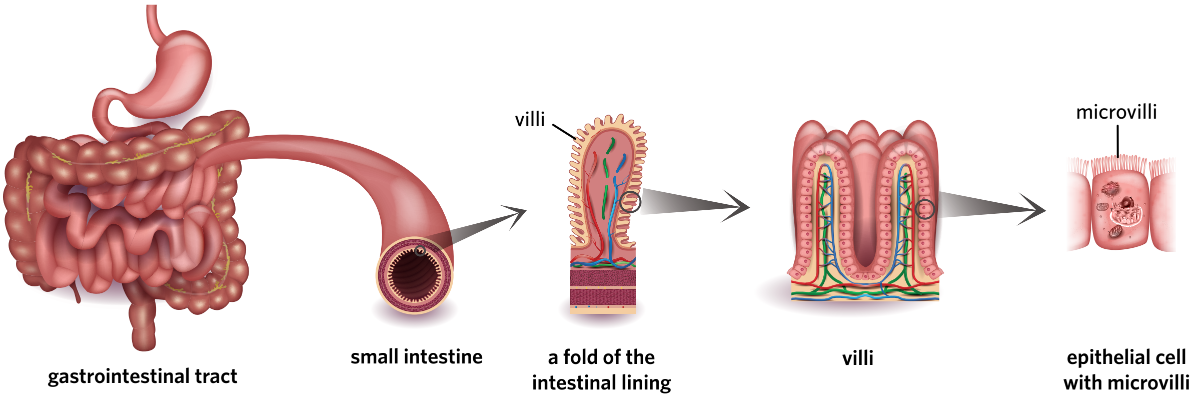


Image: Tefi/Shutterstock.com

Figure 3 Maximising the surface area to volume ratio in the small intestine

Theory summary

Cells are microscopic in size so that they maximise their surface area to volume ratio and increase the efficiency of transport.

No no, the answer is not ordering Uber eats. How about cutting up the potatoes into smaller pieces so they have a greater surface area to volume ratio? Then the potatoes can cook faster and you can eat the yummy curry earlier!

Which way would you cut them though?

Obviously, it would be option B because it has a greater surface area to volume ratio!

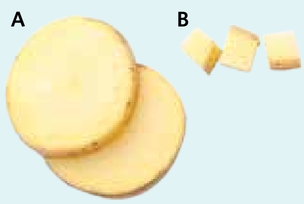


Image: Jacek Fulawka/Shutterstock.com

2C QUESTIONS

Theory review questions

Question 1

One principle reason cells are so small is so that

A the distance that molecules have to travel in, around, and out of a cell is small.

B cells can specialise their functions quickly.

Question 2

Fill in the blanks with the following terms. Terms may be used multiple times or not at all.

- higher
- lower
- equal
- shape
- size
- weight

Surface area to volume ratio is dependent on __________ and __________. Cells with a __________ surface area to volume ratio can transport molecules more efficiently than cells with a __________ surface area to volume ratio.

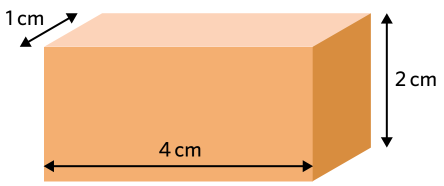
Question 3

There is a classroom of 20 Year 11 students. 15 are female and five are male. Fill in the blanks in the following sentences with the appropriate ratios.

The proportion of males to females in the class is __________. Meanwhile the proportion of females to total students in the class is __________.

Question 4

Calculate the volume of the following shape.



A 6 cm^2

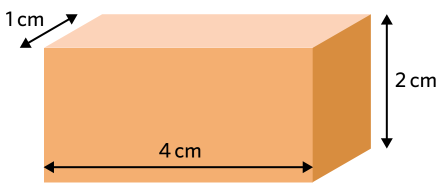
B 6 cm^3

C 8 cm^2

D 8 cm^3

Question 5

Calculate the surface area of the following shape.



A 14 cm^2

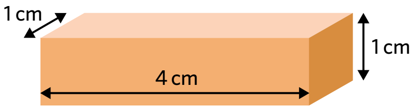
B 14 cm^3

C 28 cm^2

D 28 cm^3

Question 6

Calculate the surface area to volume ratio of the following shape. The volume is 4 cm^3 and the surface area is 18 cm^2. Use a calculator if required.



A 4.5 : 1
B 1 : 4.5
C 3 : 1
D 1 : 3

Question 7

There are two types of protists shown in the image: *Paramecium* and amoeba.

Which of the following statements is correct?

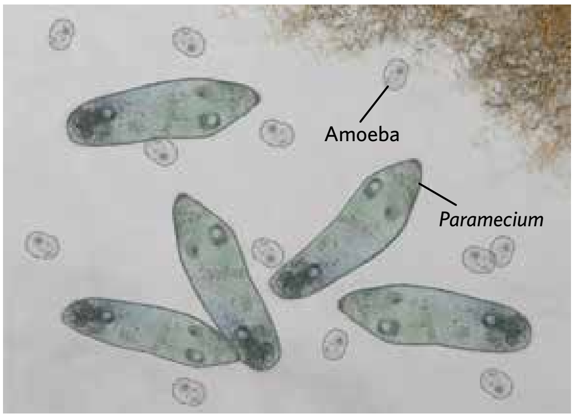


Image: Nixx Photography/Shutterstock.com

A The *Paramecium* has the highest SA:V, so is the most efficient at exchanging materials with the environment.
B The *Paramecium* has the lowest SA:V, so is the most efficient at exchanging materials with the environment.
C The amoeba has the highest SA:V, so is the most efficient at exchanging materials with the environment.
D The amoeba has the lowest SA:V, so is the most efficient at exchanging materials with the environment.

SAC skills questions

Case study analysis

Use the following information to answer Questions 8–13.

Coeliac disease is caused by the body initiating an immune response against cells in the small intestine in response to the presence of gluten. Gluten is a protein that can be found in wheat, barley, and rye.

The immune response damages villi in the small intestine, which are small finger-like projections from the walls of the intestine. They increase the surface area to volume ratio of the small intestine to allow for greater absorption of nutrients. The villi in the small intestine can absorb approximately 8 L of liquid every day!

The diagram shows a comparison between healthy villi and villi affected by an immune response.

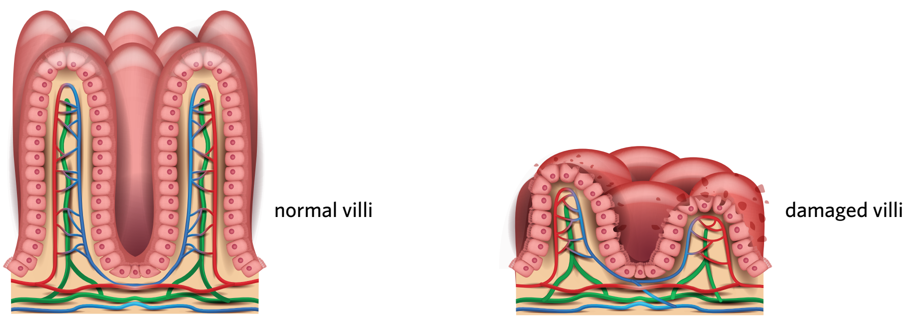


Image: Tefi/Shutterstock.com

People with coeliac disease who have damaged villi can suffer from weight loss, fatigue, and anaemia (decreased levels of red blood cells). This is due to malabsorption.

Question 8

Which substance initiates an immune response in the small intestine?

A bacteria
B gluten
C villi

Question 9

Which of the following statements is true?

A Villi are a type of cell.
B A single villi absorbs 8 L of fluid per day.
C Abnormal immune response can damage your small intestine.

Question 10

What is malabsorption?

A over absorption of nutrients
B an inability to absorb nutrients

Question 11

Villi have a larger surface area to volume ratio when they are

A long and thin.
B cube-like.

Question 12

A large surface area to volume ratio is effective for

A molecule transportation.
B storage.

Question 13

Why do people affected by coeliac disease suffer from malabsorption?

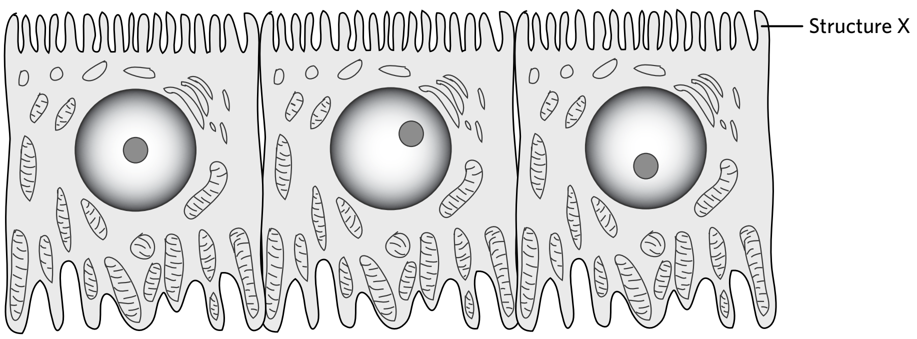
A Damaged villi have a low surface area to volume ratio.
B Damaged villi have a high surface area to volume ratio.

Exam-style questions

Within lesson

Use the following information to answer Questions 14 and 15.

A student examined a section of animal tissue and observed the following three cells.



Question 14 (1 MARK)

Structure X is

A a type of cell.

B found on skin.

C a structure with a high surface area to volume ratio.

D a structure with a high volume to surface area ratio.

Question 15 (1 MARK)

Which of the following statements is correct?

A The cells are likely used for storage of nutrients and molecules.

B The cells have a very low surface area to volume ratio.

C The cells could be found in the small intestine.

D The cells could be found in the brain.

Multiple lessons

Question 16 (1 MARK)

Green leaves on trees have many chloroplasts which undergo photosynthesis. Which leaf shape is optimal for maximising the rate of photosynthesis in a low light environment?

A a large surface area and thin plane

B a small surface area and thin plane

C a large surface area and thick plane

D a small surface area and thick plane

Adapted from VCAA 2003 Exam 1 Section B Q6h

Question 17 (5 MARKS)

Cells inside the body are very small. However, there is a drastic range of sizes between different cell types. Ova have a diameter of 100 µm, compared to red blood cells which have a diameter of 7 µm.

a Red blood cells are unique due to the absence of an organelle. Identify the organelle. (1 MARK)

b With reference to the function of the cell types, explain why ova are significantly larger than red blood cells. (2 MARKS)

c Justify which cell would have a larger surface area to volume ratio with reference to cell size and cell shape. (2 MARKS)

Key science skills and ethical understanding

Question 18 (8 MARKS)

Mrs. Singh asked her class to pair up and investigate anything in the Unit 1 & 2 Biology course, then present their results to the class to teach them the concept they investigated. Fabiano and Axel did an experiment in their class looking at how quickly a substance can move through different sized agar blocks. They used phenolphthalein-rich agar, which is an indicator that changes colour from pink to clear when levels of acidity change, and sodium hydroxide solution, which has a low acidity level to show the movement of solution.

They used three agar blocks, a 1 cm × 1 cm × 1 cm cube, a 2 cm × 2 cm × 2 cm cube, and a 3 cm × 3 cm × 3 cm cube.

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

b Describe the results you would expect to see. (1 MARK)

c Complete the following table. (3 MARKS)

Cubes	1 cm × 1 cm × 1 cm	2 cm × 2 cm × 2 cm	3 cm × 3 cm × 3 cm
Volume (cm^3)			
Surface area (cm^2)			
SA:V			

d Other than changing size, how can surface area to volume ratio be increased? (1 MARK)

e Fabiano thinks it would be a good idea to present false information to his class so that he will rank higher on the end of year exam. Axel reminds him that it would be unethical to do so and would go against an ethical concept they learned about in Chapter 1. What ethical concept would Fabiano be ignoring? (1 MARK)

CHAPTER 2 SUMMARY

Types of cells

Prokaryotes

Prokaryotes are unicellular organisms that contain DNA in a circular chromosome, have no membrane-bound organelles, and divide by binary fission. There are two prokaryotic kingdoms: Bacteria and Archaea.

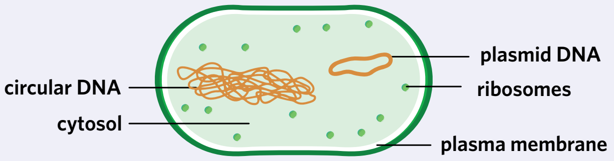


Image: Designua/Shutterstock.com

Eukaryotes

Eukaryotes can be unicellular or multicellular organisms that contain membrane-bound organelles, DNA in multiple linear chromosomes, and divide by mitosis or meiosis. There are four eukaryotic kingdoms: Animalia, Plantae, Fungi, and Protista.

Cell theory

1 All living things are made up of cells.
2 Cells are the smallest and most basic units of life.
3 All cells come from pre-existing cells.

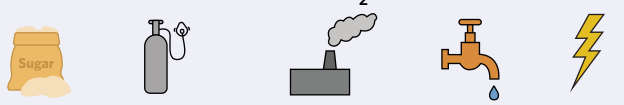
Why are cells so small?

Cells are small to allow them to maximise their surface area to volume ratio which increases the efficiency and speed of transport in and out of a cell. To increase the surface area to volume ratio of a cell or tissue, you can either decrease the size or change the shape to make it flatter and wider.

Cellular respiration

glucose + oxygen → carbon dioxide + water + energy

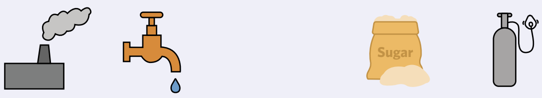
$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ + 36 ATP



Photosynthesis

carbon dioxide + water $\xrightarrow[\text{chlorophyll}]{\text{sunlight}}$ glucose + oxygen

$6\ CO_2 + 6\ H_2O \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + 6\ O_2$



Living things

To remember the eight criteria for living things, remember **MRS GREEN**

Movement
Respiration
Sensitivity

Growth
Reproduction
Equilibrium
Excretion
Nutrition

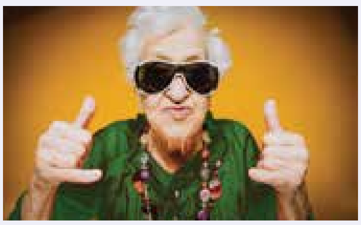


Image: Oneinchpunch/Shutterstock.com

Membrane-bound organelles

Membrane-bound organelles are structures within a cell that are enclosed by a phospholipid bilayer.

Membrane-bound organelles	Not membrane-bound
• nucleus	• ribosomes
• rough endoplasmic reticulum	• cell wall
• smooth endoplasmic reticulum	• cytoskeleton
• Golgi apparatus	
• lysosomes	
• mitochondria	
• chlororplasts	
• vacuoles	
• vesicles	

Plant cell

Plant cells contain one large vacuole, chloroplasts, and a cell wall.

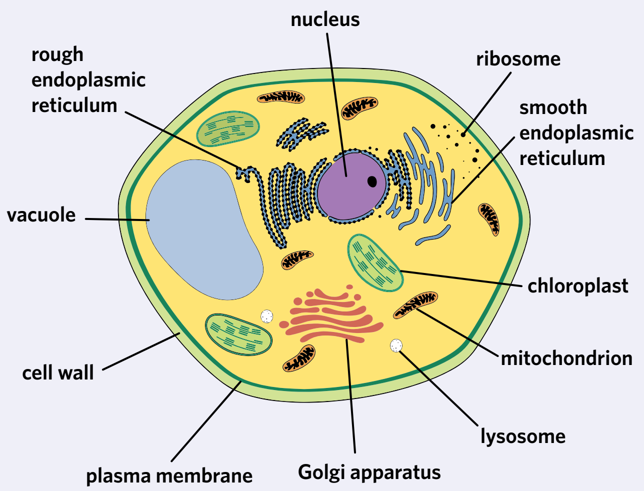


Image: Aldona Griskeviciene/Shutterstock.com

Animal cell

Animal cells do not contain chloroplasts or a cell wall, however, they can have any number of vacuoles.

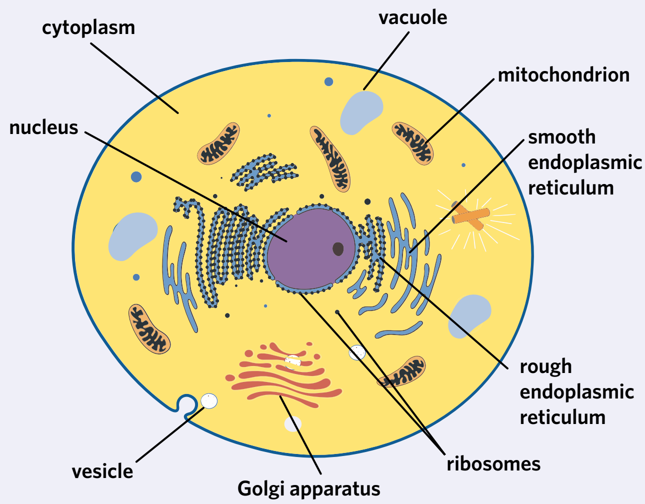


Image: Aldona Griskeviciene/Shutterstock.com

CHAPTER 2 SAC PRACTICE

SAC skills covered in this section:

✓ Case study analysis ✓ Data analysis ✓ Bioethical deep dive

LEIGH DISEASE (24 MARKS)

The disease

Leigh disease is a neurometabolic syndrome that typically presents itself within an infant's first year of life. Neurometabolic diseases involve the lack of vitamins or important proteins (known as enzymes) which are required to undertake metabolic processes in the body. Vomiting, difficulty swallowing, and diarrhoea are early symptoms of Leigh disease in infants.

Leigh disease particularly affects the enzymes involved in aerobic cellular respiration found in the mitochondria. Aerobic cellular respiration is a complicated metabolic process that converts the food we eat into energy that our body can use to power critical biological processes needed for regular function. The equation for aerobic cellular respiration is:

glucose + oxygen → carbon dioxide + water + energy

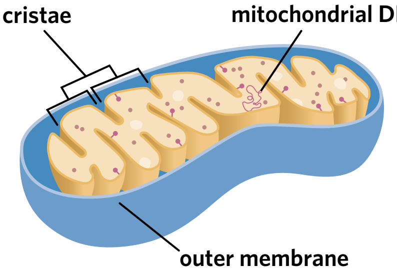
1 Identify the inputs and outputs of aerobic cellular respiration. (1 MARK)

2 Leigh disease often leads to an inability to gain weight. Identify which symptoms are related to the inability to gain weight and explain how they would cause this. (2 MARKS)

3 A common symptom of Leigh disease is the weakness of limbs, also known as peripheral neuropathy. Explain why this could occur. (2 MARKS)

The mitochondrion

Unlike most other organelles, mitochondria contain their own loop of DNA. These contain thirty-seven genes responsible for the healthy functioning of the mitochondria. The diagram shows some of the important structures found in the mitochondria.



Leigh disease can be caused by a mutation in one of 75 different genes, most of which play important roles in aerobic cellular respiration. Most of these genes are found in the nucleus but some of them are found in mitochondrial DNA, and mutations in these genes arise spontaneously in sperm or egg cells before a baby is conceived.

Mutations may also be caused by environmental factors known as mutagens. UV radiation, smoking, and alcohol are examples of common mutagens. The effect of mutations also drastically varies. 'Silent' mutations have no effect on an individual, whereas 'block' mutations in a sperm or egg cell can lead to life-changing diseases and miscarriages in foetuses. Luckily, eukaryotic organisms have developed molecules to proofread DNA and repair mutations. While mitochondrial DNA (mtDNA) has a much higher mutation rate than nuclear DNA, the importance of the genes encoded by mtDNA mean that mutations in coding regions are usually undesirable. Consequently, the coding regions of mtDNA tend to be highly conserved, meaning it mutates at a low rate.

4 State whether mitochondria are found in prokaryotes, eukaryotes, or both. (1 MARK)

5 Name another organelle apart from mitochondria or nucleus that also contains its own DNA, and explain why this organelle is/isn't found in an animal cell. (2 MARKS)

6 Scientists believe mitochondria may have initially survived as unicellular organisms similar to bacteria until they were engulfed by another larger organism. Outline two pieces of evidence that support this theory. (2 MARKS)

7 Explain why the inner membrane of mitochondria is folded. (1 MARK)

8 The mutation rate is the frequency of mutations in a section of DNA over a period of time. State whether nuclear DNA or mtDNA has a higher mutation rate. (1 MARK)

9 Explain whether DNA mutations can be repaired. (1 MARK)

Disease statistics

A study conducted by the Orphanet Journal of Rare Diseases followed a total of 130 patients with Leigh disease (Sofou et al., 2014). It was found that the median age of disease onset was seven months, with 80.8% presenting before two years of age. The table compares symptoms presented at the onset of the disease and throughout the course of the disease.

Symptom	Percentage of cohort presenting symptom at initial diagnosis (%)	Percentage of cohort presenting symptom throughout disease course (%)
Abnormal motor function	82.8	99.2
Abnormal ocular function	25.0	60.8
Feeding/sucking difficulties	14.1	45.4
Epileptic seizures	13.3	39.2
Failure to thrive	10.2	16.2

10 Complete the following table by matching the list of symptoms to their descriptions. Two have already been completed for you. (3 MARKS)

- Abnormal motor function
- Abnormal ocular function
- Feeding/sucking difficulties
- Epileptic seizures
- Failure to thrive

	Struggle to consume food or milk.
Epileptic seizures	An electrical disturbance in the brain that causes a behavioural change and fluctuations in the level of consciousness. Can be characterised by uncontrollable jerking of arms and legs.
	A child who struggles to put on weight and is significantly underweight.
	Unusual function of muscles, tendons, and ligaments, affecting movement and coordination.
Abnormal ocular function	Atypical function of the eyes affecting vision.

11 Explain what is meant by the statement 'the median age of disease onset was seven months.' (2 MARKS)

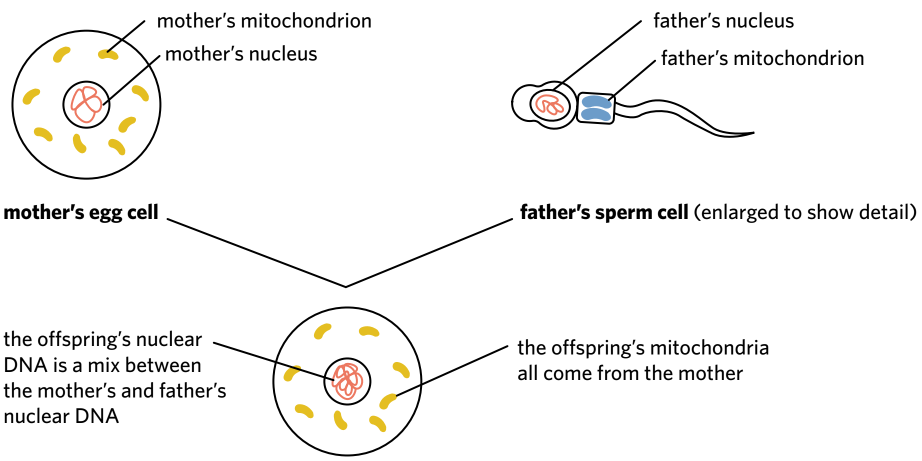
12 Identify which symptom affects the most patients at the initial diagnosis of Leigh disease. (1 MARK)

13 Identify which symptom affects the least patients as the disease progresses. (1 MARK)

14 Identify which symptom has the largest increase in incidence during the disease course. Use evidence from the table to support your answer. (2 MARKS)

Possible treatments

Unfortunately, a cure for Leigh disease is yet to be discovered. mtDNA is inherited from the mother, so Leigh disease caused by a mutation in mtDNA can be predicted by looking at the genetics of the mother.



Two controversial approaches may be used to prevent the inheritance of mitochondrial Leigh disease.

The first approach involves transferring the mother's nuclear DNA from one of her eggs into a donor egg without a nucleus but 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 allows for the father's sperm to fertilise the mother's egg. The nucleus of the fertilised egg is then transferred to a healthy, donor egg without a nucleus, ending in implantation into the mother's womb. These techniques were both first successfully completed in humans in 2016.

15 Suppose a doctor was consulting with a woman who had a mutation in a cellular respiration gene located in her mtDNA, resulting in late-onset Leigh disease. She and her husband wished to have a child but are considering the above two controversial approaches to ensure their child is healthy. If the doctor's top priority is to maximise the quality of life of their patient, which two ethical concepts would be most relevant? (1 MARK)

16 A group of scientists completed a study on comparing which treatment was more effective. Outline how the ethical concept of integrity should be applied in this study. (1 MARK)

CHAPTER 2 EXAM PRACTICE

30 min

Section A (6 MARKS)

Question 1 (1 MARK)

Which of the following would decrease the surface area to volume ratio of an object?

A reducing the physical size of the object

B increasing the volume of the object

C stretching an object

D flattening an object

Question 2 (1 MARK)

The genetic material of prokaryotic 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 3 (1 MARK)

The lysosome is responsible for the

A manufacturing of lipids.

B production of energy for the cell.

C destruction of toxins and cell waste.

D modification and packaging of protein molecules.

Adapted from VCAA 2011 Exam 1 Section A Q14

Question 4 (1 MARK)

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

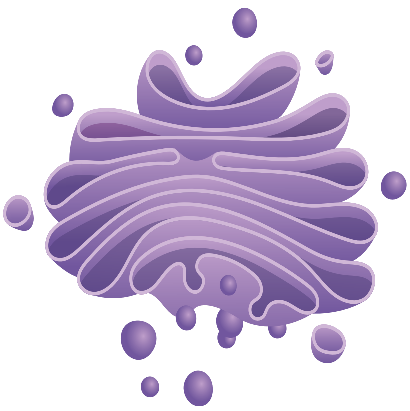


Image: LDarin/Shutterstock.com

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.

Adapted from VCAA 2011 Exam 1 Section A Q10

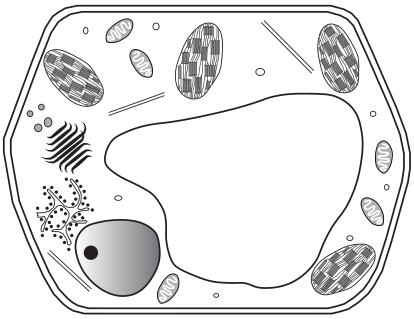
Question 5 (1 MARK)

Which organelle is the primary site of energy production in the cell?

A nucleus
B ribosome
C chloroplast
D mitochondria

Question 6 (1 MARK)

Consider the following cell.



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.

Section B (14 MARKS)

Question 7 (9 MARKS)

The diagram shows the structures of a cell.

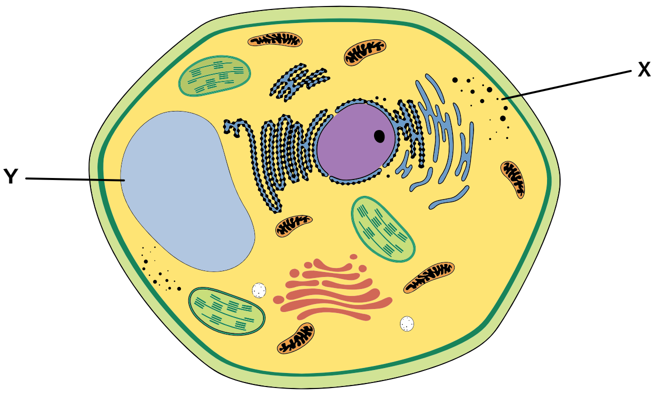


Image: Aldona Griskeviciene/Shutterstock.com

a State the three principles of cell theory. (1 MARK)
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. Explain how correct her statement is and state how this cell would be categorised. (3 MARKS)
d Consider structures X and Y.
   i Identify and outline the function of structure Y. (2 MARKS)
   ii Which structure, X or Y, would have a greater surface area to volume ratio? Justify your response. (1 MARK)

Adapted from VCAA 2012 Exam 1 Section B Q1

Question 8 (5 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:

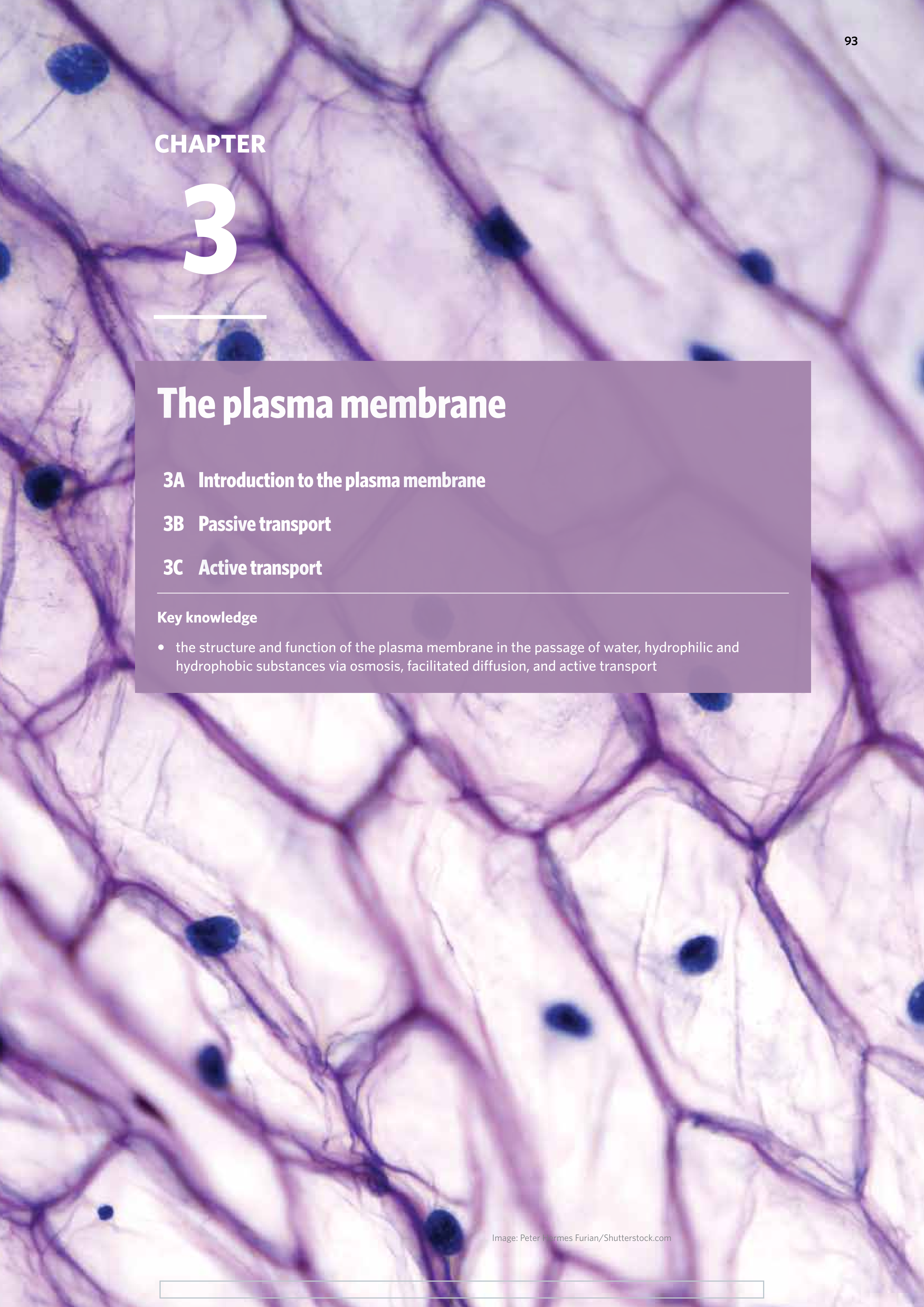
- cell wall
- ribosomes
- no nucleus
- chloroplasts
- circular DNA
- mitochondria
- one large vacuole
- plasma membrane

Looking through a microscope, scientists observed the organism divide the same way as bacteria. Additionally, it contained a flagellum which the organism used to move.

a What evidence supports the hypothesis that this organism is a living thing? (3 MARKS)

b Explain whether this organism contains membrane-bound organelles. (1 MARK)

c Name the process the newly discovered organism uses to reproduce. (1 MARK)



CHAPTER 3

The plasma membrane

Key knowledge

- the structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion, and active transport

Image: Peter Hermes Furian/Shutterstock.com

3A INTRODUCTION TO THE PLASMA MEMBRANE

Imagine that it is summer in Antarctica, and you are completely naked. You would get frostbite within an hour, then die after 2–3 hours. But other animals – like fish and seals – seem to manage these cold temperatures with ease. Even the tips of their fins don't freeze! What is so special about their cells that allows them to handle sub-zero temperatures?

A seal feeling smug about how well it deals with the cold

Image: Tarpan/Shutterstock.com

Lesson 3A

In this lesson you will learn that the plasma membrane is a phospholipid bilayer embedded with proteins, cholesterol, and carbohydrates.

◀ *Prerequisite knowledge* | *Future applications* ▶

Years 7–10
All living things are made of cells, and all cells have plasma membranes.

Lesson 2C
The surface area of cells is determined by the surface area of the plasma membrane.

Lessons 3B & 3C
Substances are actively and passively transported across the plasma membrane.

Year 12
Proteins in the plasma membrane are essential for signal transduction during the immune response.

Study design dot point

- the structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion and active transport

Key knowledge units

The function of the plasma membrane	1.1.4.1
The structure of the plasma membrane	1.1.4.2
The fluid mosaic model	1.1.4.3

The function of the plasma membrane 1.1.4.1

OVERVIEW

The plasma membrane controls the transport of substances in and out of the cell.

THEORY DETAILS

All cells have a **plasma membrane**. It is the thin boundary of the cell made up of lipids that separates the **intracellular** and **extracellular** environments. It is **selectively permeable**, which means that only particular molecules can enter and exit the cell. Thanks to the plasma membrane, cells can have a specialised internal environment.

plasma membrane the phospholipid bilayer and embedded proteins which separate the intracellular environment from the extracellular environment. Also known as **cell membrane**

intracellular inside a cell

extracellular outside a cell

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

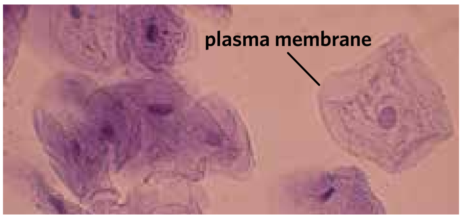


Figure 1 The plasma membrane on animal cells can be visualised as the outer edge of the cell, however individual components of the plasma membrane are too small to see with a light microscope.

The structure of the plasma membrane 1.1.4.2

OVERVIEW

The plasma membrane is a phospholipid bilayer embedded with proteins, carbohydrates, and cholesterol. Each molecule fulfils a specific function in the membrane.

THEORY DETAILS

Phospholipids

The main components of the plasma membrane are **phospholipids** (Figure 2). 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 and fatty acid tails are chemically very different from each other.

The phosphate head is:

- made of a glycerol and phosphate group
- negatively charged, making it **hydrophilic** ('water-loving') and **polar**.

The two fatty acid tails are:

- made of long chains of carbon and hydrogen
- uncharged, **hydrophobic** ('water-fearing'), and **nonpolar**.

The phosphate heads are hydrophilic so they are attracted to water which is a polar substance. Therefore, they are attracted to, and oriented towards, the aqueous intra- and extracellular environments. The fatty acid tails orient themselves away from the intra- and extracellular fluid to form the middle portion of the bilayer (Figure 2).

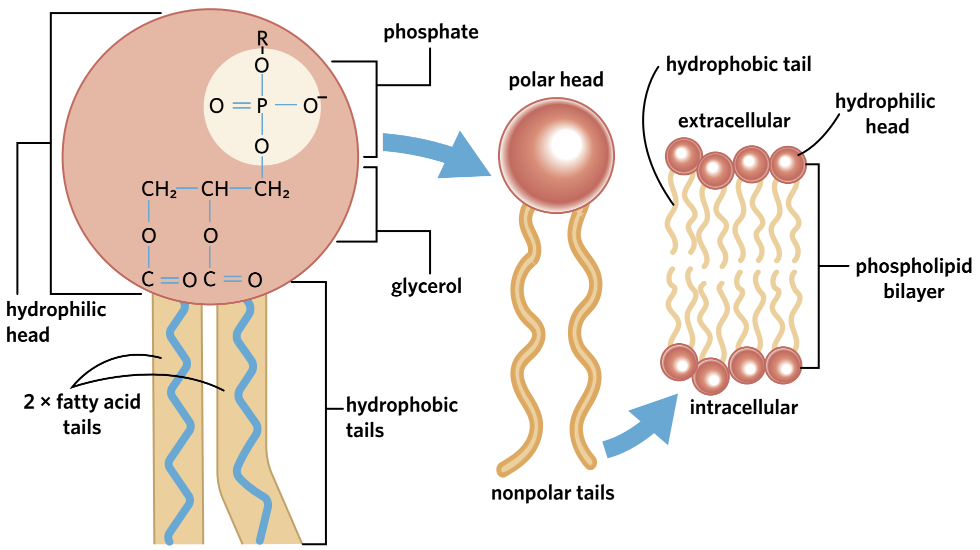


Figure 2 The structure of a phospholipid and the phospholipid bilayer

Because phospholipids have both hydrophilic and hydrophobic parts, they are **amphipathic** molecules. This amphipathic nature makes the plasma membrane stable: the fatty acid tails are repelled from water whilst the phosphate heads are attracted to water, so a stable bilayer naturally forms. This is shown in Figure 3 as phospholipids create a bilayer around water, a polar substance. This is due to the nature of hydrophilic and hydrophobic interactions. Phospholipids create a monolayer around oil, however, since oil is a nonpolar substance

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

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

hydrophobic having a tendency to repel and be insoluble in water

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

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

Memory device

Remember that *'like dissolves like'*. This means that:

- polar molecules are attracted to and dissolve in polar substances
- nonpolar molecules are attracted to and dissolve in nonpolar substances
- nonpolar molecules do not interact with polar molecules.

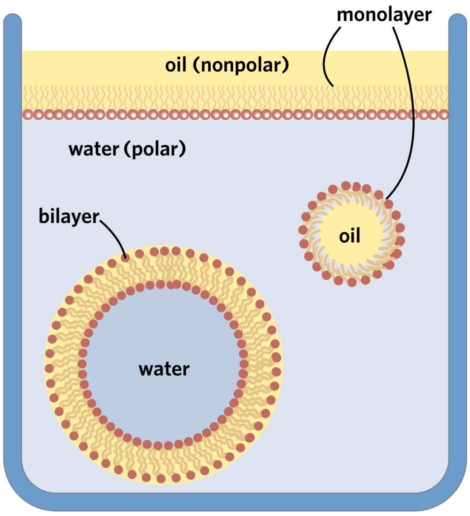


Figure 3 The natural formation of phospholipids in hydrophilic and hydrophobic environments.

Proteins, carbohydrates, and cholesterol

Proteins, **carbohydrates**, and **cholesterol** are attached to and embedded in the phospholipid bilayer. Their structures and functions are summarised in Table 1 and Figure 4.

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

Membrane molecule	Structure	Functions
Proteins	**Integral protein** – proteins that are a permanent part of the membrane **Transmembrane protein** – integral proteins that span the entire bilayer **Peripheral protein** – are temporarily attached to the plasma membrane	Transport – channels or pumps that control what enters and exits the cell, making the plasma membrane selectively permeable Catalysis – speeding up chemical reactions with the help of a protein group called enzymes 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
Carbohydrates	Usually in chains that extend 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
Cholesterol	A lipid steroid that embeds itself between the fatty acid tails of the phospholipid bilayer in animal cells. Cholesterol is replaced with similar molecules in other kingdoms, but all are functionally similar	Regulates the fluidity of the membrane. At higher temperatures, the cholesterol keeps phospholipids bound together. At lower temperatures, cholesterol disrupts the fatty acid tails, stopping phospholipids from becoming a solid boundary

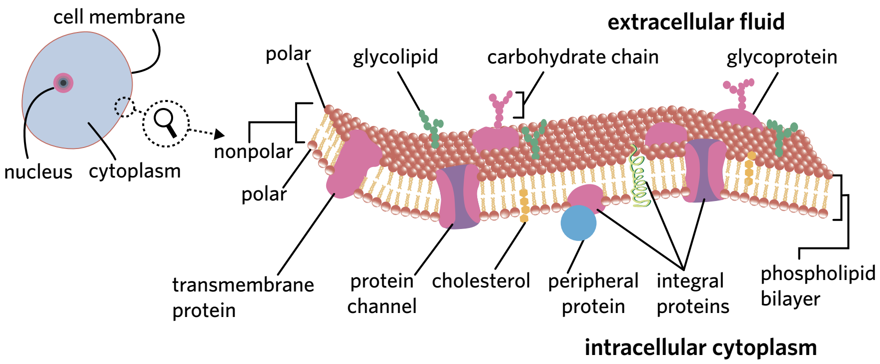


Image: Kallayanee Naloka/Shutterstock.com

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

protein a class of biomacromolecule made of amino acid monomers folded into a 3D shape, consisting of carbon, hydrogen, oxygen, nitrogen, and sometimes sulphur

carbohydrate a class of biomacromolecule made from monosaccharide monomers consisting of carbon, hydrogen, and oxygen. Also known as **saccharides** or **sugars**

cholesterol a steroid-alcohol that regulates fluidity in plasma membranes

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

transmembrane protein an integral protein that spans the entire plasma membrane

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

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

glycolipid a phospholipid bound to a carbohydrate

glycoprotein a protein bound to a carbohydrate

The fluid mosaic model 1.1.4.3

OVERVIEW

The fluid mosaic model explains that 1) molecules that make up the membrane are not held static in one place and 2) many different types of molecules are embedded in the plasma membrane.

THEORY DETAILS

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

The 'mosaic' component of the model comes from the proteins and carbohydrates embedded in the membrane (Figure 6). These molecules can also move fluidly around the bilayer, like ice floating in a glass of water. Like looking at mosaic art that is made up of many different tiles, scientists imagine that they would see a variety of molecules of different shapes and sizes when they look down at a plasma membrane.

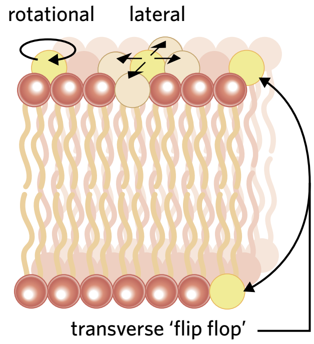


Figure 5 The ways that phospholipids can move in a fluid plasma membrane

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

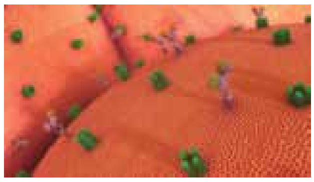


Image: sciencepics/Shutterstock.com

Figure 6 Proteins (green) and carbohydrates (purple) embedded in a membrane (red) like a mosaic

Theory in context

MOLECULES THAT REGULATE MEMBRANE FLUIDITY

Fluctuating temperatures can affect membrane fluidity. When it is hot the kinetic energy of molecules increases, so the fluidity of the plasma membrane increases. This means that phospholipids are at risk of drifting apart, creating holes in the membrane. Meanwhile, in cold environments, the plasma membrane may become too stiff and impair the transport of substances into and out of the cell. Cells of organisms in extreme environments may alter the types of fatty acids and amount of cholesterol to regulate membrane fluidity (Figure 7 and Table 2). Fatty acids can be saturated like those that make up butter, which is solid at room temperature or unsaturated like those that make up oil, which is liquid at room temperature.

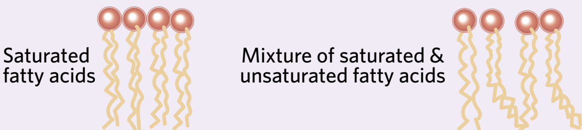


Figure 7 Saturated (left) fatty acids mean phospholipids can pack tightly, unsaturated (right) fatty acids on phospholipids can lead to more fluid membranes.

Table 2 The role of cholesterol and fatty acid type in regulating membrane fluidity

	Hot environment	**Cold environment**	**Explanation**
Amount of cholesterol	Lots	Lots	Cholesterol has large hydrophobic regions which can increase the nonpolar interactions between fatty acid tails in hot environments, keeping the fatty acid tails from drifting apart. However, cholesterol also takes up room in the membrane, preventing phospholipids from packing too tightly when it's cold.
Type of fatty acids	More **saturated**	More **unsaturated**	Unsaturated fatty acids have tails with 'kinks' due to double and triple bonds between carbon atoms. The kinks push phospholipids away from each other, increasing fluidity in cold environments. Phospholipids with saturated fatty acids can pack tightly, as carbons are only bound by single bonds with no kinks (Figure 7).

saturated a fatty acid chain with only single bonds between carbon atoms

unsaturated a fatty acid chain with at least one double or triple bond between carbon atoms

Theory summary

The plasma membrane is the selectively permeable barrier between the cell and its environment. 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 membrane fluidity, carbohydrates attach to phospholipids and proteins which play a role in cell signalling and adhesion, and proteins are involved in transport and enzymatic reactions. The structure of the plasma membrane is described by the fluid mosaic model, in which a myriad of proteins and other molecules are embedded within the membrane and can freely move around.

Fish and seals may deal with the cold better than humans because their phospholipids are composed of more unsaturated fatty acids – this creates 'kinks' in the tails, pushing individual phospholipid molecules apart from each other. This adaptation enables organisms' plasma membranes to retain fluidity and functionality at cold temperatures. Some organisms that are adapted to cold environments may also have more cholesterol in their membranes to prevent hardening. This maintains the fluidity of the plasma membrane.

3A QUESTIONS

Theory review questions

Question 1

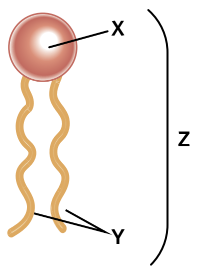
The plasma membrane of cells

A controls the movement of substances in and out of the cells.

B helps cells absorb light.

Question 2

Label the parts of the molecule.



Question 3

Fill in the blanks with the following terms. Terms may be used multiple times or not at all.

- polar/hydrophilic
- polar/hydrophobic
- nonpolar/hydrophilic
- nonpolar/hydrophobic

Phospholipids have a __________ phosphate head that orientates towards the watery extracellular and intracellular fluid. They are also made up of two __________fatty acid tails that comprise the interior of the plasma membrane.

Question 4

Label the parts of the plasma membrane from the list of terms.

- glycolipid
- cholesterol
- glycoprotein
- carbohydrate
- integral protein
- protein channel
- peripheral protein
- phospholipid bilayer
- transmembrane protein

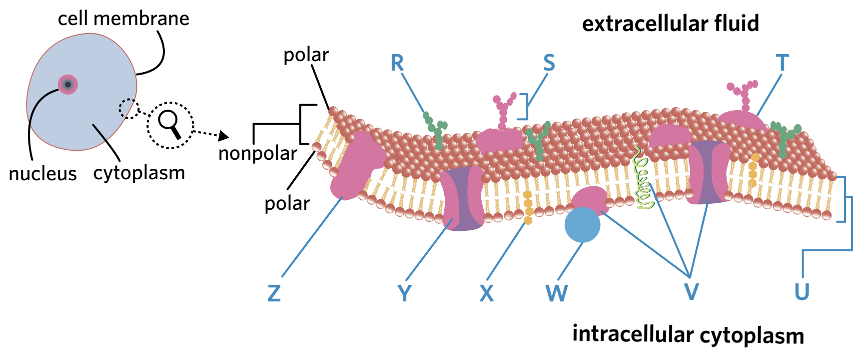


Image: Kallayanee Naloka/shutterstock.com

Question 5

The molecules that are lipid-based and regulate fluidity of the membrane are

A glycolipids.

B cholesterol.

C integral proteins.

Question 6

Which of the following describes the structure and function of carbohydrates in the plasma membrane? *(Select all that apply)*

I they are involved in signalling and adhesion

II they can be part of glycolipids or glycoproteins

III they can be attached to proteins or phospholipids

IV they are involved in regulating fluidity of the plasma membrane

Question 7

Match the protein type to its definition.

Protein type	Definition
• integral	**I** __________ temporary proteins that attach to the outside of the membrane
• transmembrane	**II** __________ proteins that are a permanent part of the membrane
• peripheral	**III** __________ integral proteins that span from the inside to the outside of the bilayer

Question 8

The plasma membrane is said to be fluid in structure because

A the phospholipids within the bilayer move laterally, transversely, and rotationally within the structure.

B there are many different molecules embedded in the membrane.

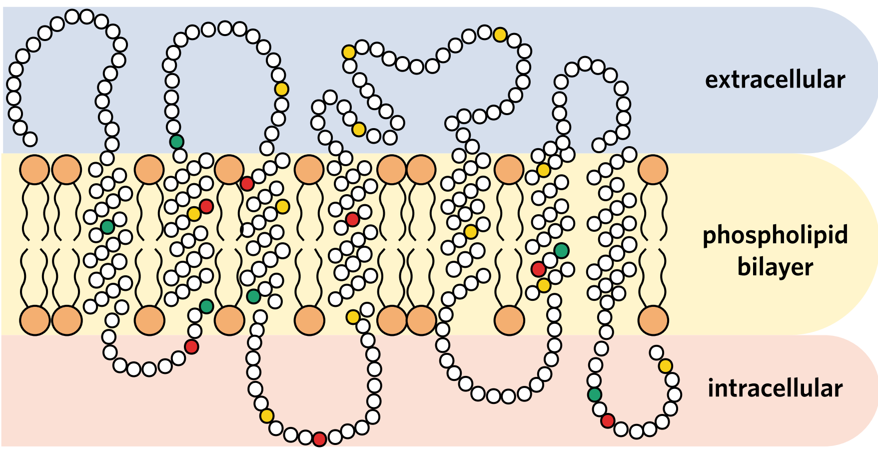
SAC skills questions

Case study analysis

Use the following information to answer Questions 9–13.

Scientists are beginning to understand how humans and other animals detect smells. In the nose, an odour molecule dissolves in the nasal mucous that surrounds olfactory receptors. These receptors are embedded to the plasma membrane of nasal tissue that sits behind each nostril. The receptors consist of chains of amino acids anchored in the plasma cell membrane that transverse it seven times as shown in the diagram. Stimulating a receptor leads to changes to the cell, which in turn leads to the generation of a neural signal to the brain.

Each receptor can detect several related scents that pass through nasal mucus, and each scent can typically activate several olfactory receptors. Scientists think humans have around 400 different scent receptors, and depending on the combination of receptors stimulated, this can lead to the detection of more than one trillion unique odours.



Question 9

According to the case study, the correct pathway for scent detection is

A odour molecules dissolve in nasal mucous → olfactory receptor stimulated → neural signal generated → brain recognises scent

B brain recognises scent → olfactory receptor stimulated → neural signal generated

Question 10

What is meant by the term 'olfactory receptor' in this case study?

A the nose

B a cell that detects scents

C a transmembrane protein that detects scents

Question 11

The odour molecules for garlic and onion will

A only stimulate one odour receptor each.

B always stimulate different odour receptors.

C stimulate some of the same odour receptors and some different odour receptors.

Question 12

The olfactory receptor is 'transmembrane' because

A it is embedded in the plasma membrane of cells.

B it spans the entire width of the phospholipid bilayer.

Question 13

Parosmia is a smell disorder that causes people to have a distorted sense of smell. For instance, the odour of freshly brewed coffee may instead smell overpowering and rotten instead of rich and chocolatey. Parosmia may be caused by

A an absence or damage to some olfactory receptors.

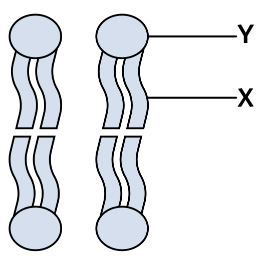
B an absence of all olfactory receptors.

Exam-style questions

Within lesson

Use the following information to answer Questions 14–16.

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



Question 14 (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 15 (1 MARK)

The structure labelled Y in the molecule is

A a cell.

B a protein.

C a phosphate head.

D a monosaccharide.

Adapted from VCAA 2015 Section A Q2

Question 16 (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.

Question 17 (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 18 (6 MARKS)

Consider the diagram of a plasma membrane.

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

b Identify the chemical nature of Molecule Q. (1 MARK)

c Explain why scientists describe the plasma membrane as a 'fluid mosaic'. (1 MARK)

Adapted from VCAA 2011 Exam 1 Section B Q4a

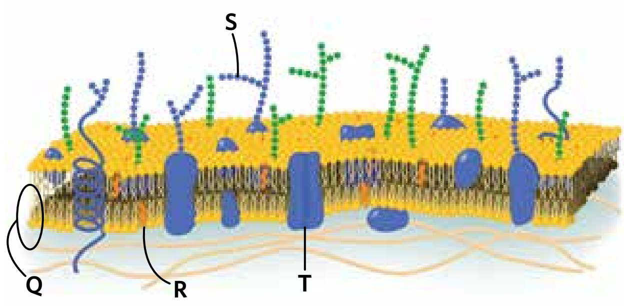


Image: JamiliaMarini/Shutterstock.com

Multiple lessons

Question 19 (1 MARK)

Which organelle is not surrounded by a phospholipid bilayer?

A ribosome

B Golgi body

C mitochondria

D smooth endoplasmic reticulum

Question 20 (1 MARK)

Which of the following options is correct?

A Cells with a high plasma membrane surface area compared to cytosol volume are more effective at exchanging materials with their environment.

B Cells with a high plasma membrane surface area compared to cytosol volume are less effective at exchanging materials with their environment.

C Cells with a low plasma membrane volume compared to cytosol surface area are more effective at exchanging materials with their environment.

D Cells with a high plasma membrane volume compared to cytosol surface area are more effective at exchanging materials with their environment.

Question 21 (1 MARK)

Different types of cells and organelles have different membranes. In particular, the composition and amount of proteins in a cell or organelle's membrane changes depending on the cell/organelle type. The table shows the ratio of protein to lipid in membranes of various cell/organelle types, as well as the maximum membrane surface that doesn't have any proteins attached (i.e. the amount of the cell surface that is pure lipid bilayer).

Membrane	Ratio of protein : total lipid	Maximum membrane surface that is pure lipid bilayer %
Red blood cell plasma membrane	1.50	67
Myelin cell plasma membrane	0.28	98
Endoplasmic reticulum	0.90	83
Inner membrane of mitochondria	3.55	40
Outer membrane of mitochondria	1.22	72

According to the table, the cell/organelle type with the largest percentage of phospholipid surface area is

A myelin.

B red blood cells.

C endoplasmic reticulum.

D the inner membrane of the mitochondria.

Key science skills and ethical understanding

Question 22 (6 MARKS)

In 1925, Evert Gorter and François Grendel performed important experiments that have helped scientists to determine the structure of the cell membrane. Gorter and Grendel already knew from previous experiments that cell membranes were made of lipids, but they weren't sure how many lipids were involved. To find out, they isolated some red blood cells and measured their surface area. Next, they used a Langmuir-Blodgett trough to determine how large an area the lipids could cover.
They found that the lipids could cover a surface area approximately two times the size of the red blood cell surface area.

a Suggest a reason why Gorter and Grendel found that lipids covered double the surface area of the red blood cell. (1 MARK)

b Gorter and Grendel chose red blood cells to test because these cells have no internal organelles or nucleus.
Explain why this makes red blood cells a good choice for this experiment. (2 MARKS)

c Gorter and Grendel made a few mistakes during their experiment. First, they made a calculation error when determining the surface area of red blood cells. Additionally, their method did not allow them to accurately extract all the lipids from the cells. Identify the two types of errors that were made. (2 MARKS)

d Gorter and Grendel provided a detailed method of their experiment and reported their mistakes honestly. Which ethical concept did the two scientists uphold? (1 MARK)

3B PASSIVE TRANSPORT

It's your school's athletics carnival, and disappointingly, very few other Year 11s in your house have shown up. You accidentally make eye contact with the Vice House Captain, and before you know it, your name is down for ten races – including the 1 500 m and 3 000 m.

You feel rather disgruntled, but the Vice House Captain reassures you by showing you a range of 'sports drinks' for people who compete in more than six events. Some of the bottles say 'isotonic', others say 'hypotonic', and still more say 'hypertonic'. What drink type will rehydrate you the most? Which will give you the most energy? And which will just make you feel sick?

Image: Roger Brown Photography/ Shutterstock.com

Lesson 3B

In this lesson you will learn how molecules are transported across the plasma membrane without using energy.

◀ *Prerequisite knowledge*

Chapter 2
The plasma membrane is the key structure that regulates transport into and out of the cell.

Lesson 3A
The polarity of the plasma membrane determines which molecules can diffuse freely into and out of the cell, and which require the aid of protein channels or pumps.

Future applications ▶

Chapters 5 & 6
Passive transport across membranes is fundamental to tissue and organ function, including during transpiration in plants and the creation of urine in animals.

Year 12
Concentration gradients across membranes help generate energy in the processes of aerobic cellular respiration and photosynthesis.

Study design dot point

- the structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion, and active transport

Key knowledge units

Diffusion	1.1.4.4
Facilitated diffusion	1.1.4.5
Osmosis	1.1.4.6

Diffusion 1.1.4.4

OVERVIEW

Diffusion is the movement of particles down their concentration gradient. Nonpolar and small molecules can freely diffuse across the plasma membrane.

THEORY DETAILS

Transport across membranes

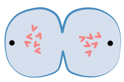
In lesson 3A, we learned that a cell's **plasma membrane** is **selectively permeable**. This means that only certain substances can cross it, depending on their polarity/charge, size, and concentration on either side of the membrane. This is important so that the **cytosol** can preserve a specialised internal environment separate from the extracellular fluid.

There are several ways that molecules can cross the plasma membrane. In this lesson, we focus on the methods that do not require a cell to use energy – termed **passive transport**. In lesson 3C, we will explore the methods that require a cell to use energy – termed **active transport**.

plasma membrane the phospholipid bilayer and embedded proteins which separate the intracellular environment from the extracellular environment. Also known as cell membrane

selective permeability a property of cell membranes that ensures only specific substances pass across them. Also known as semipermeable

cytosol the aqueous fluid that surrounds the organelles inside a cell



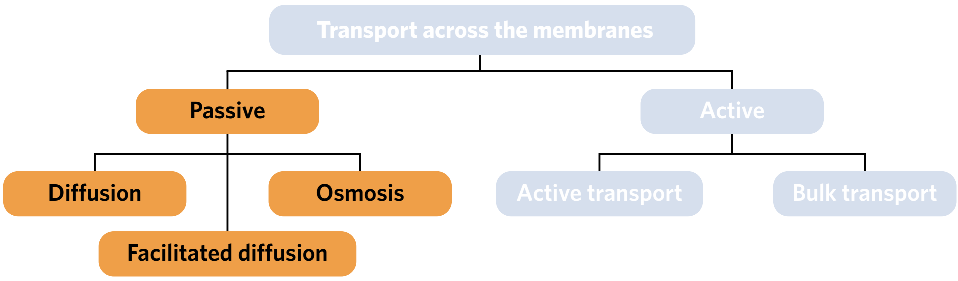


Figure 1 The methods of selectively transporting molecules across the plasma membrane

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

active transport movement of molecules across a semipermeable membrane that requires energy

Simple diffusion

Diffusion occurs when molecules move from an area of high concentration to an area of low concentration (or 'down their **concentration gradient**'). This occurs due to the **kinetic energy** stored inside each molecule, which causes them to randomly move around and bounce off each other. Over time, this random movement leads to an even dispersion of particles in an area. As shown in Figure 2, dissolved molecules (the **solute**) can diffuse through a liquid such as water (the **solvent**).

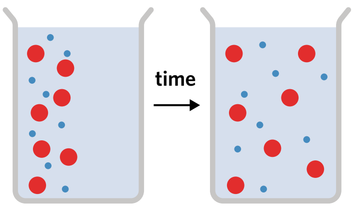


Figure 2 Diffusion of particles through a glass of water. Initially, all the particles are located in the top left corner, but they diffuse throughout the entire glass over time.

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

concentration gradient the difference in solute concentration between two adjacent areas

kinetic energy the energy a particle or body possesses due to motion

solute a substance dissolved in the solvent

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

Instead of being completely impermeable to all types of molecules like a boundary shown in Figure 3a, the plasma membrane is selectively permeable – so some molecules can diffuse through (Figure 3b).

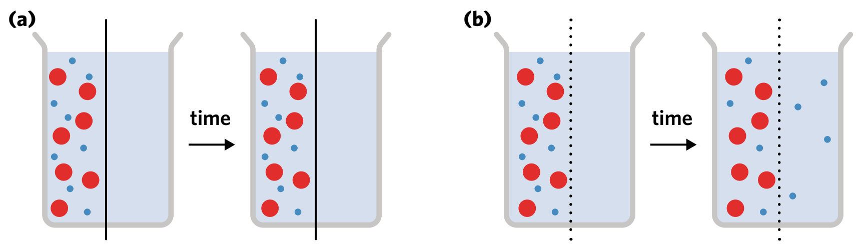


Figure 3 **(a)** Impermeable boundary prevents the diffusion of molecules, compared to **(b)** a selectively permeable membrane which enables the diffusion of molecules.

What types of molecules can freely diffuse across the plasma membrane?

Features that allow a molecule to freely diffuse across the plasma membrane include:

- Polarity – **nonpolar**, uncharged, or **hydrophobic** molecules (e.g. O_2, H_2, CO_2, lipids) can cross the membrane because most of the plasma membrane is nonpolar (in the form of fatty acid tails), and nonpolar molecules have an affinity for each other.
- Size – small molecules like water are able to slip through the lipids in the phospholipid bilayer. However, if a small molecule is highly charged – like an ion (e.g. H^+, K^+, Cl^-) – then it still can't cross the membrane by simple diffusion.

Therefore, only small, nonpolar molecules can freely diffuse across the phospholipid bilayer. Large and **hydrophilic** molecules, such as ions, amino acids, proteins, glucose, or nucleic acids however, will simply bounce off the membrane and be unable to diffuse through. This leads to a higher concentration of these molecules on one side.

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

hydrophobic having a tendency to repel and be insoluble in water

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

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

Will the nonpolar, small molecules diffuse into or out of the cell?

Molecules diffuse into or out of the cell depending on their concentration on 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, then O_2 will diffuse out of the cell and into the extracellular fluid. As these small, nonpolar molecules always diffuse from areas of high concentration to areas of low concentration, we say they are moving 'down' their concentration gradient.

Lesson link

Go back to ***lesson 3A*** if you can't remember the terms hydrophobic, hydrophilic, **polar,** and nonpolar.
You should understand that because the plasma membrane is mostly hydrophobic, hydrophobic molecules are easily transported across.
In contrast, hydrophilic molecules cannot diffuse straight across the membrane as they are repelled by the hydrophobic fatty acid tails.

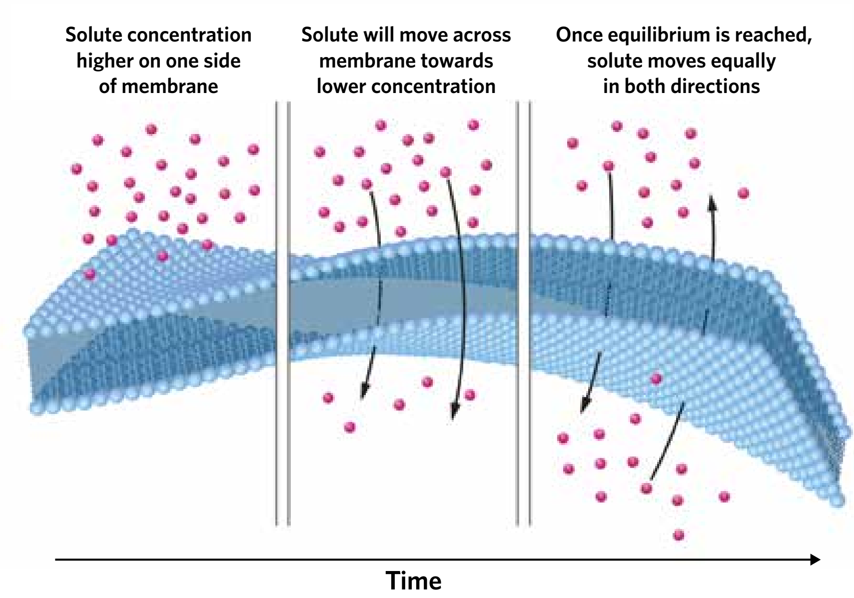


Image: Aldona Griskeviciene.Shutterstock.com

Figure 4 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.

Memory device

Diffusion doesn't just occur in cells. 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. So the expression 'he who smelt it dealt it' is true – the dealer will be the first person to smell their perfume before it diffuses throughout the room.

Image: MBLifestyle/Shutterstock.com

Figure 5 Gases spread out evenly throughout a room over time.

Facilitated diffusion 1.1.4.5

OVERVIEW

Molecules that are too large or too charged to freely cross the plasma membrane can use a membrane protein, such as a protein channel, to move down their concentration gradient into or out of the cell. This process is called facilitated diffusion.

THEORY DETAILS

Facilitated diffusion is the passive movement of molecules down their concentration gradient through a membrane-bound protein. This allows large and/or polar molecules like glucose and ions to move between the intra- and extra-cellular environments via the use of a **protein channel** or a **carrier protein**.

- Protein channels are pores or holes in the membrane that let a specific substance through.

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

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

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

- Carrier proteins bind to the substance that is being transported and undergo a **conformational change** to push the substance down its concentration gradient 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 transport. 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.

conformational change a change in the three-dimensional shape of macromolecules such as proteins

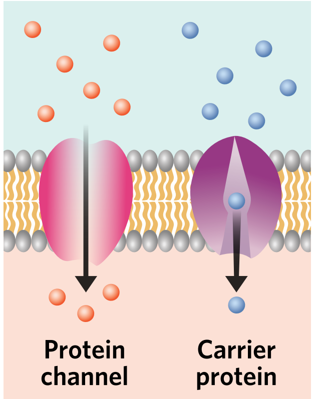


Figure 6 Facilitated diffusion using protein channels and carrier proteins

Osmosis 1.1.4.6

OVERVIEW

Osmosis is the diffusion of water from an area of low solute (high solvent) concentration to an area of high solute (low solvent) concentration.

THEORY DETAILS

Osmosis is the diffusion of water across a selectively permeable membrane from areas of low solute concentration to areas of high solute concentration. Water molecules can move through the phospholipid bilayer despite being hydrophilic due to how extremely small they are, water movement can be increased by protein channels known as aquaporins.

Osmosis is important as the selectively permeable nature of the membrane means that 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 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 down their concentration gradient out of the cell through facilitated diffusion, but it is usually easier for water to cross the membrane.

In the example above, there is a higher concentration of solute (sugar molecules) inside the cell compared to outside the cell. When we describe differences in solute concentrations between two compartments, we use the term **tonicity** (Figure 7). There are three different types of tonicity that can characterise a solution:

- **hypertonic** solutions have comparatively higher solute concentrations, so water moves into a hypertonic solution from adjacent areas with lower solute concentrations.
- **isotonic** solutions have equal solute concentrations, so there is no net movement of water. It's important to note that there is still movement of water into and out of a compartment, but the rate of water moving in is equal to the rate of water moving out so the net movement is zero.
- **hypotonic** solutions have comparatively low solute concentrations, so water moves from a hypotonic solution into adjacent areas with a higher solute concentration.

osmosis the passive transport of a solvent (typically water) through a semipermeable membrane from a region of low solute (high solvent) to a region of high solute (low solvent)

tonicity a measure of the relative concentration of solutes on either side of a semipermeable membrane, described as hypertonic, hypotonic, or isotonic

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

isotonic describes a solution with the same solute concentration as another solution

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

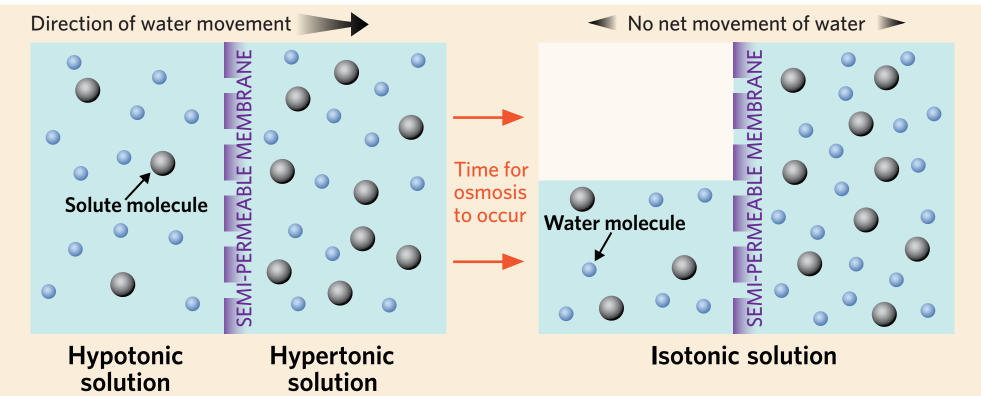


Figure 7 A model of osmosis. Note the movement of water from a hypotonic solution into a hypertonic solution, which over time will create two isotonic solutions.

Memory device

At a children's birthday party, if the red cordial is super concentrated, then the kids are going to become hyperactive. Therefore, the solution that has a high concentration of solutes is hypertonic.

Image: Christin Lola/Shutterstock.com

Figure 8 The effects of too much red cordial on children

The effect of tonicity on cells

The tonicity of solutions can impact cell size. If a plant cell cytosol is hypertonic compared to extracellular fluid, water will move into the cell and cause it to swell and become **turgid**. The cell will stay turgid (rather than burst) due to the presence of a cell wall.

turgid describes plant cells that are swollen and firm from water uptake

When water moves out of a plant cell, which happens if the cell is hypotonic compared to the extracellular fluid, the cell shrinks and becomes **plasmolysed**. As animal cells don't have cell walls, when they are placed in hypotonic solutions their volume can increase until they **lyse**.

plasmolysed describes plant cells with weak and sagging plasma membranes from water loss

lyse to cause a cell plasma membrane to burst or break

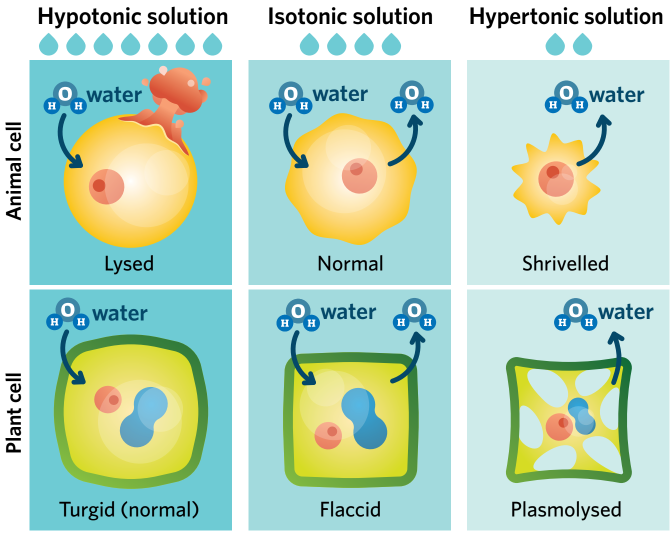


Image: VectorMine/Shutterstock.com

Figure 9 The effect of tonicity on animal and plant cells

Theory in action

Check out scientific investigation 3.1 to put this into action!

Lesson link

Clearly, it's important for cell survival to make sure your body fluids are neither too concentrated nor too watery! In ***lesson 6A***, you'll learn about how your body finds this 'Goldilocks zone' to regulate water balance.

Regulating tonicity and osmosis is biologically very important. For example, high turgor pressure in plant stems prevents the plant from wilting. Additionally, if you have ever been placed on a drip in hospital, you are given a saline solution to stay hydrated – not pure water. This saline solution is isotonic to our cells, ensuring that the cells in your blood do not shrivel or lyse.

Theory summary

Table 1 A summary of the types of passive transport

Passive transport type	Molecules transported	Direction of travel	Protein required?	Energy requirement
Diffusion	nonpolar/hydrophobic, small molecules e.g. oxygen, carbon dioxide	down concentration gradient	No	None
Facilitated diffusion	polar/hydrophilic, large molecules e.g. ions, glucose, amino acids	down concentration gradient	Yes	None
Osmosis	water	from hypotonic to hypertonic solution	Sometimes (aquaporins)	None

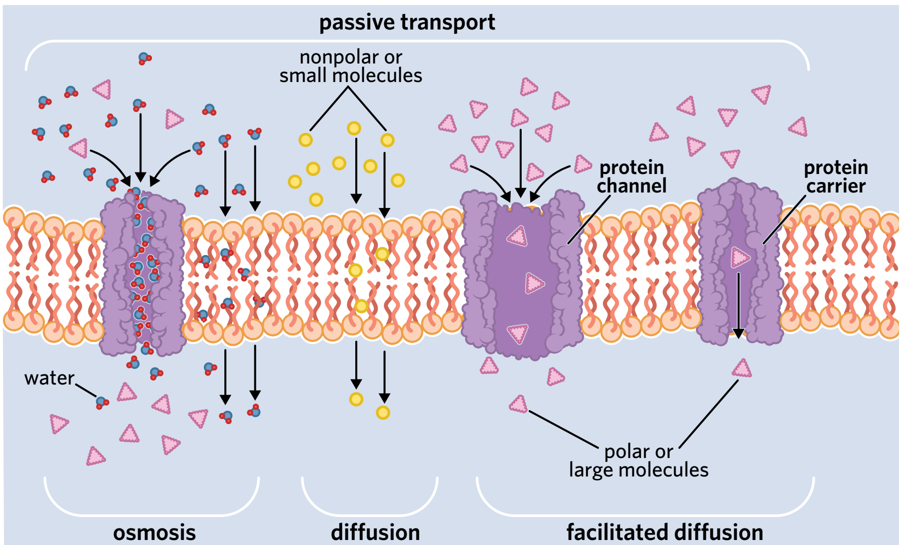


Figure 10 The three different processes of passive transport

Each of those sports drinks has a different concentration of solutes relative to your blood, which will affect how easily you rehydrate and the amount of energy you will get from the drink.

Hypotonic – these drinks have a lower concentration of solutes than your blood, so water moves from your gut and into your blood easily, rehydrating you quickly. These drinks are great for days when you do lots of exercise.

Isotonic – these drinks have the same concentration of solutes as your blood, so you won't rehydrate as quickly as you would with a hypotonic drink. You might, however, get some sugars for energy in these drinks.

Hypertonic – these drinks have a higher concentration of solutes than your blood. They can cause dehydration as they don't let water easily diffuse from your gut into your bloodstream, but are great if you need lots of sugars for more energy.

Unfortunately for this athlete it doesn't matter which drink he chooses because sports drinks aren't absorbed through the eye/nose.

Image: PeskyMonkey/Shutterstock.com

3B QUESTIONS

Theory review questions

Question 1

Passive transport involves the movement of molecules

A down their concentration gradient, without the cell using energy.

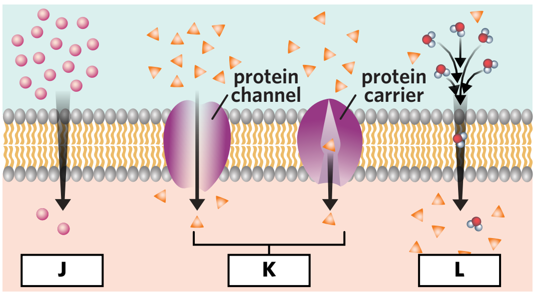
B against their concentration gradient, without the cell using energy.

C down their concentration gradient, requiring the cell to use energy.

D against their concentration gradient, requiring the cell to use energy.

Question 2

Label processes J, K, and L in the diagram.



Question 3

Fill in the blanks in the following sentences.

Simple diffusion involves small, __________ molecules moving __________their concentration gradient across the plasma membrane. In contrast, __________ involves large or __________ molecules moving __________ their concentration gradient through channel __________.

Question 4

Which of the following statements about osmosis are true? (*Select all that apply*)

I Water moves from regions of low water concentration to high water concentration.

II Water moves from areas of high solute concentration to low solute concentration.

III Water moves from areas of low solute concentration to high solute concentration.

IV Water moves from hypertonic regions to hypotonic regions.

V Water moves from hypotonic regions to hypertonic regions.

Question 5

Red blood cells were placed in solutions M, N, and O, and changes in their shape and size were observed over time. Label the tonicity of each solution from the list of terms.

- hypertonic
- isotonic
- hypotonic

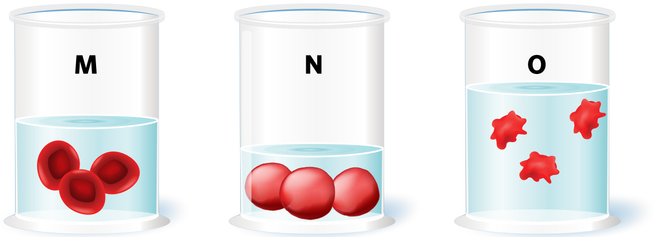


Image: Designua/Shutterstock.com

Question 6

Match the type of passive transport to the description. Terms may be used multiple times or not at all.

Type of passive transport

- diffusion
- osmosis
- facilitated diffusion

Description

I __________ hydrophobic molecules move this way

II __________ energy is not required to move molecules this way

III __________ protein carriers or channels are required

IV __________ direction of movement depends upon the concentration of solutes

V __________ hydrophilic molecules move this way

SAC skills questions

Scientific methodology comparison

Use the following information to answer Questions 7–12.

Cystic fibrosis is an inherited disease that affects nearly 3 500 Australians (Ruseckaite et al., 2017). It is caused by malfunctions in the CFTR protein channel. When working properly, CFTR controls the facilitated diffusion of chloride across membranes. When it doesn't work, CFTR is unable to help move chloride to the cell surface. Without the chloride to attract water out of the cell via osmosis, mucus in organs like the lungs and guts becomes thick and sticky. This can lead to difficulties in breathing and a high risk of lung infection. As the average life expectancy for a person born with cystic fibrosis is around 40 years old, many scientists are researching ways to improve the quality and length of life.

Researchers wanted to test if a particular treatment improved lung function in people with cystic fibrosis. The treatment involved inhaling 7% hypertonic salt (saline) solution twice daily. The standard salt concentration inside cells is 0.9%.
Two methods were proposed:

Method 1

- one group of 100 people with stable cystic fibrosis, where individuals inhale 4 mL of 7% saline solution twice daily for 48 weeks
- a second group of 100 people with stable cystic fibrosis, where individuals inhale 4 mL of 0.9% saline solution twice daily for 48 weeks.

Method 2

- one group of 100 people with stable cystic fibrosis, where individuals inhale 4 mL of 7% saline solution twice daily for 48 weeks
- a second group of 100 people without cystic fibrosis, where individuals inhale 4 mL of 0.9% saline solution twice daily for 48 weeks.

For both methods, lung function and instances of bacterial infection were measured before, after, and during the 48 week trial.

Question 7

CFTR is

A an acronym for the disease cystic fibrosis.

B a protein channel involved in facilitated diffusion.

C a protein channel only found in people without cystic fibrosis.

Question 8

Inhalation of hypertonic saline solution may help people with cystic fibrosis because

A water will move into cells via osmosis, making mucus secretions thicker.

B water will move out of cells via osmosis, making mucus secretions thicker.

C the saline solution is watery and this will make mucus secretions less thick.

D water will move out of cells via osmosis, making mucus secretions less thick.

Question 9

In Method 1, the independent variable is

A the concentration of saline solution inhaled.

B inhalation of the 0.9% saline solution.

C inhalation of the 7% saline solution.

Question 10

Using the information provided, a potential source of error in Method 1 is

A the small sample size.

B the length of the experiment.

C variability in age, lifestyle, and gender of subjects.

Question 11

In Method 2, the control group is

A the group of people who inhale 7% saline solution.

B the group of people who inhale 0.9% saline solution.

C non-existent – a true comparative group of similar subjects has not been set up.

Question 12

The control group in Method 1 inhaled 4 mL of 0.9% saline solution because

A 0.9% salt is isotonic to the cytosol, so scientists can be sure that any effects of the treatment are due to inhalation of a hypertonic solution rather than inhalation of a liquid.

B scientists wanted to check if lower concentrations of salt would have the same therapeutic benefit as 7%.

Exam-style questions

Within lesson

Question 13 (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 protein channels in their plasma membranes.

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

D These individuals use simple diffusion to transport glucose across the plasma membrane.

Adapted from VCAA 2017 Sample Exam Section A Q4

Question 14 (1 MARK)

Substances that can move by diffusion directly through the phospholipid bilayer of the plasma membrane include

A amino acids.

B potassium ions.

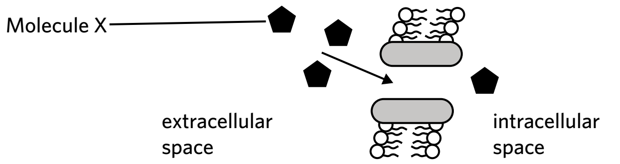
C hydrogen molecules (H_2).

D polar carbohydrate molecules.

Adapted from VCAA 2018 Exam Section A Q1

Question 15 (1 MARK)

Consider the diagram showing the transport of Molecule X across the plasma membrane. What evidence supports the conclusion that Molecule X is hydrophilic?



A Molecule X is moving down its concentration gradient.

B Molecule X is diffusing freely across the plasma membrane.

C Molecule X requires energy to move across the plasma membrane.

D Molecule X requires a protein channel to assist with transport across the membrane.

Multiple lessons

Question 16 (8 MARKS)

A small, hydrophobic molecule is highly concentrated in extracellular fluid compared to the cytosol of a target cell. Consider the diagram of the target cell's plasma membrane.

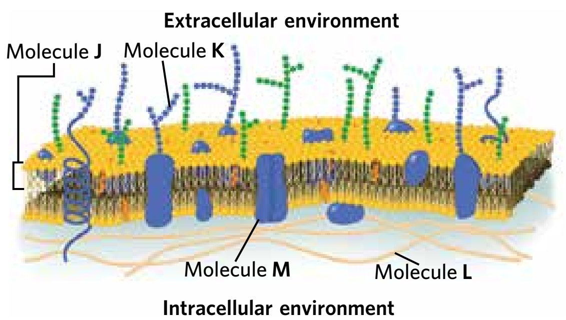


Image: J.Marini/Shutterstock.com

a There are different modes of transport for molecules to cross the membrane.

  i Draw an arrow representing the path taken by the hydrophobic molecule across the plasma membrane. (1 MARK)

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

b Name and outline the functions of Molecules J, K, and L. (3 MARKS)

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

Key science skills and ethical understanding

Question 17 (7 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 circumferences again and noted observations about their firmness. The diagram shows the set-up of Kinji's experiment.

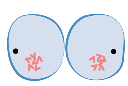


Image: Designua/Shutterstock.com

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

b Identify two other variables that would need to be controlled to ensure the experiment produced a valid result. (2 MARKS)

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

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

e When Kinji collects her results, she is surprised to find that her hypothesis is not supported. Given that she is completing this experiment for a SAC and she wants to do well, she decides to start the experiment again from scratch and delete her old results. Referring to an ethical concept, explain whether Kinji's actions are ethical. (2 MARKS)

Adapted from VCAA 2018 Section B Q11

3C ACTIVE TRANSPORT

Think back to the last time you were sick with a stomach bug or food poisoning. Chances are that your parents ran down to the pharmacy and brought you back some type of powder that they mixed with water and made you drink, so that you wouldn't 'dehydrate'. What is in this magical concoction? Do these drinks actually work? How do they help you in your recovery? Or are they just a placebo?

Image: Krakenimages.com/Shutterstock.com

Lesson 3C

In this lesson you will learn that active transport uses energy to move molecules across the plasma membrane against their concentration gradient.

Prerequisite knowledge | *Future applications*

Chapter 2
All cells have selectively permeable plasma membranes that control what enters and exits their internal environment.

Lesson 3B
Passive transport does not require energy to move molecules across the plasma membrane.

Lesson 5B
Active transport is used to absorb nutrients into the roots of plants, and to translocate substances in the phloem.

Lesson 6C
Vesicles transport glucose protein pumps to the plasma membrane to regulate blood glucose concentration.

Study design dot point

- the structure and function of the plasma membrane in the passage of water, hydrophilic and hydrophobic substances via osmosis, facilitated diffusion and active transport

Key knowledge units

Active transport	1.1.4.7
Bulk transport	1.1.4.8

Active transport 1.1.4.7

OVERVIEW

Active transport of substances across membranes involves using protein pumps to move molecules against their concentration gradient.

THEORY DETAILS

Active transport involves transporting substances across the membrane using energy. There are two types of active transport: **protein-mediated active transport** (this is usually just called 'active transport') and **bulk transport**. This first section of the lesson focuses on protein-mediated active transport – we'll get to bulk transport after that.

active transport movement of molecules across a semipermeable membrane that requires energy

protein-mediated active transport a type of active transport which involves using membrane proteins to move molecules across a membrane against their concentration gradient. Also known as **active transport**

bulk transport a type of active transport that uses vesicles to move large molecules or groups of molecules into or out of the cell. Also known as **cytosis**

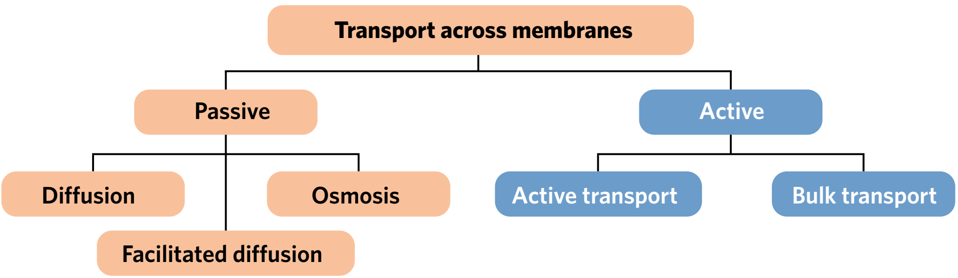


Figure 1 The different types of passive and active transport

When do cells need to use protein-mediated active transport? Sometimes, there is a big difference in the concentration of substances inside the cell compared to outside the cell. Take Figure 2a, for example. In this instance, there is a higher concentration of potassium ions (K^+) inside the cell compared to the extracellular fluid. Despite this, the cell may still require more K^+ to function optimally – so it must somehow draw the K^+ into the cytosol, against its concentration gradient. To make matters more difficult, K^+ cannot simply diffuse across the plasma membrane as it is a charged molecule. Furthermore, the cell cannot use facilitated diffusion either, as K^+ ions need to move against its concentration gradient. In this scenario, the cell must use energy and **protein pumps** to move the ions against their concentration gradient and into the cytoplasm (Figure 2b).

There are many situations when a molecule must be transported against its concentration gradient, but they all require:

- energy, usually in the form of **adenosine triphosphate (ATP)**
- membrane proteins, typically protein pumps and **carrier proteins**.

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

1 Binding – the target molecule for transport binds to a specific protein pump

2 **Conformational change** – energy released from the reaction ATP ⇨ ADP + P_i causes a conformational change in the protein pump. This energy comes from breaking the bond between the second and third phosphate ions in the ATP molecule (Figure 3)

3 Release – the target molecule is pushed through the protein and released to the other side of the membrane.

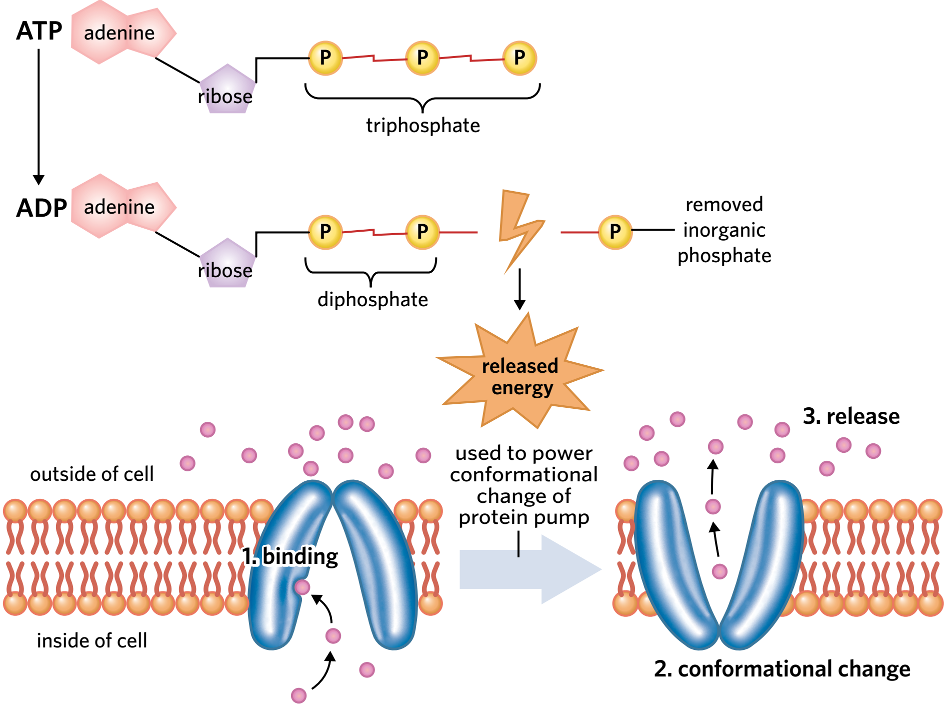


Figure 3 The reaction ATP → ADP + P_i releases energy which leads to a conformational change in protein pumps.

Besides ensuring cells can access appropriate concentrations of particular molecules, active transport can also be used to control water movement. As you learned in lesson 3B, water moves from areas of low solute concentration to areas of high solute concentration.

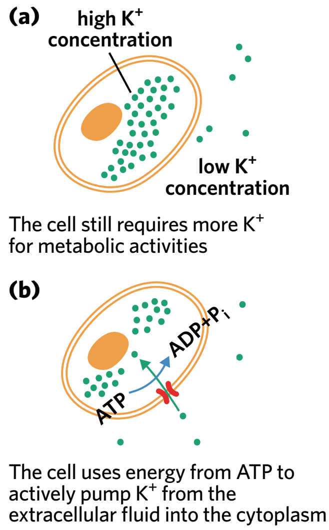


Figure 2 **(a)** The cell has a high concentration of K^+ compared to the extracellular fluid, but still requires more K^+, so **(b)** it uses a protein pump and energy from ATP to move K^+ into the cytoplasm.

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

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

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

conformational change a change in the three-dimensional shape of macromolecules such as proteins

Therefore, pumping solutes into cells can result in water following passively via **osmosis**. Similarly, to remove unwanted water, the cell can pump solutes into the extracellular space and water will diffuse into the hypertonic region.

osmosis the passive transport of a solvent (typically water) through a semipermeable membrane from a region of low solute (high solvent) to a region of high solute (low solvent)

Theory in context

THE SODIUM-POTASSIUM (Na^+/K^+) ION PUMP

The sodium-potassium (Na^+/K^+) protein pump maintains ideal concentrations of Na^+ and K^+ in the cell. It also plays a role in generating nervous impulses, which are caused by changes in the voltage of cell membranes of neurons. Na^+ has a very high extracellular concentration, whilst K^+ has a very high intracellular concentration. The sodium-potassium pump can be used to move Na^+ out of the cell and K^+ into the cell.

The Na^+/K^+ pump works as follows:

1. The cycle starts with the pump open to the cytoplasm, where it binds three Na^+.
2. ATP is broken down 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 bond strongly to Na^+ so these ions are released.
3. Two K^+ are bound to the pump, and this triggers the release of the free-floating phosphate, which was leftover following the breakdown of ATP in step 2.
4. The pump changes shape again, opening to the cytoplasm and releasing K^+ back into the cell. The cycle can start again.

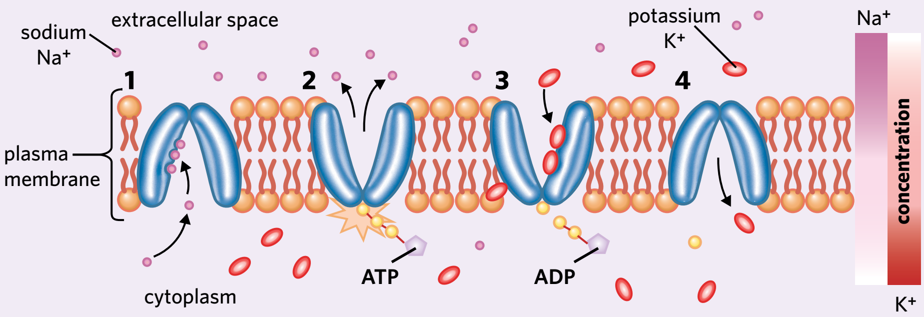


Figure 4 The mechanism of the Na^+/K^+ pump

Bulk transport 1.1.4.8

OVERVIEW

Bulk transport, the movement of groups of molecules across the plasma membrane, comes in two forms: exocytosis and endocytosis.

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 – into or out of the cell using **vesicles**. 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. Often, proteins are made at **ribosomes** located on the surface of the **rough endoplasmic reticulum**, sorted, packaged, and modified at the **Golgi apparatus**, and then transported by vesicles to the plasma membrane for exocytosis. This is an important process because cells often need to release products such as hormones, neurotransmitters, and antibodies in large amounts. Alternatively, molecules that are too large to cross the membrane through a protein channel undertake exocytosis. There are three steps in exocytosis (Figure 5):

1. Vesicular transport – a vesicle containing **secretory products** is transported to the plasma membrane
2. Fusion – the membranes of the vesicle and cell fuse
3. Release – the secretory products are released from the vesicle and out of the cell.

vesicle a small membrane-bound sac that transports or stores substances within a cell

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

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

ribosomes small RNA-protein structures that are the site of protein synthesis. They either float freely in the cytoplasm or are attached to the RER

rough endoplasmic reticulum (RER) a membranous chain of connected and flattened sacs which are coated with ribosomes on their outer surface that synthesise and modify proteins

Golgi body stacked flattened sacs that are the site of protein sorting, packaging, and modification. Also known as the **Golgi apparatus** or **Golgi complex**

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

Exocytosis is possible because the plasma membrane is fluid and 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 slightly bigger.

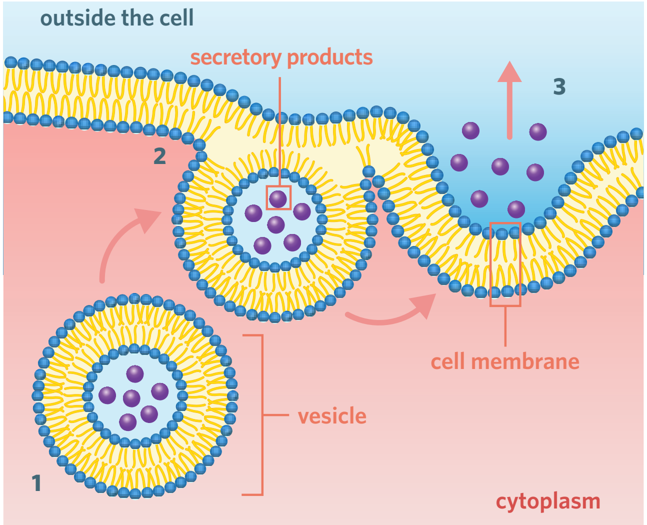


Image: Fancy Tapis/Shutterstock.com

Figure 5 The process of exocytosis

Memory device

- 'Exo' is derived from a Greek word that means 'outside', so you can remember that exocytosis involves moving substances out of the cell
- 'Endo' is derived from a Greek word that means 'within', so you can remember that endocytosis involves moving substance into the cell

Endocytosis

Endocytosis involves transporting large molecules or groups of molecules into the cell. The process is essential because many of the molecules that cells require to survive are too large to take in through protein channels in the plasma membrane. Once inside the cell, these substances can be broken down, used for metabolic processes, or become structural elements of the cell. Endocytosis can also be an effective defence mechanism. If a cell engulfs an invader or toxin, a **lysosome** can fuse with the vesicle to digest its contents.

lysosome a membrane-bound vesicle that contains digestive enzymes. They are responsible for breaking down cell waste

There are three steps in endocytosis (Figure 6):

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.

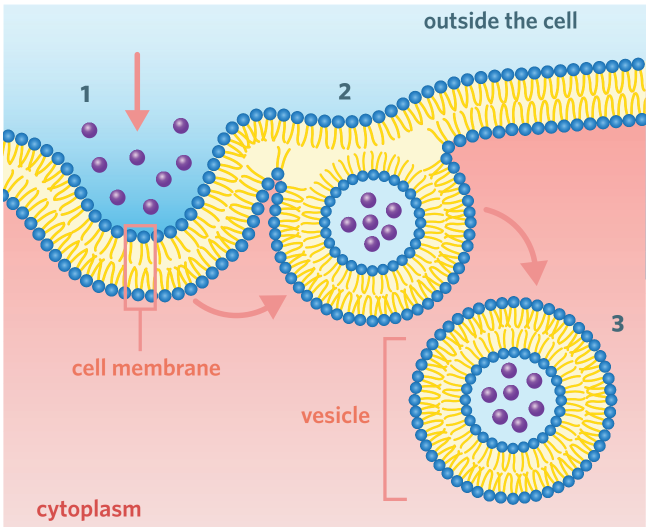


Image: Fancy Tapis/Shutterstock.com

Figure 6 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.

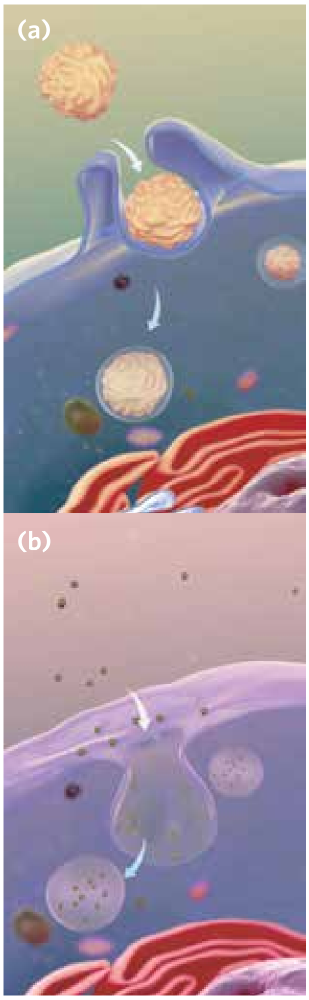


Figure 7 **(a)** Phagocytosis and **(b)** pinocytosis

There are several types of endocytosis. In particular, you should know about **phagocytosis** ('cell eating'), which 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.

phagocytosis endocytosis of solid material or food particles

pinocytosis endocytosis of liquid or dissolved substances

Theory summary

Active transport uses energy to transport substances across the plasma membrane, and includes protein-mediated active transport and bulk transport. Active transport moves molecules against their concentration gradients with protein pumps whereas bulk transport moves large molecules or groups of molecules into (endocytosis) or out of (exocytosis) cells using vesicles.

When you are sick and are vomiting or have diarrhoea, you lose way more water than usual and are at risk of dehydration. The best way to prevent this from happening is called oral rehydration therapy (ORT), and is probably the drink that you have received from your parents in the past.

The aim of ORT is to fast-track absorption of both water and sodium into the body. This is because dehydrated people lose large amounts of sodium along with water, and sodium is important for bodily functions. Unfortunately, ORT isn't as simple as drinking water mixed with sodium. This is because protein pumps can only transport sodium out of the gut lumen when it is paired with glucose, using a type of active transport called secondary active transport. ORT drinks contain both sodium and glucose. After you drink them, sodium and glucose are absorbed inside your gut epithelial cells, allowing water to follow them via osmosis as it moves to the hypertonic region.

Oral rehydration salts contained in sachets like this are estimated to have saved more than 70 million lives.

3C QUESTIONS

Theory review questions

Question 1

Active transport differs from passive transport because

A ATP is required to move molecules.

B no ATP is required to move molecules.

C vesicles are required to move molecules.

D membrane proteins are required to move molecules.

Question 2

Protein-mediated active transport involves: (*Select all that apply*)

I ATP

II energy

III protein pumps

IV protein channels

V moving molecules down their concentration gradient

VI moving molecules against their concentration gradient

Question 3

During active transport, energy is used to

A change the conformation of protein pumps or carrier proteins.

B energise molecules for transportation across the membrane.

C block protein channels.

Question 4

When ions are pumped into a cell, making it hypertonic to the environment, water will

A move out of the cell via osmosis.

B be actively pumped into the cell.

C passively move into the cell.

D not be affected.

Question 5

Bulk transport

A comes in two forms: pinocytosis and phagocytosis.

B moves large molecules or groups of molecules using vesicles.

C harnesses vesicles to transport secretory products into the cell.

D uses energy to move small substances against their concentration gradient.

Question 6

Identify the substance(s) that can be transported by exocytosis. (*Select all that apply*)

I proteins

II large molecules

III secretory products

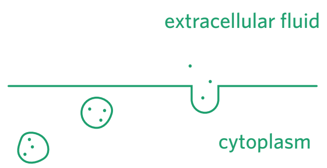
IV groups of molecules

V small, nonpolar molecules

Question 7

Categorise the following diagrams as **endocytosis**, **exocytosis**, or **active transport**.

I



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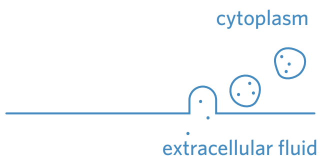

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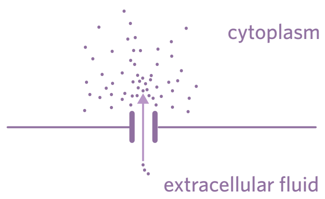


SAC skills questions

Case study analysis

Use the following information to answer Questions 8–12.

Neurons are specialised cells that transmit electrical signals around your body. The signal might instruct a muscle to contract or a gland to release a hormone. But how exactly are electrical signals generated inside a neuron?

Most of the time, the inside of a neuron is negatively charged. This charge, between –40 and –90 millivolts, is called the resting membrane potential. The negativity is maintained because positive ions are pumped out of the cell all the time. The main ions involved in regulating the membrane potential are sodium and potassium ions, which move in and out of the cell via the sodium-potassium pump.

When a neuron receives a chemical signal, protein channels near the signal open and positive ions flow down their concentration gradient into the cell. This makes that area of the cell temporarily positive, generating an action potential. This triggers the next region of the cell to open its protein channels, and so on, like a domino effect. Once the inside of the neuron reaches approximately 30 millivolts, the channels close and the cell can return to its resting state.

Question 8

During its resting state, a neuron is

A negatively charged.

B positively charged.

C neutral.

Question 9

The triggering of protein channels to open is likened to a 'domino effect' because

A a number of actions leads to one big event.

B a single action sets off a chain of similar events.

C protein channels are shaped and coloured like dominoes.

Question 10

The resting potential is maintained by

A passive transport.

B active transport.

C bulk transport.

D osmosis.

Question 11

The action potential is maintained by

A passive transport.

B active transport.

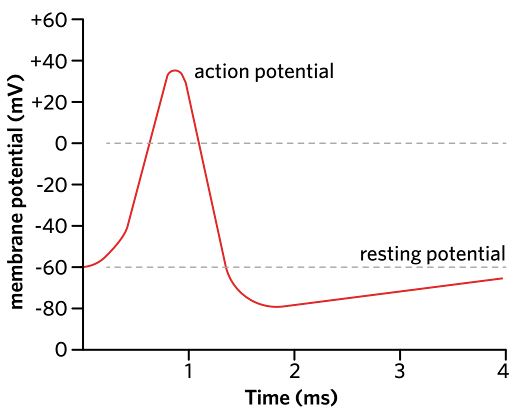
C bulk transport.

D osmosis.

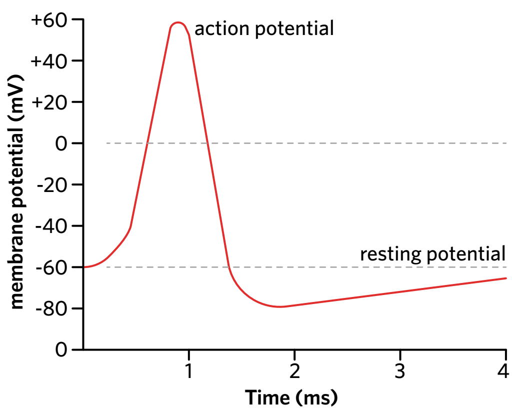
Question 12

Which of the following graphs best depicts the change in charge of a neuron?

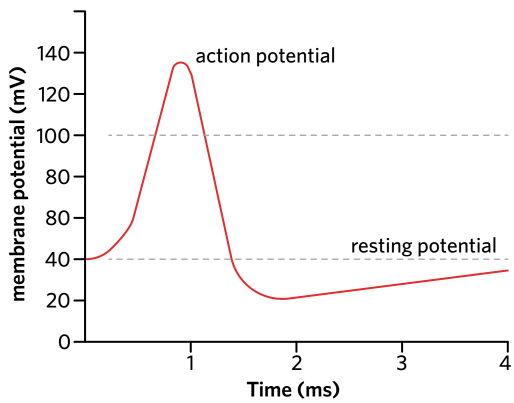
A



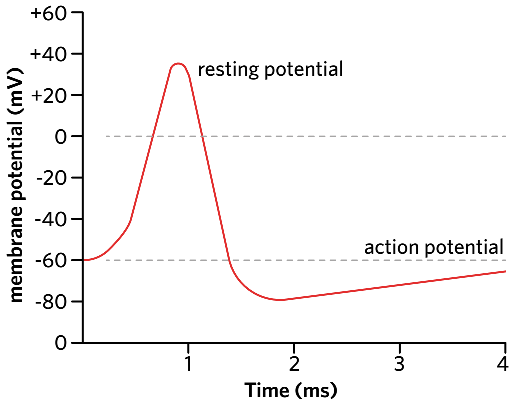
B



C



D



Exam-style questions

Within lesson

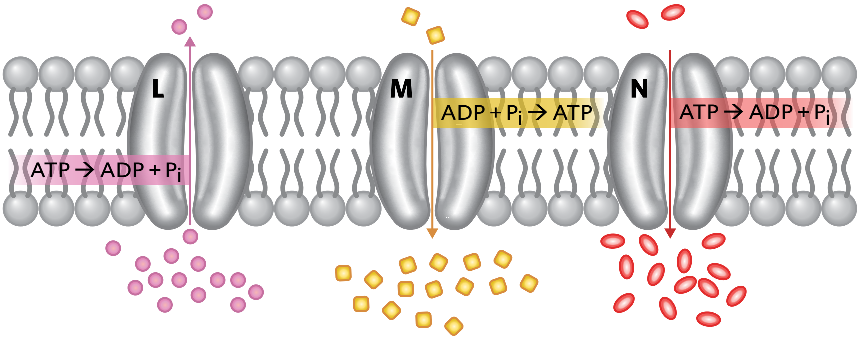
Question 13 (1 MARK)

Protein export does not involve

A vesicular transport of proteins out of the cell.
B the fusion of vesicles with the plasma membrane.
C specialised vesicles transporting hydrophobic substances.
D sorting and modification of proteins at the Golgi apparatus.

Question 14 (1 MARK)

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



A Protein M and Protein N are both undertaking active transport.
B Protein L and Protein N are both undertaking active transport.
C All three proteins are involved in bulk transport.
D Protein N is undertaking active transport.

Question 15 (4 MARKS)

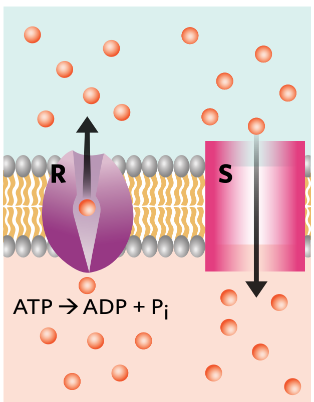
Novel nanomaterials called 'nanomedicines' are being developed to diagnose and treat disease. To work, nanomedicines must enter a cell and interact with particular sub-cellular molecules. Nanomedicines gain entry into target cells through endocytosis.

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)

Multiple lessons

Question 16 (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

Question 17 (1 MARK)

Gastrin is a protein 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. Gastrin is likely released from the cell via

A protein channels.

B endocytosis.

C exocytosis.

D diffusion.

Use the following information to answer Questions 18 and 19.

Rapid plant movements occur when plant structures such as leaves, flowers, or pollen move quickly. For example, when the sensitive '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: shutting/Shutterstock.com

Question 18 (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 19 (1 MARK)

Pumping potassium and chloride ions into cells leads to high 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 osmosis.

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

Question 20 (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 a cell through the plasma membrane?

A R

B S

C U

D T & U

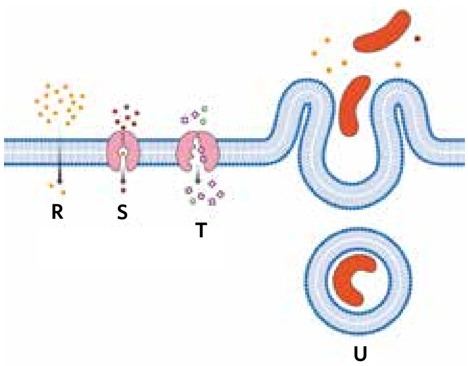
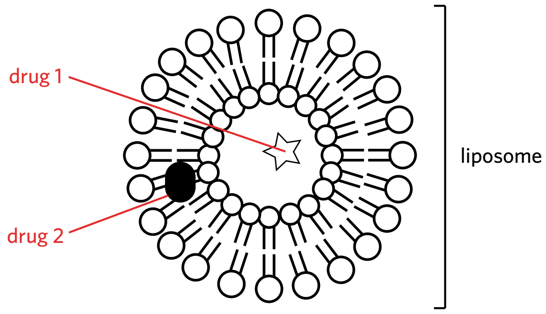


Image: Aldona Griskeviciene/Shutterstock.com

Question 21 (4 MARKS)

Liposomes are found in the cytosol and are formed from a double layer of phospholipid molecules identical to those found in plasma membranes. Liposomes can also be manufactured and used to carry medicinal drugs into cells.



Adapted from VCAA 2007 Exam 1 Section A Q2

a Identify if Drug 1 or Drug 2 is soluble in lipids. Justify your response. (2 MARKS)

b Other medicines can be delivered to cells without the aid of a liposome. Describe one other process by which a drug could enter a cell. (2 MARKS)

Key science skills and ethical understanding

Question 22 (6 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 a protein called 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. They theorised that, after absorbing APP via endocytosis, the APP is cleaved in the cell to produce beta-amyloid. This beta-amyloid then leaves the cell, and builds up in the extracellular space surrounding neurons.

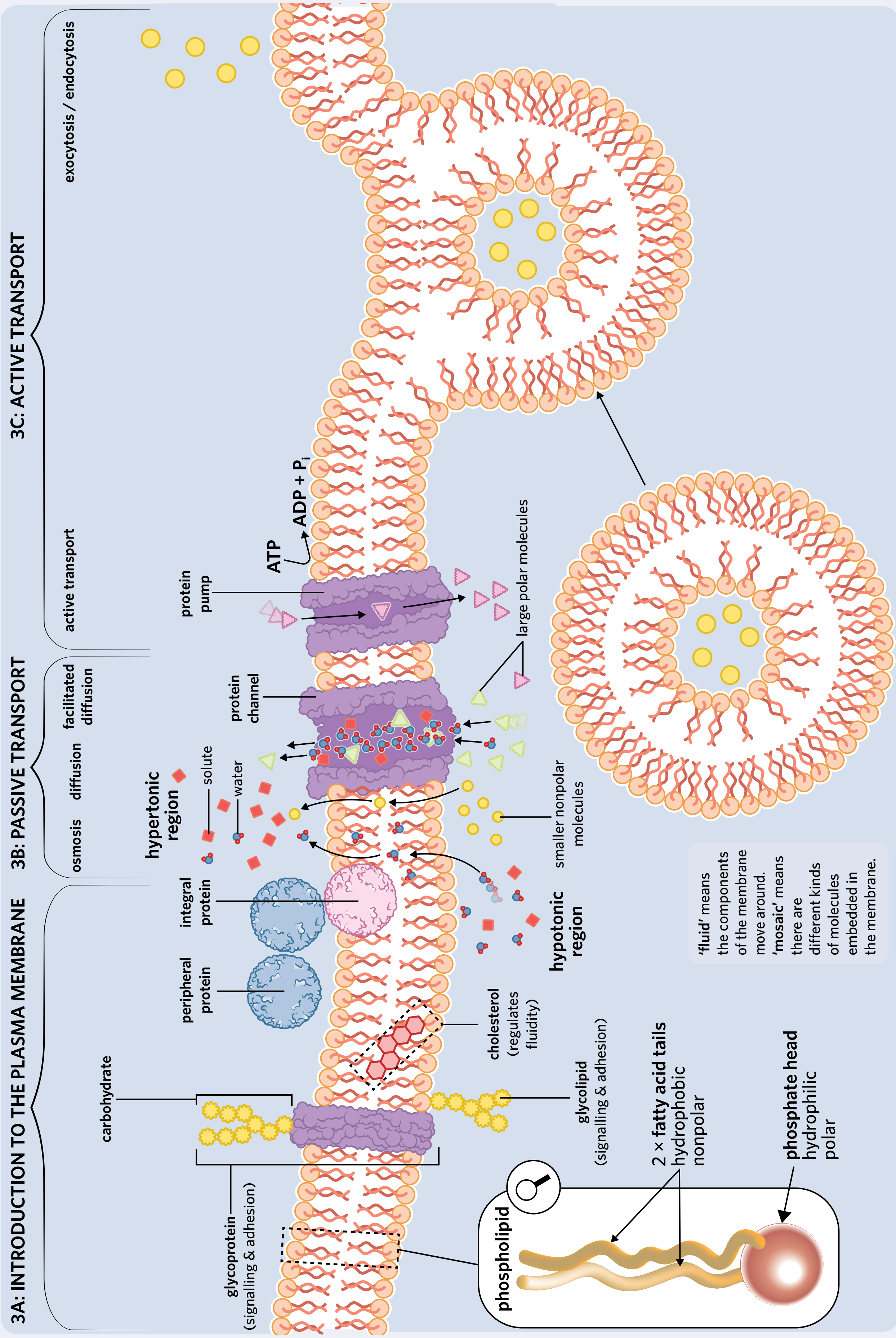
The scientists cultured neurons from mice and aged them *in vitro*. Neurons undergo three developmental stages: they develop axons and dendrites after a week, reach peak maturation at 21 days, and exhibit aging at 28 days. The researchers compared 21- and 28-day-old neurons for differences in APP endocytosis and beta-amyloid levels. It is thought that more mature neurons have higher levels of APP endocytosis.

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

b With reference to a particular bioethical concept, explain why the scientists undertook this experiment *in vitro*. (2 MARKS)

c The scientists found that aged neurons had 50% more beta-amyloid, double the amount of APP endocytosis, and larger vesicles. Do these results support the scientists' hypothesis? Justify your response. (2 MARKS)

CHAPTER 3 SUMMARY



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CHAPTER 3 SAC PRACTICE

SAC skills covered in this section:

✓ Case study analysis ✓ Data analysis ✓ Scientific methodology analysis ✓ Bioethical deep dive

SALMON FARMING (22 MARKS)

Ronda is an aquaculture researcher undertaking her PhD at the University of Melbourne. She studies how to sustainably rear aquatic and marine species in farms for food. She is collecting some dead salmon samples off her friend, Frode, so that she can examine the chemical properties of their plasma membranes. Ronda is going to compare the chemical composition of their membranes to other Atlantic salmon grown in different environments around the world. The company funding her research, OzSal, hopes to use her results to find potential sites that would be suitable for Atlantic salmon farms. They are particularly interested in sites along the coasts of Victoria and South Australia. Frode's salmon farm is very successful, and is located in Tromsø, Norway, where water temperatures range from 4.4–11.2 °C.

1 Using the information in the paragraph above, describe what is meant by the term 'aquaculture'. Justify your response. (2 MARKS)

2 List the five types of molecules typically found in plasma membranes. (1 MARK)

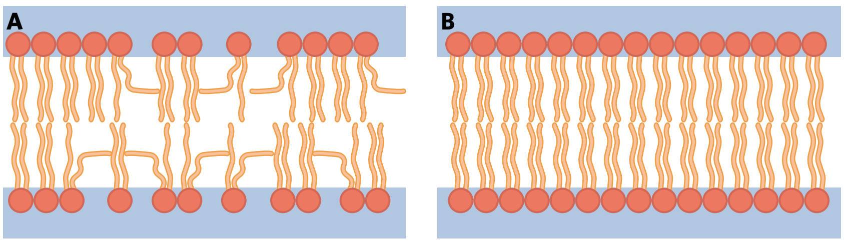
3 Complete the table to outline the ways in which hydrophobic and hydrophilic substances can cross the plasma membrane. (4 MARKS)

	Active or passive?	Direction	ATP required?	Protein required?	Type of molecules that move
Diffusion					
Osmosis					
Facilitated diffusion					
Active transport					

4 The salmon samples that Ronda collected died naturally then sunk to the bottom of the sea cage where they were collected by divers. She considered catching and killing live fish, but decided that this was unethical when another method was feasible. Identify the relevant bioethical concept and explain how it may have influenced Ronda's decision. (2 MARKS)

5 A neighbouring salmon farmer, Ida, decided not to be involved in Ronda's experiment, explaining that having extra people around the farm was disruptive and potentially unsafe. Which approach to bioethics has most likely informed Ida's decision? (1 MARK)

Ronda has already sampled Atlantic salmon that are grown off the West Coast of Tasmania. The water temperature there ranges from 12.5–17.2 °C. Using electron spin resonance and fluorescence techniques, she found that the salmon grown in Norway had plasma membranes with the same chemical composition as the salmon grown in Tasmania. However, she discovered that the phospholipid bilayer of each type of Atlantic salmon looked quite different:



6 Which image, A or B, depicts the membrane of Atlantic salmon grown in Norwegian waters? Justify your response, and explain the benefits of having different bilayers in different environments. (3 MARKS)

7 Explain if Norwegian Atlantic salmon have saturated or unsaturated fatty acid tails in their phospholipids. (1 MARK)

OzSal was thrilled by Ronda's findings. They believed this meant they could open up new salmon farms all along the coast of Victoria and South Australia. Ronda, however, objected to their plans, suggesting that there wasn't sufficient evidence to indicate salmon would thrive in these areas. Additionally, she said more consideration of the potential biological and social consequences of introducing salmon into these regions had to be undertaken.

8 Identify one biological and one social consequence of opening a salmon farm in a new location. (2 MARKS)

Prior to seeing Ronda's results, the scientific community had assumed the level of saturation of phospholipids in the plasma membrane would be the same within a species. Looking at Ronda's work, her colleague Wei from Federation University came up with two potential hypotheses to explain the results:

- Hypothesis 1 – the Atlantic salmon in Tasmania are genetically distinct from the Atlantic salmon in Norway, and their plasma membrane saturation levels have changed over generations to suit Tasmanian waters.
- Hypothesis 2 – individuals of a species can regulate their plasma membrane saturation level to suit their environment.

Wei wanted to design an experiment to test Hypothesis 1. She was encouraged by both her laboratory supervisor and university's ethics committee to conduct her initial experiment on a bacterial species, as many features of the plasma membrane are universal across organisms.

Wei designed two potential methods to culture the *E.coli* bacteria at different temperatures to test Hypothesis 1.

Method 1:

1. On one Petri dish, grow a colony of *E. coli* at 15 °C.
2. Repeat step 1 at 25 °C and 35 °C.
3. Measure the saturation level of fatty acids in plasma membranes of each colony every generation for four generations.

Method 2 was the same as Method 1, except that Wei replicated the experiment four times.

9 Describe how Wei would replicate the experiment. (1 MARK)

10 Explain the benefits of experimental replication. (1 MARK)

Wei conducted her experiment and collected the following results:

Temperature raised at (°C)	**Generation**			
	1	2	3	4
	Ratio of saturated : unsaturated fatty acids			
15	1 : 4	1 : 4	1 : 4	1 : 4
25	2 : 3	2 : 3	1 : 5	2 : 3
35	3 : 2	3 : 2	3 : 2	3 : 2

11 Do Wei's results support Hypothesis 1? Justify your response. (2 MARKS)

12 One of Wei's measurements is very unusual. Identify which measurement is inconsistent. (1 MARK)

13 Wei decides this measurement occurred due to a random error. Suggest how Wei could avoid this error if she ran this experiment again. (1 MARK)

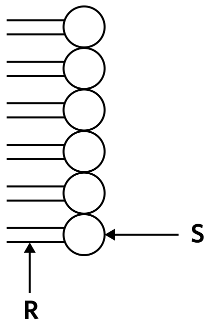
CHAPTER 3 EXAM PRACTICE

30 min

Section A (8 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 R and S do not remain in a fixed position within the membrane.

D The R and S 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

Use the following information to answer Questions 3–5.

Consider the diagram.

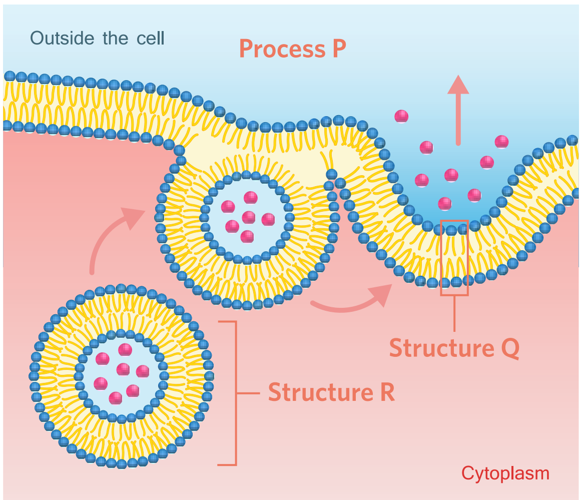


Image: Fancy Tapis/Shutterstock.com

Question 3 (1 MARK)

Process P is an example of

A protein-mediated active transport.

B endocytosis.

C pinocytosis.

D exocytosis.

Question 4 (1 MARK)

Structure Q

A is hydrophobic.

B is the site of facilitated diffusion.

C packages and sorts protein molecules for export from the cell.

D can be embedded with proteins, glycoproteins, and cholesterol.

Question 5 (1 MARK)

Structure R is a

A carrier protein.

B lysosome.

C vesicle.

D cell.

Question 6 (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 seawater 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 seawater 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 7 (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 8 (1 MARK)

Both fungi and plant cells have plasma membranes. 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

Section B (12 MARKS)

Question 9 (6 MARKS)

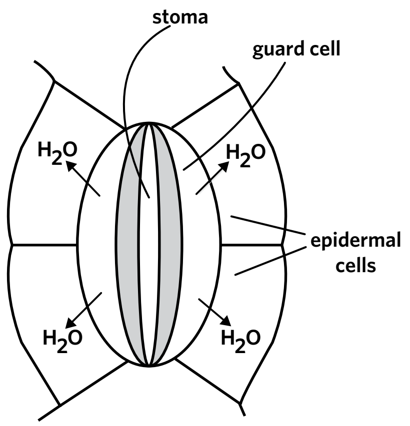
Plants require the passive movement of water for normal cellular function.

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. A stoma is made up of two guard cells, with surrounding epidermal cells. This plant is in bright light. When water leaves the guard cells, the stoma closes preventing the plant from exchanging 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 10 (6 MARKS)

The diagram represents a cross-section of part of a cell membrane.

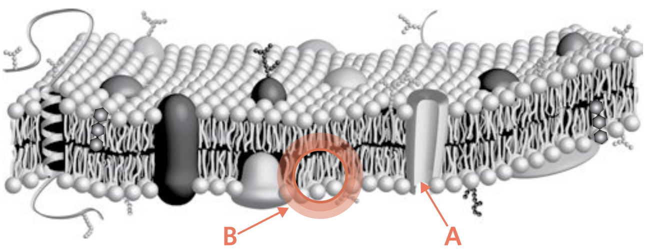


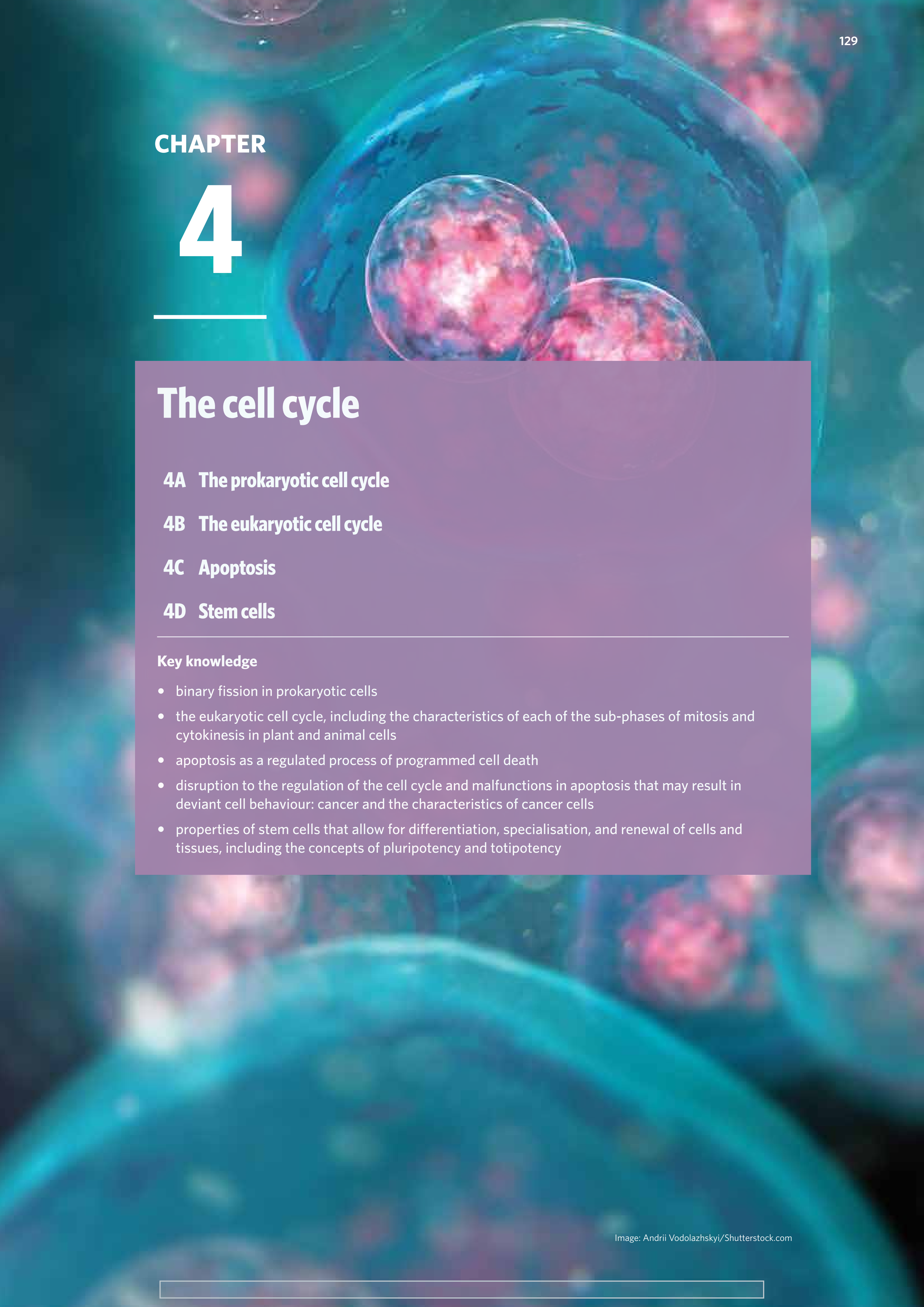
Image: Magnetix/Shutterstock.com

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



CHAPTER

4

The cell cycle

Key knowledge

- binary fission in prokaryotic cells
- the eukaryotic cell cycle, including the characteristics of each of the sub-phases of mitosis and cytokinesis in plant and animal cells
- apoptosis as a regulated process of programmed cell death
- disruption to the regulation of the cell cycle and malfunctions in apoptosis that may result in deviant cell behaviour: cancer and the characteristics of cancer cells
- properties of stem cells that allow for differentiation, specialisation, and renewal of cells and tissues, including the concepts of pluripotency and totipotency

Image: Andrii Vodolazhskyi/Shutterstock.com

4A THE PROKARYOTIC CELL CYCLE

Have a stomach ache and stuck on the toilet? As you google your symptoms, you hypothesise that you are suffering from a case of food poisoning. Immediately, you think back to what you ate last night, hoping to find the culprit behind your agony. Then, you remember that after watching a video on Facebook about medium-rare chicken, you'd decided to give it a shot. Despite the numerous warnings from friends about the safety of medium-rare chicken, you bravely went ahead.
Have you ever wondered why properly cooking chicken is so important? Is there something hiding in our meat?

Image: 54613/Shutterstock.com

Lesson 4A
In this lesson you will learn the purpose of cellular replication in the form of binary fission.

◀ *Prerequisite knowledge*

Lesson 2A
The characteristics of prokaryotic and eukaryotic cells.

Future applications ▶

Lesson 4B
Eukaryotic cells replicate through mitosis instead of binary fission.

Year 12
A method to combat harmful bacterial growth is to target cell wall synthesis in binary fission with antibiotics.

Study design dot point

- binary fission in prokaryotic cells

Key knowledge units

Introduction to cell replication	1.1.5.1
Binary fission	1.1.5.2

Introduction to cell replication 1.1.5.1

OVERVIEW

Cell replication is critical for both eukaryotes and prokaryotes.

THEORY DETAILS

Cell replication is a critical process for organisms to undergo in order to survive. Its purposes include growth and development, maintenance and repair, and reproduction. These are shown in Table 1.

Table 1 Purposes of cell replication

Purpose	Explanation
Growth and development	All humans begin as a single cell. From there, we replicate rapidly, becoming an embryo, foetus, and then a baby. As we grow larger, our cells don't actually become larger. Instead, we are simply made of more cells. Therefore, for a multicellular organism to grow and develop, it is important that cells replicate.
Maintenance and repair	Cells are constantly dying as they age or become damaged. Cell replication allows these cells to be replaced, ensuring the proper functioning of an organism.
Reproduction	Prokaryotic and eukaryotic cells replicate to reproduce. When they replicate, they are enlarging their population.

Exponential growth

Cells replicate exponentially, meaning that after each round of replication the number of cells present doubles. For example, the rapid nature of **binary fission** allows a single bacterium to replicate into a few million bacteria in a very short span of time. A colony of *Escherichia coli* (*E.coli*) bacteria doubles in size every 20 minutes (Figure 1). Therefore, if we began with just a single bacterium, after seven hours, we would have over two million bacteria.

binary fission the method of cell replication used by prokaryotes

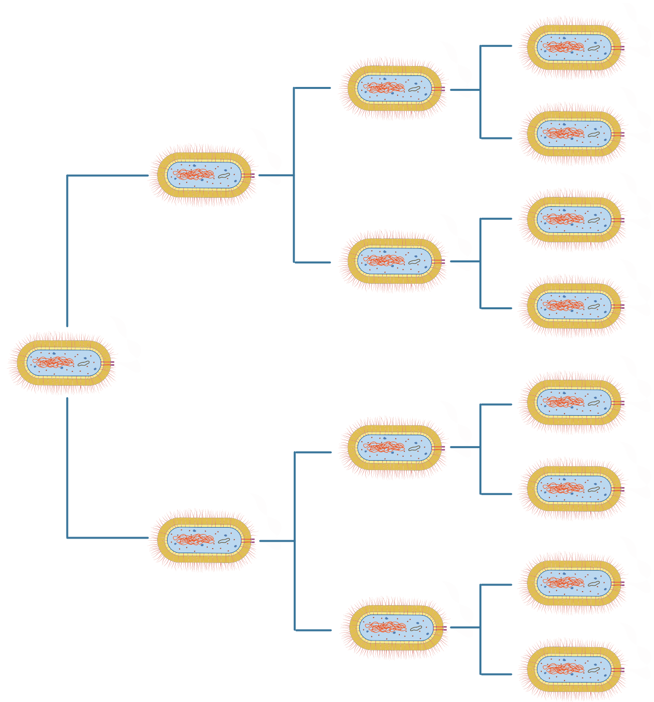


Image: Aldona Griskeviciene/Shutterstock.com

Figure 1 The exponential growth of *E. coli* bacteria

Binary fission 1.1.5.2

OVERVIEW

Prokaryotes, such as bacteria, reproduce rapidly via binary fission, which produces two genetically identical copies of a cell.

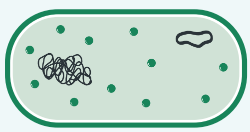
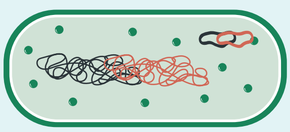
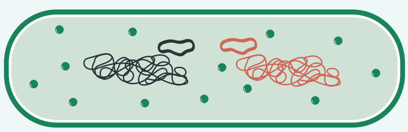
THEORY DETAILS

In lesson 2A, we learned about the differences between prokaryotic and eukaryotic cells. One of these differences was their method of replication. We should remember that prokaryotes such as bacteria replicate through binary fission, which is a type of **asexual reproduction**. The following table describes the various stages of binary fission (Table 2).

asexual reproduction a method of reproduction that produces genetically identical cells without the fusion of gametes (sex cells)

plasmid a small, circular loop of DNA that is separate from a chromosome, typically found in bacteria

Table 2 The process of binary fission

	A prokaryotic cell before cell replication.
	The circular chromosome is uncoiled and the DNA is replicated. **Plasmids** also replicate.
	During this stage, the cell elongates as it prepares to separate into two new cells and the duplicated circular chromosomes migrate to opposite ends. *cont'd*

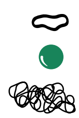
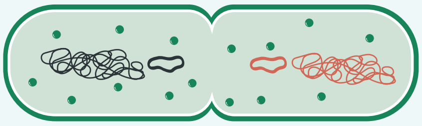
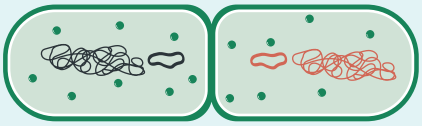
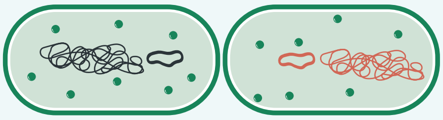


Figure 2 Key for Table 2

Table 2 Continued

	The cell then begins to undergo **cytokinesis** – the process of separating into two new cells – by pinching inwards and creating a **septum**. Because plasmids replicate independently of the circular chromosome, these will not always be evenly distributed between the two new cells.
	A new cell wall and membrane are formed down the centre of the cell.
	Finally, two new genetically identical cells are formed.

cytokinesis the division of the cytoplasm and formation of two daughter cells

septum a dividing wall formed during binary fission

Memory device

To help you remember the different stages of binary fission, you can use the following acronym!

D – DNA replication

E – Elongation

S – Septum formation

C – Cell division

Image: pikcha/Shutterstock.com

Figure 3 Think of a desk to remember the stages of binary fission

Theory summary

The main purposes of cell replication include growth and development, maintenance and repair, and reproduction. Binary fission is composed of the following major steps: DNA replication, elongation, septum formation, and cell division.

In every piece of chicken, there are many bacteria hiding. Salmonella *are the bacteria responsible for your bad time, and have a replication time of approximately forty minutes. From the supermarket, to the fridge, to your mouth, these bacteria would have replicated well into the thousands or millions. That is why chicken must be thoroughly cooked at temperatures above 75 °C, until it is no longer pink, to be considered safe to eat. Now that you understand the importance of properly cooking chicken, you will never have to be stuck on the toilet again!*

4A QUESTIONS

Theory review questions

Question 1

Cell replication is a form of

A exponential growth.

B linear growth.

Question 2

What are the main purposes of cell replication? (*Select all that apply*)

I growth and development

II prokaryotic development

III prokaryotic reproduction

IV maintenance and repair

V prokaryotic repair

Question 3

When humans grow larger, their cells

A remain relatively constant in size.

B become significantly larger.

C become smaller.

Question 4

Prokaryotes replicate to

A increase their population.

B repair cells.

Question 5

Fill in the blanks with the following terms.

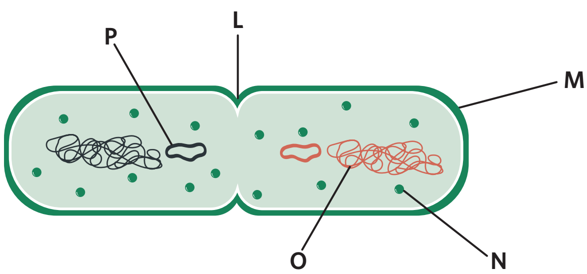
- asexual reproduction
- binary fission
- identical

The process of prokaryotic replication is called __________. This form of replication is also a type of __________, where two genetically __________ cells are produced.

Question 6

Label the parts of the prokaryotic cell from the list of terms.

- cell wall and membrane
- circular chromosome
- ribosome
- plasmid
- septum

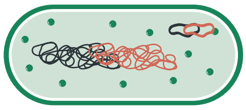


Question 7

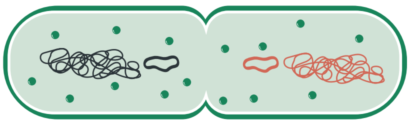
Match the images of binary fission to their descriptions.

- the uncoiling of the prokaryotic circular chromosome and the replication of DNA
- the formation of a new cell membrane and cell wall
- a prokaryotic cell prior to binary fission
- the formation of a septum

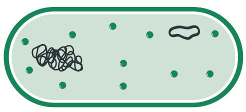
I



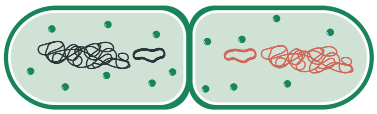
II



III



IV



Question 8

Plasmids are not evenly distributed between newly replicated cells because

A there are not enough plasmids present to evenly distribute them.

B they replicate independently of the cell.

SAC skills questions

Case study analysis

Use the following information to answer Questions 9–14.

In the early 1900s, there was no effective treatment for bacterial infections. If you were grazed or scratched, you were at risk of developing a life-threatening infection. Often, doctors could do little but make you comfortable while they hoped for the best. Fortunately, this drastically changed with the discovery of the first antibiotic: penicillin.

Penicillin was discovered in 1928 by Alexander Fleming. Fleming's discovery is often attributed to luck, leading him to say 'one sometimes finds what one is not looking for.' Returning from a holiday, he had observed an unexpected mould growing in a Petri dish colonised with the bacteria known as *Staphylococcus*. Surprisingly, the entire dish was covered with the bacteria except for a small area around the mould. This led Fleming to hypothesise that the mould was secreting a compound inhibiting bacterial growth. Later, he discovered that penicillin helped inhibit bacterial growth by interfering with cell wall synthesis in some strains of bacteria.

However, over time, bacteria have evolved to become resistant to penicillin-based antibiotics due to their widespread use. For example, some bacteria can now produce chemicals which disable penicillin. The race is now on for scientists to develop new forms of antibiotics against these bacteria. Hopefully, just like Fleming, luck is on their side!

Question 9

The discovery of penicillin is largely attributed to

A luck.

B skill.

Question 10

Penicillin is an

A antifungal.

B antibiotic.

C antiviral.

Question 11

The mould was not surrounded by any bacterial colonies because

A it was secreting a compound inhibiting bacterial growth.

B the bacterial colonies had not yet reached the mould.

Question 12

Penicillin inhibits bacterial growth by

A competing with bacteria for resources and space.

B interfering with cell wall synthesis.

Question 13

The process that penicillin interferes with is called

A cell maintenance and repair.

B growth and development.

C binary fission.

Question 14

Before antibiotics are made available to the public, scientists must test each antibiotic extremely rigorously. Sometimes, testing of certain antibiotics can last for several years before they are considered safe for human consumption. A potential negative social consequence of their experiments could be the

A bacteria's resistance to antibiotics.

B inability to help cure sick patients.

C harming of bacteria.

Exam-style questions

Within lesson

Question 15 (1 MARK)

Overexposure to the sun can lead to serious burns in the upper layers of our skin. In response, cells undergo

A cell replication for growth and development.

B cell replication to replenish damaged cells.

C binary fission to replenish damaged cells.

D cell replication to reproduce.

Question 16 (1 MARK)

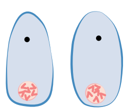
Staphylococcus aureus has a replication time of around 2 hours. If scientists began with a single bacterium, the number of bacteria after 12 hours would be

A 128.

B 64.

C 32.

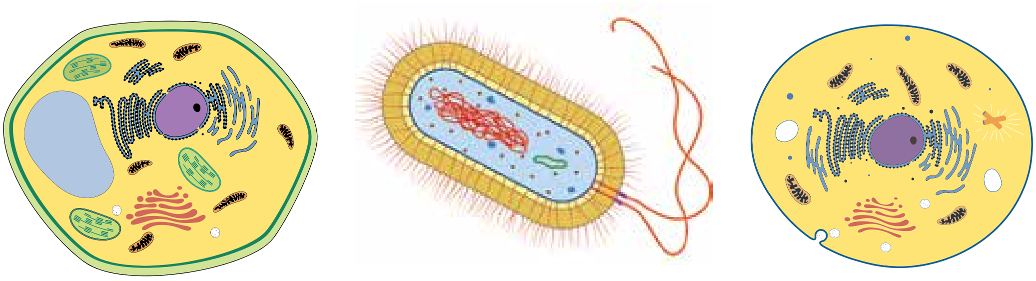
D 15.



Multiple lessons

Question 17 (1 MARK)

The diagrams represent various cells from different organisms.



X Y Z

Image: Aldona Griskeviciene/Shutterstock.com

Which of the cells replicate through binary fission?

A X only

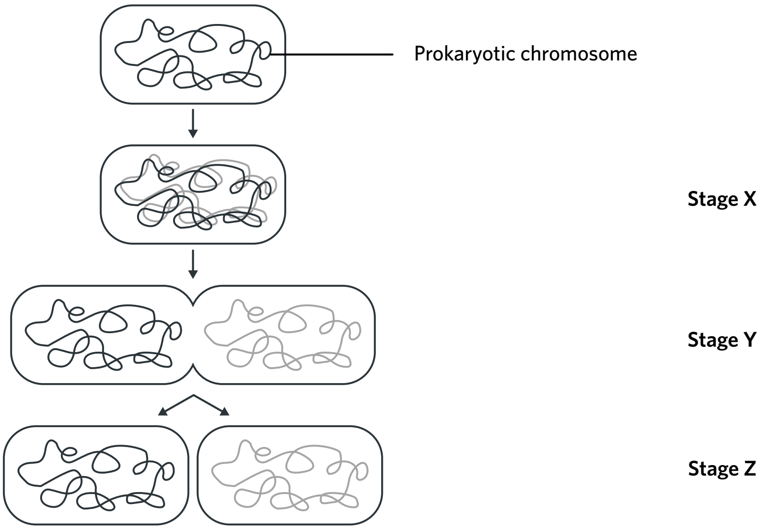
B Y only

C Z only

D X, Y, and Z

Question 18 (3 MARKS)

The image depicts a bacterial cell undergoing binary fission.



a Cell replication requires a large amount of energy. Name the organelle primarily responsible for the production of ATP in eukaryotes. (1 MARK)

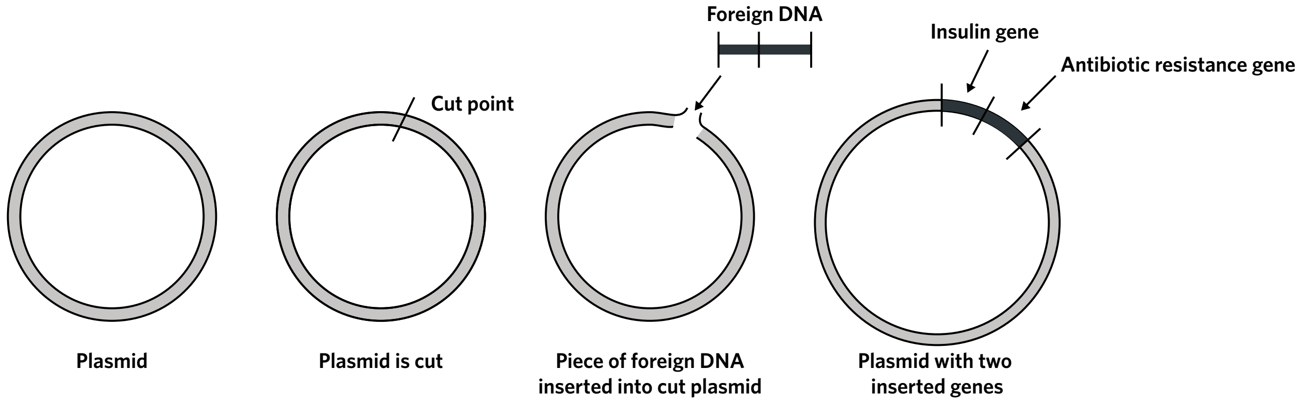
b State the shape of the bacterial chromosome. (1 MARK)

c Explain what is occurring during the stage labelled 'Y'. (1 MARK)

Key science skills and ethical understanding

Question 19 (8 MARKS)

Genes can be transferred from one species to another in different ways. One method conducted in laboratories is to use plasmids, circular pieces of DNA found in some bacteria. In this method, a plasmid is cut, a piece of foreign DNA is inserted, and the plasmid is sealed back together again. The foreign piece of DNA usually contains more than one gene. Many copies of the new plasmid are then incubated with bacteria, and the bacteria can accept some of the plasmids into their cytoplasm. Once the bacteria accept the plasmid, they can then freely begin expressing the genes encoded by it. In the example shown, the gene for insulin (a hormone that regulates your blood sugar level) and the gene for antibiotic resistance to tetracycline (an antibiotic) have been inserted into a plasmid. When bacteria accept the foreign plasmid, they can begin to produce insulin, which the scientists can extract for therapeutic purposes.



a Suggest an advantage of using bacteria to produce insulin. (1 MARK)

b Unfortunately, when incubated together, bacteria rarely accept the plasmid into their cytoplasm. Generally, only one or two bacteria in a colony will accept the plasmid and begin expressing the genes.

For the plasmid shown in the example, researchers will spread the incubated bacteria on a Petri dish containing the antibiotic tetracycline, which kills all bacteria that are not tetracycline resistant.

Explain why scientists kill the bacteria which are not resistant to tetracycline. (1 MARK)

c Identify two precautions scientists should adopt to prevent contamination of their plasmids and bacteria. (2 MARKS)

d Unfortunately, one scientist accidentally coughed on one of the Petri dishes containing the bacteria. Name the type of error this represents. (1 MARK)

e Individuals suffering from diabetes are often dependent on insulin produced by large pharmaceutical companies. However, these companies typically patent their discoveries, meaning that they can charge whatever price they want for their medication. This can lead to certain medications being inaccessible for individuals due to cost.

i Identify and explain which ethical concept is being undermined. (2 MARKS)

ii Describe one potential solution that could help medication become more accessible for everyone. (1 MARK)

4B THE EUKARYOTIC CELL CYCLE

Have a bad case of sunburn? Regretting that you didn't put on any sunscreen? As you feel the tenderness of your skin and the subsequent pain, you begin to think about the cause of this phenomenon. Why is there so much pain from sunburns? How do sunburns heal? How can we make them heal faster?

Image: dimid_86/Shutterstock.com

Lesson 4B

In this lesson you will learn that the eukaryotic cell cycle is a five stage process in which eukaryotic cells grow and replicate.

◀ Prerequisite knowledge | *Future applications ▶*

Years 7–10
Nuclear DNA is packaged into chromosomes.

Lesson 4A
While prokaryotes replicate through binary fission, eukaryotic cells replicate through mitosis.

Lesson 4C
Cancer can arise when the cell cycle is disrupted, leading to an imbalance in cell production and cell death.

Lesson 7B
A similar process exists for the production of gametes (sex cells) known as meiosis.

Study design dot point

- the eukaryotic cell cycle, including the characteristics of each of the sub-phases of mitosis and cytokinesis in plant and animal cells

Key knowledge units

The eukaryotic cell cycle	1.1.6.1
Mitosis and cytokinesis	1.1.6.2

The eukaryotic cell cycle 1.1.6.1

OVERVIEW

The eukaryotic cell cycle is composed of three stages including interphase, mitosis, and cytokinesis.

THEORY DETAILS

There are three stages of the eukaryotic cell cycle:

- **interphase** — cellular growth and duplication of **chromosomes**
- **mitosis** — separation of **sister chromatids** and the formation of two new nuclei
- **cytokinesis** — division of the cytoplasm and formation of two daughter cells.

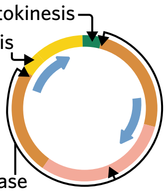


Figure 1 The three main stages of the eukaryotic cell cycle

In this section, we will focus primarily on interphase which is composed of three sub-stages. The next section will cover mitosis and cytokinesis in greater detail.

interphase the first stage of the eukaryotic cell cycle which involves cellular growth and duplication of chromosomes. Composed of three phases: G1, S, and G2

chromosome a structure composed of DNA tightly wrapped around histone proteins. Carries the genetic information (genes) of a cell

mitosis the second stage of the eukaryotic cell cycle, which involves the complete separation of sister chromatids and nuclei

sister chromatids the two identical halves of a replicated chromosome

cytokinesis the division of the cytoplasm and formation of two daughter cells

Interphase

Interphase is the first and longest stage of the cell cycle. During interphase, the cell synthesises the necessary DNA, proteins, and organelles required for growth and replication (Figure 2). At this time, DNA in the nucleus exists as long **chromatin** threads instead of discrete chromosomes (Figure 3). The three sub-stages of interphase are generally the G1 phase, the S phase, and the G2 phase. If further cell replication is not required, the cell can exit the cycle during the G1 phase and enter the G0 (resting) phase.

chromatin chromosomes (DNA and proteins) that have been unwound and loosely packed during interphase

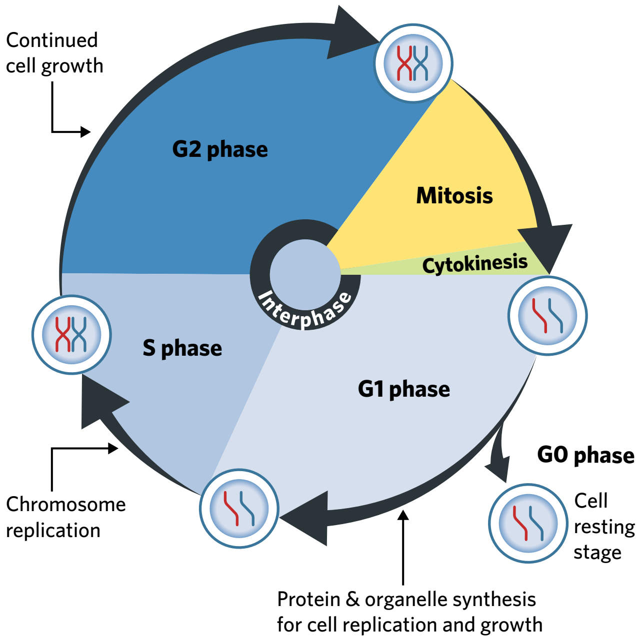


Figure 2 The sub-phases of interphase as part of the eukaryotic cell cycle

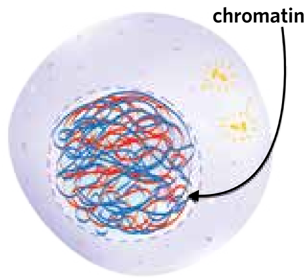


Image: Achiicchii/Shutterstock.com

Figure 3 A cell during interphase

Gap 1 (G1) phase

In the G1 phase, the cell grows by:

- increasing the volume of its cytosol
- synthesising proteins for DNA replication
- replicating its organelles.

At the end of the G1 phase, the cell either proceeds to the S phase or exits the cell cycle and enters the G0 phase.

Gap 0 (G0) phase

Cells that are not required to replicate rest in the G0 phase. Cells in G0 are either **quiescent** or **terminally differentiated**. While quiescent cells are dormant and have the ability to re-enter the cell cycle, terminally differentiated cells remain in G0 indefinitely.

quiescent dormant cells which can re-enter the cell cycle

terminally differentiated cells that have fully specialised and no longer replicate

chromatid one half of a double-stranded chromosome

centromere the structure which holds sister chromatids together

Theory in context

G0 PHASE

Ever wondered why it's so important to wear helmets while riding bikes, or while playing contact sports like rugby? The reason is that most of our nerve cells are terminally differentiated. If they are damaged, they cannot repair themselves or be replaced. Other cells, such as those in the liver, are considered to be quiescent. This is because the liver can regenerate even if a portion has been surgically removed or damaged.

Synthesis (S) phase

During the S phase, the cell replicates its DNA turning one chromosome into two genetically identical sister **chromatids** (Figure 4). While sister chromatids are held together by a **centromere**, the pair is regarded as a single chromosome. When the sister chromatids separate in mitosis, each chromatid is considered a single chromosome.

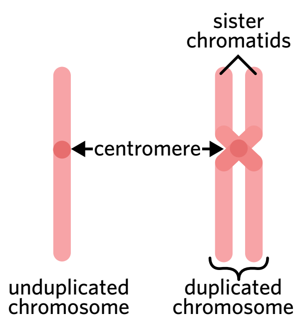


Image: Umi Kaltsumi/Shutterstock.com

Figure 4 Single and double-stranded chromosomes

In humans, our **somatic cells** are **diploid**, meaning they contain two sets of paired chromosomes as shown in Figure 5. As there are 23 chromosome pairs in humans, each somatic cell will contain 2 × 23 = 46 chromosomes. After the S phase, each somatic cell will still contain 46 chromosomes. Diploid cells are also referred to as being '2*n*', with the '*n*' referring to the number of sets of chromosomes. Each organism has its own number of chromosomes in diploid cells (2*n*). For example, each diploid cell of a sheep has 54 chromosomes (2*n*=54), and each diploid cell of a potato has 48 chromosomes (2*n*=48). It's important to note that a larger 2*n* value does not indicate greater complexity of body structures.

somatic cells any cell that is not a reproductive cell (such as sperm and egg cells). Somatic cells contain two sets of chromosomes – one inherited from each parent

diploid cells or organisms that have two sets of chromosomes (2*n*)

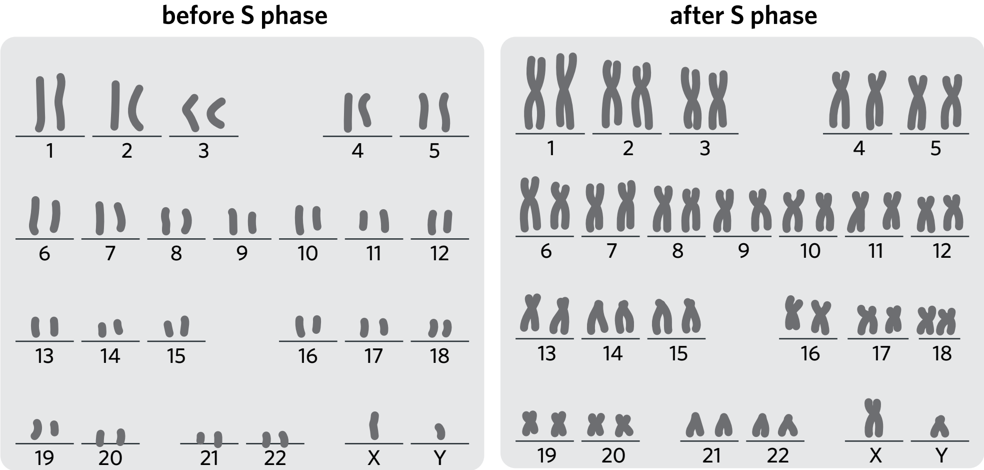


Figure 5 A karyotype comparing a human's 23 pairs of chromosomes before and after S phase

Gap 2 (G2) Phase

The G2 phase is the final stage of interphase where the cell continues to grow and prepare itself for mitosis. The G2 phase is similar to the G1 phase in that it involves:

- increasing the volume of the cytosol
- synthesising proteins in preparation for mitosis.

Mitosis and cytokinesis 1.1.6.2

OVERVIEW

Mitosis is the second stage of the eukaryotic cell cycle and involves the separation of the newly replicated chromosomes into two new nuclei. Cytokinesis is the third and final stage of the eukaryotic cell cycle, where the cell divides into two **daughter cells**.

daughter cell the formation of a new cell following cell replication

Memory device

To help remember the stages of the cell cycle, consider the following mnemonic!

I	Interphase	Isaac
P	Prophase	Please
M	Metaphase	Make
A	Anaphase	Another
T	Telophase	Two
C	Cytokinesis	Cells

THEORY DETAILS

Mitosis

Mitosis consists of four sub-stages: prophase, metaphase, anaphase, and telophase.

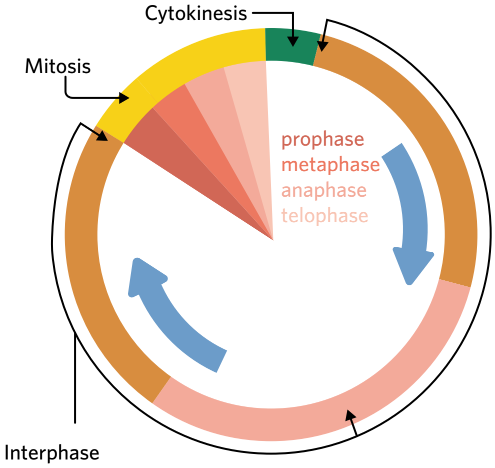
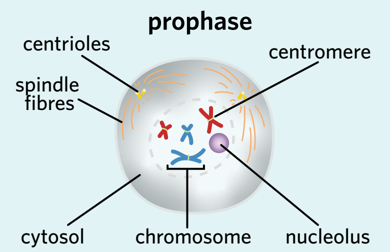
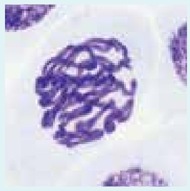
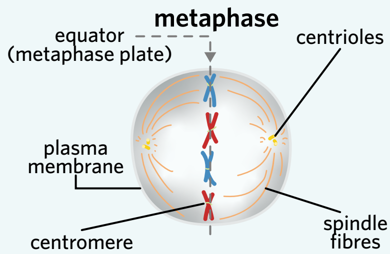
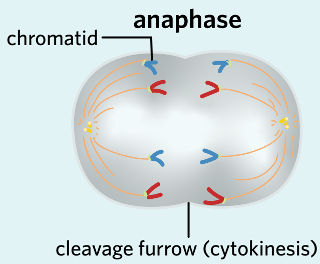
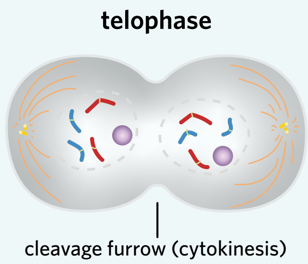


Figure 6 The sub-stages of mitosis and cytokinesis

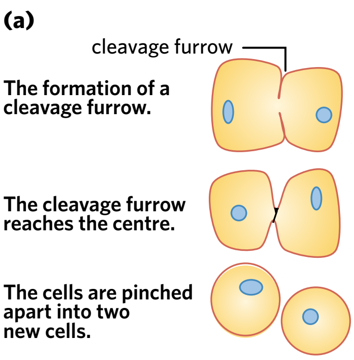
Table 1 The four stages of mitosis

Stage	Description	Image	Microscopic image
Prophase	Prophase begins with the **condensation** of chromatin around histones into distinct chromosomes, so that they become visible under a microscope. Simultaneously, the **centrioles** migrate towards opposite ends (or poles) of the cell, and **spindle fibres** begin to form. The nuclear membrane breaks down and the nucleolus disappears.		
Metaphase	In metaphase, the spindle fibres fully form and attach to the centromere of each chromosome. This allows the spindle fibres to guide the chromosomes towards the **equator** of the cell where they line up.		
Anaphase	The spindle fibres contract, splitting the centromere and pulling sister chromatids to opposite ends of the cell.		
Telophase	The chromosomes densely pack together at either end of the cell, and new nuclear membranes form, producing two genetically identical nuclei. The spindle fibres disintegrate and the chromosomes decondense. Telophase is very similar to the reverse of prophase.	 Images (top to bottom): Achiichiii/Shutterstock.com	

Cytokinesis

After mitosis, cells will undergo cytokinesis. In this stage, the cytoplasm divides and the organelles evenly distribute themselves before separating into two daughter cells.

- In animals, this occurs when a **cleavage furrow** develops and pinches the plasma membrane into two cells (Figure 7a).
- In plants, because they have a cell wall, a **cell plate** first forms at the equator before separating into two cells (Figure 7b).



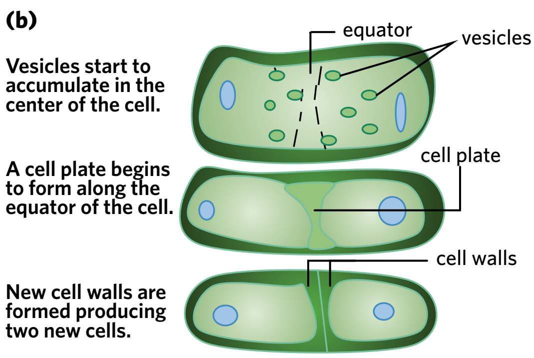


Figure 7 Cytokinesis in **(a)** animal and **(b)** plant cells

chromosome condensation the shortening and thickening of chromosomes, as DNA is tightly wrapped around histone proteins

centrioles cylindrical structures composed of protein which form the spindle fibres during mitosis and meiosis

spindle fibres structures which aid in the movement of chromosomes to either pole of the cell during mitosis and meiosis

equator the centre line between opposite ends of the cell that the chromosomes line up on during metaphase

cleavage furrow an indentation of the plasma membrane during cytokinesis

cell plate a component involved in the formation of a cell wall

Regulation of the cell cycle

The cell cycle has three checkpoints where the cell inspects itself for errors before proceeding to the next stage. These checkpoints occur at the end of the G1 and G2 phases, and during metaphase. If any errors are detected, the cell can pause for repairs. However, if the damage is irreparable, then the cell undergoes programmed cell death.

- The G1 checkpoint verifies that the cell has grown to the correct size, has synthesised enough protein for DNA replication, checks if the DNA has been damaged during mitosis and cell growth, and checks if there are enough nutrients and oxygen (favourable conditions for mitosis).
- The G2 checkpoint ensures that DNA has replicated properly in the S phase, and that the cell has enough resources for mitosis.
- In the metaphase checkpoint, the cell checks the formation of the spindle fibres. If the chromosomes are lined up in the correct location, the cell proceeds to anaphase.

Theory in action

Check out scientific investigation 4.1 to put this into action!

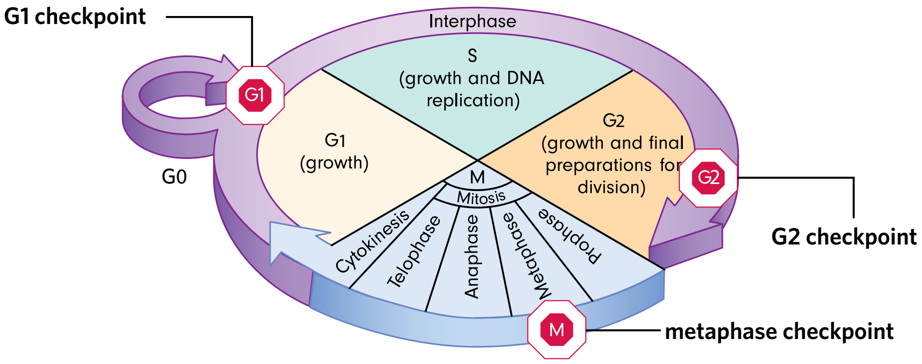


Image: Emre Terim /Shutterstock.com

Figure 8 The checkpoints of the cell cycle

Theory summary

Overall, the eukaryotic cell cycle is a complex process involving three major stages: interphase, mitosis, and cytokinesis. Interphase is the longest stage, where the cell prepares itself for replication and growth by synthesising all the necessary proteins and organelles, and by replicating DNA. Mitosis is the formation of two genetically identical nuclei. Cytokinesis is the final stage in which the cytoplasm is divided and the original cell separates into two daughter cells.

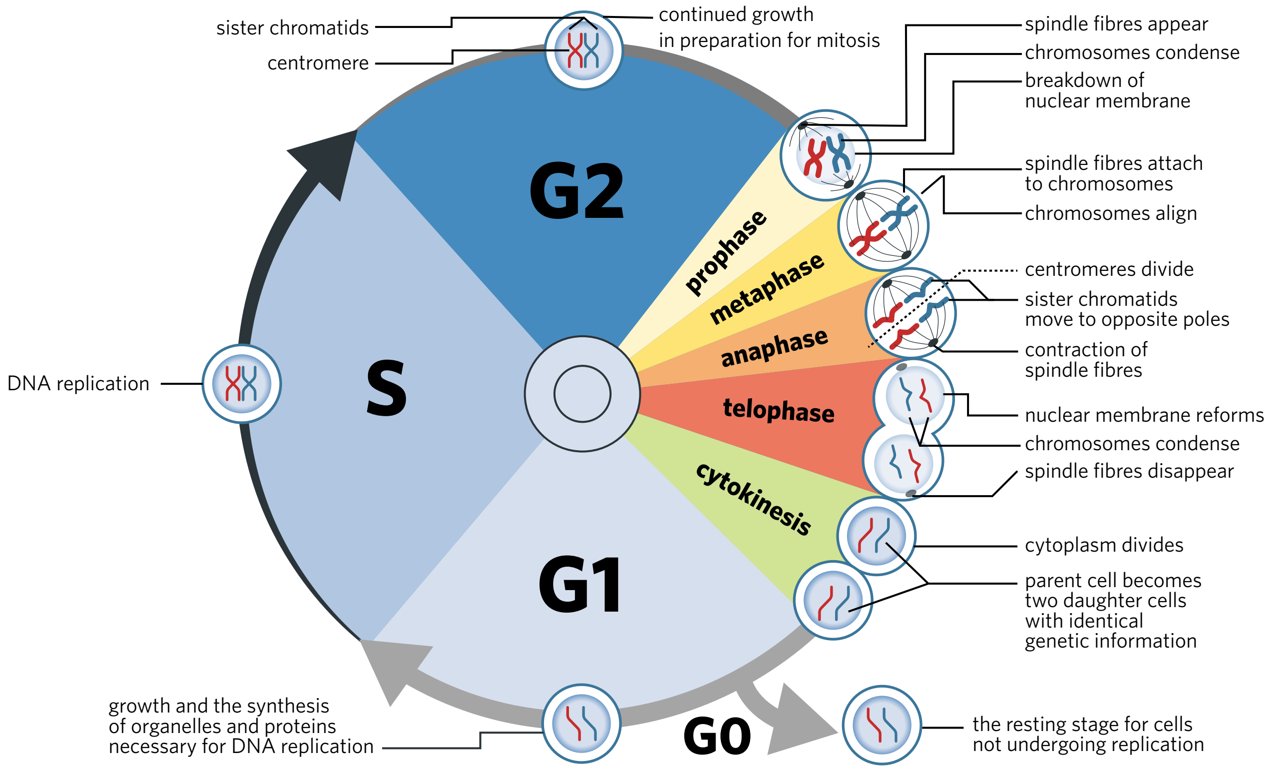


Figure 9 Summary of the eukaryotic cell cycle

Sunburn is actually caused by the harsh UV rays from the sun damaging the DNA in our skin cells. Damaged cells are then detected by the various checkpoints in the eukaryotic cell cycle and can either be repaired, or if irreparable, they can undergo programmed cell death. Our skin cells are then replenished by other skin cells when they replicate through the eukaryotic cell cycle. Unfortunately, there isn't much we can do to speed up the eukaryotic cell cycle. Maybe next time you should just remember to slip, slop, slap, seek, and slide!

4B QUESTIONS

Theory review questions

Question 1

One reason eukaryotic cells replicate is to

A replenish damaged cells.

B create an excessive number of cells.

Question 2

Fill in the blanks with the following terms.

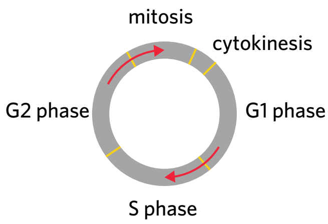
- cytokinesis
- interphase
- mitosis

The eukaryotic cell cycle begins with __________, which includes the G1 phase, G0 phase, S phase, and G2 phase. Afterwards, two genetically identical nuclei are produced through __________. Finally, in __________, the cell divides into two daughter cells.

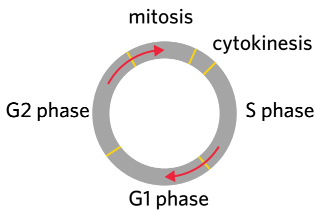
Question 3

Which of the following diagrams correctly shows the stages of the cell cycle?

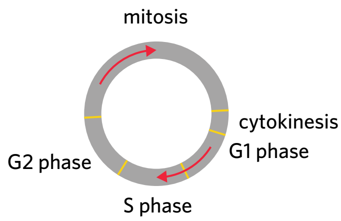
A



B



C



Question 4

Match the name of each stage from the following list to the correct description.

Stage name

- S
- G0
- G2
- G1

Stage description

I __________ the stage where cells are resting and no longer replicating. These cells are considered to be either quiescent or terminally differentiated cells

II __________ the growth of a cell through the replication of organelles, synthesis of proteins for DNA replication, and the increasing volume of the cell's cytosol

III __________ the stage where DNA replicates resulting in two genetically identical sister chromatids

IV __________ the continued growth of the cell prior to mitosis

Question 5

Mitosis does not occur in

A bacterial cells.

B fungal cells.

C plant cells.

Question 6

Mitosis in humans leads to the production of

A cells with 23 chromosomes which are not identical to the parent cell.

B cells with 46 chromosomes which are not identical to the parent cell.

C cells with 46 chromosomes which are identical to the parent cell.

D cells with 23 chromosomes which are identical to the parent cell.

Question 7

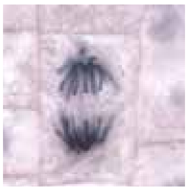
Match the stages of mitosis to their pictures.

Stage name

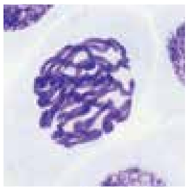
- metaphase
- prophase
- telophase
- anaphase

Stage images

I



II



III

IV

Question 8

Match the stage of mitosis to its characteristics. Terms may be used multiple times or not at all.

Stage name

- telophase
- prophase
- metaphase
- anaphase

Stage description

I __________ the formation of two genetically identical nuclei and the decondensation of chromosomes into chromatin

II __________ the reformation of the nuclear envelope and the breakdown of spindle fibres

III __________ the separation of sister chromatids into separate chromosomes

IV __________ the alignment of chromosomes along the equator of the cell

V __________ chromatin condenses into distinct chromosomes

VI __________ the nuclear membrane and nucleus disintegrate

VII __________ the completion of spindle fibre formation

VIII __________ the contraction of spindle fibres

Question 9

During cytokinesis in animals

A the nucleus divides into two genetically identical nuclei.

B the cell divides into two genetically identical cells.

Question 10

The formation of a cell plate in cytokinesis occurs in

A plant cells.

B animal cells.

SAC skills questions

Case study analysis

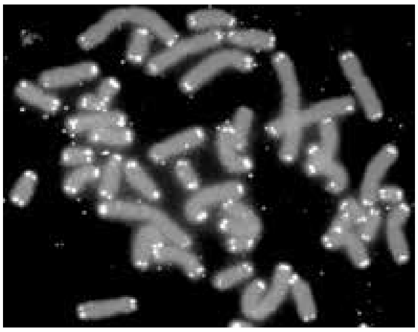
Use the following information to answer Questions 11–17.

During DNA replication, the ends of chromosomes lose small fragments of DNA. This is problematic because proteins, which are essential to all living organisms, are encoded by DNA. If DNA is lost or damaged, then certain proteins can no longer be made. Fortunately, our bodies have evolved a solution to this problem: telomeres.

Telomeres are stretches of DNA attached to the ends of chromosomes, and are shown as the white dots in the picture. Telomeres do not encode proteins, but they are vital in protecting regions of coding DNA from being damaged during DNA replication.

When the telomeres become too short, the cell initiates a programmed death sequence. Over time, as the number of cell deaths accumulate, our body's tissues gradually deteriorate and the visible effects of ageing arise.

Research into telomeres has drastically advanced our understanding of the ageing process. By measuring telomere degradation, we can measure the rate at which we age. While telomeres do shorten over time naturally, bacterial, viral, and fungal infections can speed up the process. Poor diet, lack of sleep, and dehydration also increase cellular ageing, but to a lesser extent.



Question 11

Telomeres are

A located at the ends of chromosomes.

B located in the middle of chromosomes.

Question 12

Telomeres are regions which

A code for proteins.

B do not code for proteins.

Question 13

If a cell undergoes programmed death, this may be caused by

A long telomeres.

B short telomeres.

Question 14

Fragments of telomeres are lost during

A the G1 phase.

B the G2 phase.

C the S phase.

D mitosis.

Question 15

Bacterial, viral, and fungal infections contribute heavily to ageing because such infections

A cause cellular damage which requires an increase in cell replication.

B specifically target telomeres.

Question 16

Recently, scientists have begun trialling methods to increase the length of telomeres in mice. However, the testing has been met with heavy criticism from animal rights groups claiming that their experiments are unethical. This is because

A the consequences of the treatment are unknown and potentially harmful to mice.

B they believe that the testing should instead be conducted on humans.

Question 17

After a series of successful trials in mice, scientists now offer the treatment to humans. In the treatment, parents can elect to have their embryos altered so that their children can live for longer. However, the treatment costs a large sum of money. This financial cost is problematic because the

A embryo cannot consent to this treatment.

B treatment is not equitable as it is not accessible by everyone.

Exam-style questions

Within lesson

Question 18 (1 MARK)

Metaphase occurs at which stage of the cell cycle?

A cytokinesis

B interphase

C G1 phase

D mitosis

Use the following information to answer Questions 19 and 20.

The diagram shows a cell at anaphase.

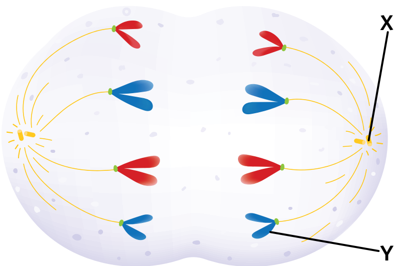


Image: Achiichii/Shutterstock.com

Question 19 (1 MARK)

The structure labelled X is a

A centriole.

B spindle fibre.

C strand of DNA.

D nuclear membrane.

Question 20 (1 MARK)

The structure labelled Y is a

A chromatin.

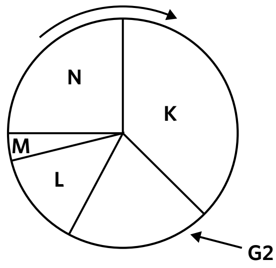
B centromere.

C chromosome.

D sister chromatid.

Question 21 (1 MARK)

The following diagram is a representation of the eukaryotic cell cycle.



Formation of two new nuclei occurs in section

A K.

B L.

C M.

D N.

Adapted from VCAA 2011 Exam 2 Section A Q1

Use the following information to answer Questions 22 and 23.

During the eukaryotic cell cycle, there are three major checkpoints where cells are inspected before proceeding to the next stage. If errors are detected at these checkpoints, the cell pauses and carries out repairs. If the errors are irreparable, then the cell undergoes a programmed death sequence. Occasionally, malfunctions arise where spindle fibres are inhibited from forming.

Question 22 (1 MARK)

The inability to form spindle fibres would have the greatest effect during

A interphase.

B anaphase.

C telophase.

D prophase.

Question 23 (1 MARK)

The inability to form spindle fibres would likely result in the

A correct alignment of the chromosomes along the equator.

B cell entering the G0 phase to carry out repairs.

C cell resting at a checkpoint indefinitely.

D programmed death of the cell.

Question 24 (1 MARK)

Which one of the following is a correct statement about the eukaryotic cell cycle?

A Chromosomes line up at the equator of the cell during metaphase.

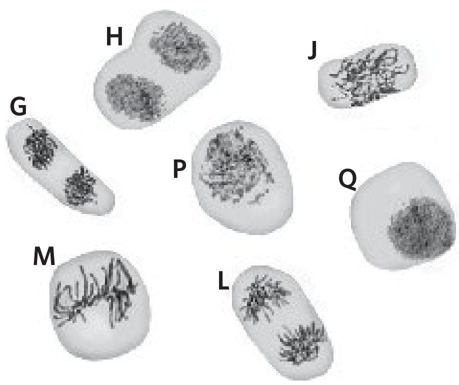
B Chromatids separate to opposite ends of the cell during prophase.

C Sister chromatids are considered to be two chromosomes.

D During telophase, a cell separates into two new cells.

Question 25 (3 MARKS)

The following images show plant cells from a tissue that is undergoing mitosis.



a State the correct order of events for mitosis with the letters G, H, J, L, M, P, and Q. (1 MARK)

b Identify and describe the stage depicted in J. (2 MARKS)

Adapted from VCAA 2012 Exam 2 Section A Q12

Multiple lessons

Question 26 (4 MARKS)

When DNA condenses into chromosomes, the DNA wraps tightly around proteins called histones. Proteins are large polymers which are made out of many repeating monomers called amino acids.

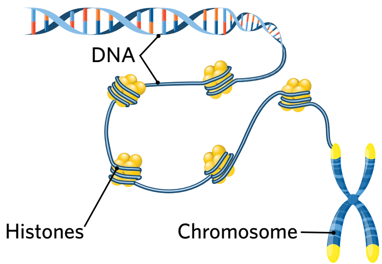


Image: Designua/Shutterstock.com

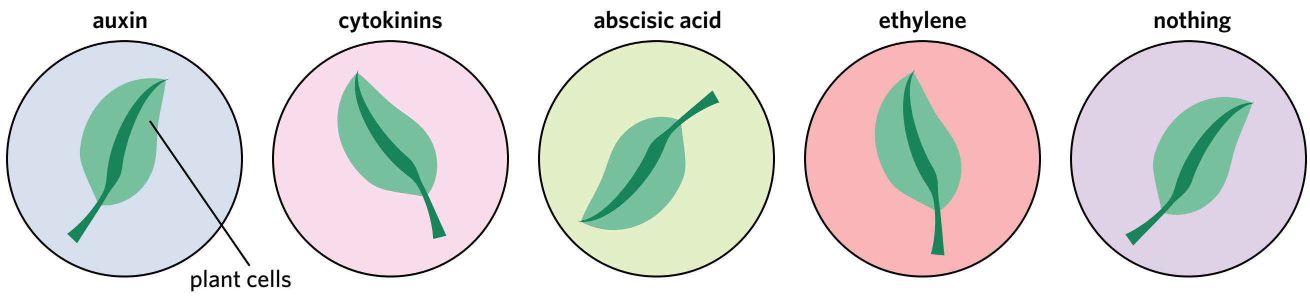
a Why do cells synthesise a large number of amino acids during the G1 phase? (2 MARKS)

b During the G1 phase, the cell also grows in size. With reference to SA:V, how would this affect transport across the membrane? (2 MARKS)

Key science skills and ethical understanding

Question 27 (9 MARKS)

There are many different plant signalling molecules known as hormones. Some examples include auxins, cytokinins, abscisic acid, and ethylene. Charlie read online that one of these hormones stimulated cell division by promoting cytokinesis. Unfortunately, he had forgotten which one it was. To identify the mystery hormone, he prepared various cultures of plant cells and placed them in a Petri dish containing the nutrients required for growth and a solution containing a single hormone. He then left each dish for several days, and then measured the size and number of cells in each culture.



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

b Identify the dependent variable. (1 MARK)

c Identify the independent variable. (1 MARK)

d Identify the control and explain the purpose of using a control in this experiment. (2 MARKS)

e Compare the process of cytokinesis in plant and animal cells. (2 MARKS)

f Just like plant hormones, similar hormones can also exist in animals. Recently, scientists have begun experimenting with cultured beef. Cultured beef is formed by nurturing muscle cells harvested from living cows. However, a debate has risen among the scientists, who have raised concerns over its commercialisation. While some claim that companies must disclose the method of production, others argue that it is not their responsibility.

Identify one potential social and biological implication relevant to the use of cultured meat. (2 MARKS)

4C APOPTOSIS

Do you have webbed fingers or toes? Do you know someone who has webbed fingers or toes? Chances are, you've encountered someone who does and they're likely better than you at swimming. It's actually more common than you probably think. Approximately one in every 2 000–3 000 babies is born with webbed fingers and toes, a condition known as syndactyly. But how does this phenomenon occur? Is there something different happening in their cells?

Image: JorgeMRodrigues/Shutterstock.com

Lesson 4C

In this lesson you will learn about apoptosis, the regulated removal of malfunctioning, diseased, or unwanted cells. When the normal cell cycle is disrupted or apoptosis malfunctions, cancer can develop.

◀ Prerequisite knowledge

Lesson 3A
Receptors for signalling molecules are embedded within the plasma membrane.

Lesson 4B
The cell cycle is regulated by a series of checkpoints at the ends of the G1 phase, G2 phase, and metaphase.

Future applications ▶

Lesson 4D
Tissues or cell types damaged by cancer can be replaced using differentiated stem cells.

Year 12
Immune cells are involved in the stimulation and functioning of apoptosis.

Study design dot points

- apoptosis as a regulated process of programmed cell death
- disruption to the regulation of the cell cycle and malfunctions in apoptosis that may result in deviant cell behaviour: cancer and the characteristics of cancer cells

Key knowledge units

Introducing apoptosis	1.1.7.1
Stages of apoptosis	1.1.7.2
Apoptosis and cancer	1.1.8.1

Introducing apoptosis 1.1.7.1

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.

apoptosis the controlled death of cells in the body. Also known as **programmed cell death**

THEORY DETAILS

Our body is made up of 30 – 40 trillion cells. Of these, scientists think that ~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 becomes unnecessary it will receive signals that initiate apoptosis, causing the eventual death of the cell.

There are two pathways of apoptosis: the **mitochondrial** and the **death receptor pathways** (Table 1), both of which cause the activation of **caspase enzymes**. Following caspase activation, the two pathways become nearly identical.

Image: Kateryna Kon/Shutterstock.com

Figure 1 A model of a cell undergoing apoptosis

Table 1 The mitochondrial and death receptor pathways of apoptosis

Pathway	Description
Mitochondrial pathway	When internal components of the cell (such as DNA) are damaged mitochondria detect this damage and release **cytochrome c** into the cytosol. Cytochrome c binds with cytosolic proteins to form an apoptosome, which activates caspase enzymes, initiating apoptosis.
Death receptor pathway	Death signalling molecules can be recognised by death receptor proteins on the surface of cells, and are often released by immune cells. When these molecules bind to a death receptor surface protein, caspase enzymes are activated, initiating apoptosis.

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 catalysts that cleave specific intracellular proteins during apoptosis

cytochrome c a protein embedded in the inner mitochondrial membrane

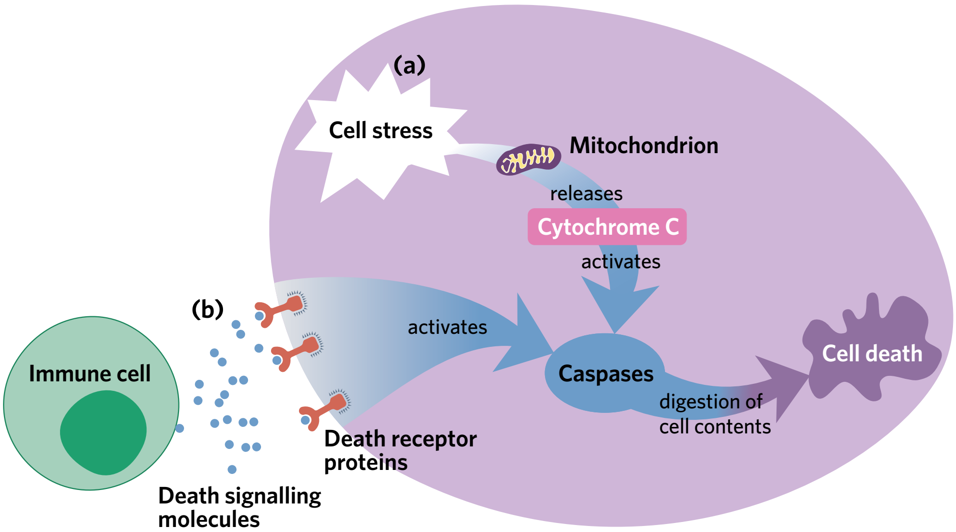


Figure 2 The **(a)** mitochondrial and **(b)** death receptor pathways of apoptosis

Theory in context

NECROSIS

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 in nearby cells and tissues.

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 internal signals. This leaves the death receptor pathway as the external pathway of apoptosis and is triggered by signals external to the cell.

Stages of apoptosis 1.1.7.2

OVERVIEW

Following the initiation of apoptosis and the activation of caspases, apoptosis is composed of the following stages: digestion of cell contents, cell shrinking, membrane blebbing and formation of apoptotic bodies.

THEORY DETAILS

After the activation of caspases and the initiation of apoptosis, apoptosis progresses as the four-stage process:

1 Activation of caspases – the mitochondria detect internal DNA damage and release cytochrome C.

2 Digestion of cell contents – caspases cleave intracellular proteins, which leads to the breakdown of organelles.

3 Cell shrinks – the cell and nucleus shrink as intracellular material is broken down.

4 Membrane **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 broken down intracellular material.

blebbing the bulging of the plasma membrane to form apoptotic bodies

apoptotic bodies vesicles containing cell contents that are released from a dying cell during apoptosis and engulfed by phagocytes

After apoptosis, **phagocytes** engulf and digest the free-floating apoptotic bodies by **phagocytosis**.

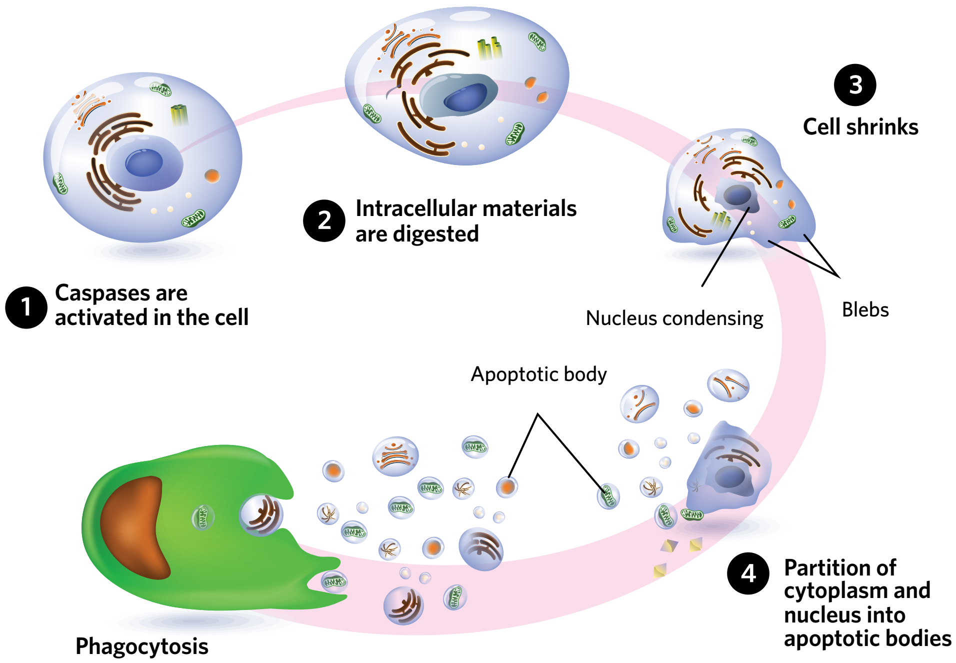


Image: Designua/Shutterstock.com

Figure 3 The process of apoptosis. Note that phagocytosis occurs after apoptosis and is not considered a stage of apoptosis

phagocyte a cell of the immune system responsible for engulfing and destroying harmful microorganisms and foreign material

phagocytosis endocytosis of solid material or food particles

Apoptosis and cancer 1.1.8.1

OVERVIEW

If the cell cycle is disrupted or insufficient, damaged cells can replicate exponentially, leading to the development of tumours and cancers.

THEORY DETAILS

When functioning properly, apoptosis is vital to the healthy functioning and development of 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. You should remember from lesson 4B that there are a series of checkpoints in the eukaryotic cell cycle which regulate cell replication:

- G1 checkpoint – inspects for DNA damage
- G2 checkpoint – confirms that DNA has correctly replicated in the S phase
- Metaphase checkpoint – confirms that spindle fibres have correctly attached to the centromeres of chromosomes.

If errors are detected at any of these checkpoints, the cell should either repair itself or undergo apoptosis. Note that failure to initiate apoptosis is not always a result of errors occurring at the checkpoints. For example, cells may no longer express functional death receptor proteins, leading to an inability for death signalling molecules to initiate apoptosis By failing to initiate, cells have a reduced rate of apoptosis.

Unfortunately, when the rate of apoptosis decreases too much, cell growth can increase exponentially, resulting in the formation of **tumours**. Tumours can be classified into two categories:

- **benign tumours** – these are relatively slow-growing masses of cells that are generally enclosed within a capsule which prevents the abnormal cells from separating and invading other parts of the body
- **malignant tumours** – the cells of some benign tumours can mutate further and become malignant when they gain the ability to invade nearby tissues and/or enter the bloodstream or lymphatic system. From here, they can travel to other parts of the body and grow.

tumour a mass of abnormal cells

benign tumour a tumour that lacks the ability to spread throughout other tissues and organs

malignant tumour abnormal cells with the ability to invade nearby tissue and migrate to other parts of the body. Also known as **cancerous cells**

While benign and malignant tumours share similar characteristics, only malignant tumours are considered to be **cancerous** due to their ability to migrate from the primary tumour site and invade other tissues. In Table 2, the characteristics of both benign and malignant tumours/cancer cells are summarised. It's important to note that the final characteristic – tissue invasion and metastasis – is unique to cancer cells.

cancer a disease caused by the uncontrolled replication of cells with the ability to migrate to other parts of the body

Table 2 Characteristics of benign tumours and malignant tumours/cancer cells

Characteristic	Description
Self-sufficiency	Typically, cells require chemical growth signals to initiate cell replication. However, in tumour cells, they can replicate without these signals by either producing their own chemical signals, or by permanently activating cell growth and replication pathways.
Antigrowth deactivation	There are many different mechanisms present in cells to prevent cell replication when it is not needed. In tumour cells, these mechanisms can be disabled, thereby allowing cell replication to initiate.
Increased survival	Due to mutations in the regulation of the cell cycle, apoptosis no longer functions correctly in tumour cells. Tumour cells are also capable of replicative immortality, which theoretically allows them to divide forever, enhancing their survival. However, in practice, due to limitations such as the inability for blood vessels to form in the centre of tumours and provide the necessary nutrients, tumour cells can still die.
Blood supply formation	Tumour cells can form new blood vessels when growing to maintain adequate nutrient and oxygen supply.
Tissue invasion and metastasis	When benign tumour cells become malignant/cancerous they are capable of invading nearby layers of tissue and migrating to other parts of the body away from the primary tumour site, typically via the bloodstream or lymphatic system (**metastasis**).

metastasis the migration of tumour cells from the primary tumour site to distant parts of the body

Figure 4 Human lung cancer

Theory in context

INCREASING APOPTOSIS: DISEASES AND DISORDERS

Apoptosis is sometimes kicked into overdrive, which makes healthy cells undergo programmed cell death.

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). 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.

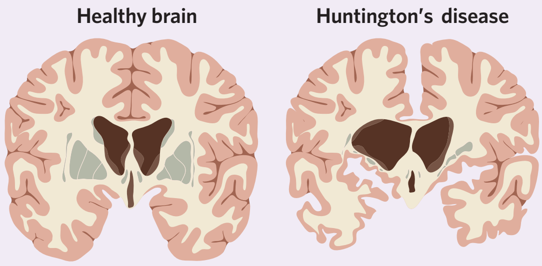


Image: Blamb/Shutterstock.com

Figure 5 Sufferers of Huntington's disease, a neurological disorder, often have large tissue gaps caused by excessive cell death.

Theory summary

Apoptosis is an integral process of the body. It is necessary for controlling total cell numbers in the body and for the removal of diseased or damaged cells. There are two pathways of apoptosis initiation: the mitochondrial pathway (which recognises intracellular signals) and the death receptor pathway (which recognises extracellular signals).

Following caspase activation and apoptosis initiation, apoptosis involves the digestion of cell contents, the shrinking of the cell, and the blebbing and breakage of the cell. Following apoptosis, apoptotic bodies are digested by phagocytes.

Disruptions to the cell cycle and cell function can cause malfunctions in apoptosis. A decrease in the rate of apoptosis can cause the accumulation of cells, resulting in diseases such as cancer.

When apoptosis does not occur sufficiently during development, abnormalities can arise. For example, as foetuses, our fingers and toes are all fused by skin. As we develop, our bodies induce apoptosis in the cells of the skin between our fingers to form individual digits. Foetuses with syndactyly have a decreased rate of apoptosis during development, causing the skin between their fingers to remain intact, resulting in webbed fingers.

4C QUESTIONS

Theory review questions

Question 1

Apoptosis

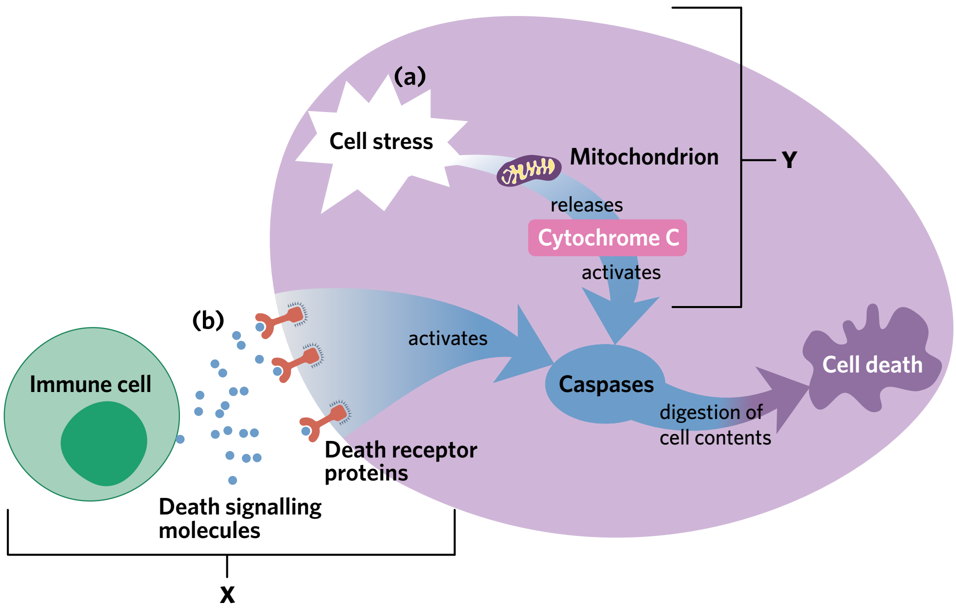
A only begins after significant damage to a cell.

B causes cell death in a controlled manner.

C causes a cell to expand and rupture.

Question 2

Label each pathway, X and Y, as either the 'mitochondrial pathway' or the 'death receptor pathway'.



Question 3

Both the mitochondrial and the death receptor pathways of apoptosis involve

A the release of cytochrome c.

B activation of caspases.

Question 4

Fill in the blanks with the following terms.

- apoptotic bodies
- proteins
- shrinks

After the initiation of apoptosis, caspases begin digesting __________ within the cell. Then, the cell __________, the nucleus becomes smaller, and intracellular material is digested. Finally, the cell blebs and breaks apart into __________.

Question 5

The digestion of apoptotic bodies by phagocytes occurs

A before apoptosis.

B during apoptosis.

C after apoptosis.

Question 6

Fill in the blanks with the following terms. Terms may be used multiple times or not at all.

- death signalling molecules
- decrease
- cancer
- increase

Many diseases are caused by an alteration in the rate of apoptosis in particular tissues of the body. A __________ in the rate of apoptosis can be caused by the lack of __________, increasing the chances of developing __________.

Question 7

Which of the following are checkpoints of the cell cycle? (*Select all that apply*)

I metaphase checkpoint

II anaphase checkpoint

III telophase checkpoint

IV prophase checkpoint

V G1 checkpoint

VI G2 checkpoint

VII S checkpoint

Question 8

Some cells may be resistant to apoptosis if they

A don't produce enough death signalling molecules inside the cell.

B express non-functional death receptors.

Question 9

Match each characteristic of cancer cells to its description.

Characteristic of cancer cell

- increased survival
- self-sufficiency
- antigrowth deactivation
- tissue invasion and metastasis

Description

I __________ decreased rates of apoptosis and the theoretical ability to replicate infinitely

II __________ the inhibition of mechanisms which prevent cell replication

III __________ the occupation and migration of abnormal cells to other parts of the body

IV __________ the production of chemical signals which initiate cell replication or the permanent activation of cell replication pathways

SAC skills questions

Case study analysis

Use the following information to answer Questions 10–16.

In 2019, it was estimated that over 3 000 Australians were diagnosed with bladder cancer (Australian Institute of Health and Wellbeing [AIHW], 2019). Bladder cancer involves the uncontrolled growth of cells which originate from the lining of the bladder. In an effort to combat the increasing rates of bladder cancers, scientists have turned to an unexpected ally: anthrax.

Anthrax is a toxin released by the bacterium *Bacillus anthracis* and is often associated with bioterrorism. When inhaled, individuals develop severe breathing problems. The mortality rate of those infected with inhaled anthrax is 70–80% if early detection and treatment do not occur. Jack et al. (2019) are now using a modified strain of the toxin which binds to a receptor located on the surface of cancerous bladder cells. The scientists hope that by injecting this modified strain of anthrax into patients, it will stimulate apoptosis in cancerous bladder cells.

Before scientists begin human trials, they have decided to experiment on terminally ill dogs. Fortunately, after five rounds of the treatment, scientists documented a 30% reduction in the size of malignant tumours within dogs (Jack et al., 2019). With such promising results, human trials are definitely on the horizon. Who would have thought that something conventionally considered a death sentence would now be used to treat cancer?

Question 10

Bladder cancer involves the formation of tumour cells

A enclosed by a sturdy capsule.

B in the lining of the bladder capable of invading nearby tissues.

Question 11

If anthrax is inhaled, then individuals will have

A a 70–80% chance of dying.

B breathing difficulty.

Question 12

The results of the trial in dogs suggest that

A modified anthrax may be an effective treatment for bladder cancer.

B anthrax is an effective weapon for bioterrorists.

Question 13

Bladder cancer is caused by

A too much apoptosis.

B a lack of apoptosis.

Question 14

A reduction in malignant tumour size suggests that the

A bladder cells are having more difficulty forming their own blood vessels.

B mutations in regulatory proteins must have been repaired.

C rate of cell growth is less than the rate of apoptosis.

D bladder cells are producing more growth factors.

Question 15

Anthrax stimulates apoptosis by initiating the

A death receptor pathway and the release of cytochrome c.

B mitochondrial pathway and the release of cytochrome c.

C mitochondrial pathway and the activation of caspases.

D death receptor pathway and the activation of caspases.

Question 16

To test whether anthrax was effective at reducing the number of cancerous bladder cells, researchers began by using dogs as test subjects. Based on the ethical principle of non-maleficence, scientists should have first

A cultured cancerous cells *ex vivo* to reduce harm to the dogs and other animals.

B used smaller animals such as rats to reduce harm to the dogs.

Exam-style questions

Within lesson

Question 17 (1 MARK)

Cells can die by apoptosis or necrosis. Apoptosis

A begins after the plasma membrane is pierced by death signalling molecules.

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.

Question 18 (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 19 (1 MARK)

During apoptosis, blebbing

A can be characterised by bulging of the plasma membrane.

B is only caused by damage done to the DNA of a cell.

C causes a cell to appear smoothed out and stretched.

D occurs after the production of apoptotic bodies.

Question 20 (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 brain cells (neurons) via apoptosis.

In the brain of someone suffering from Alzheimer's, you would expect to find

A high concentrations of free-floating caspases.

B increased numbers of old brain cells.

C high concentrations of phagocytes.

D excessive tumours.

Question 21 (2 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. (1 MARK)

b What role is carried out by phagocytes after apoptosis? (1 MARK)

Multiple lessons

Question 22 (8 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. Changes in the structure of the death receptor protein may prevent death signalling molecules from stimulating apoptosis.

a Explain why the misfolding of the receptor protein can increase chances of developing thyroid lymphoma. (2 MARKS)

b Certain proteins in the BCL-2 family have been known to repress the mitochondrial pathway of apoptosis.

- **i** Identify the primary function of the mitochondria within cells. (1 MARK)
- **ii** Outline the steps in the mitochondrial pathway of apoptosis. (3 MARKS)
- **iii** Predict the activity of BCL-2 proteins in cancerous cells compared to normal cells. Justify your response. (2 MARKS)

Key science skills and ethical understanding

Question 23 (7 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 'malignant 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 molecules 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 ageing 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 ~30% (Baker et al., 2016). In Australia, senolytic drugs have not yet been approved for human trials.

a Identify two types of 'apoptosis-resistant' cells. (1 MARK)

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)

d Often, doctors withhold treatment to terminally ill cancer patients. Doctors may do this if they believe that further treatment would severely impact their patient's quality of life. However, patients and their families may sometimes disagree with the doctor's assessment and demand further treatment.

Using an ethical principle, discuss whether doctors should be allowed to withhold treatment from patients. (2 MARKS)

4D STEM CELLS

It's a typical 40°C day in Melbourne and as usual, your nose suddenly begins bleeding. As blood trickles down your face, you scramble for some tissues to help stop the bleeding. After much effort, the bleeding stops, but not before you've ruined several tissues and your new t-shirt.

Because red blood cells don't have a nucleus, they cannot replicate by mitosis. However, this doesn't mean that you will be forever deficient in red blood cells. In fact, red blood cells are constantly being replenished. But where do they come from? How are they produced?

Image: BeautifulPicture/Shutterstock

Lesson 4D

In this lesson you will learn about stem cells, which have the remarkable ability to develop into a number of specialised cell types.

◀ *Prerequisite knowledge*

Years 7–10
Multicellular organisms rely on coordinated and interdependent internal systems which are composed of specialised cells produced by stem cells.

Future applications ▶

Lesson 9B
Stem cells may be useful when cloning organs or an entire organism, where unspecialised stem cells are created and induced to develop into various types of body cells.

Year 12
Particular stem cells can differentiate into immune cells.

Study design dot point

- properties of stem cells that allow for differentiation, specialisation, and renewal of cells and tissues, including the concepts of pluripotency and totipotency

Key knowledge units

What are stem cells?	1.1.9.1
Potency of stem cells	1.1.9.2

What are stem cells? 1.1.9.1

OVERVIEW

Stem cells are undifferentiated cells with the capability of differentiating into specialised cells with a particular function.

THEORY DETAILS

What is a stem cell?

In our body, there are many different types of cells such as heart cells, skin cells, and neurons. These cells don't just magically appear. Instead, each cell begins as a **stem cell** and through the process of **differentiation**, they develop into **specialised** cells with a particular function. For example, blood stem cells give rise to platelets, red blood cells, and white blood cells (Figure 1). To be considered a stem cell, a cell must be unspecialised and capable of self-renewal (Table 1).

stem cell undifferentiated cells with the capability of differentiating into specialised cells

differentiation the development of a stem cell into a specialised cell with a particular function

specialised cells which serve a unique, particular function

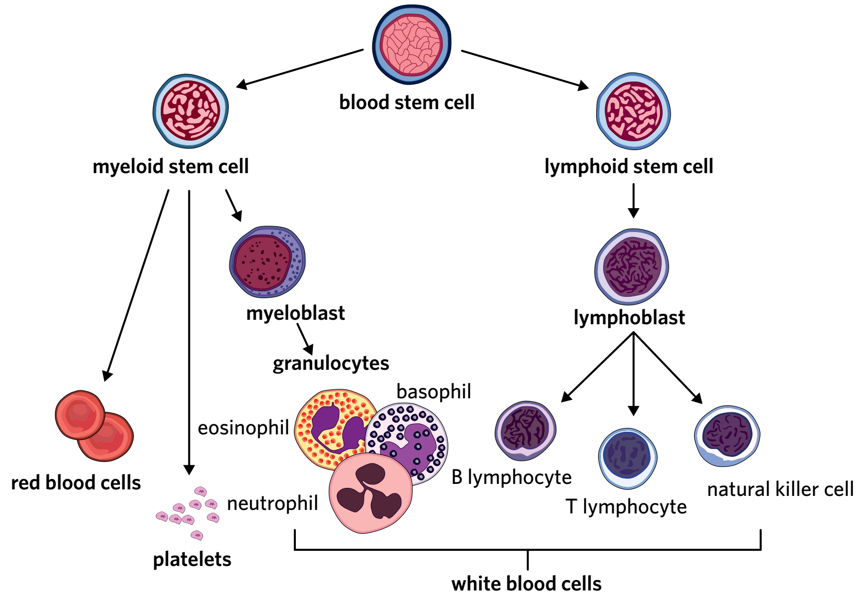


Image: Udaix/Shutterstock.com

Figure 1 The differentiation of a blood stem cell

Table 1 The two properties of stem cells

Property	Description
Self-renewal	Stem cells have the capacity to replicate without disrupting their ability to differentiate by producing both a differentiated cell and a copy of themselves when they replicate (Figure 2).
Potency	Stem cells are undifferentiated cells which can give rise to differentiated cells with a specialised function.

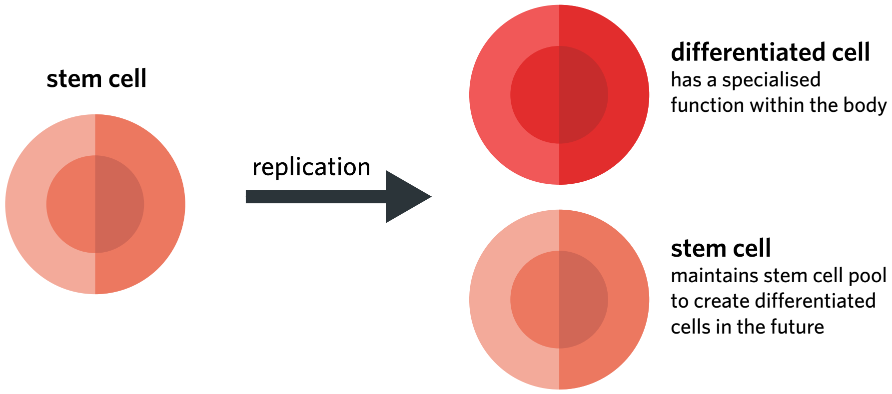


Figure 2 The stem cell properties of differentiation and self-renewal

Potency of stem cells 1.1.9.2

OVERVIEW

The potency of a stem cell measures its capacity to differentiate into different cell types.

THEORY DETAILS

Not all stem cells are created equal. Instead, they have varying capabilities, with some stem cells being able to differentiate into any cell type, and others capable of differentiating into only a handful of cell types. Based on these relative capabilities, we can categorise stem cells according to their relative potency. The more cell types a stem cell can differentiate into, the greater its potency. The different potencies are outlined in Table 2.

Table 2 Stem cell potencies

Potency	Description	Examples
Totipotent	Stem cells that can differentiate into any cell type.	The **zygote**, which is the first cell produced following fertilisation of an egg cell by sperm. This cell can differentiate into placental cells and any of the cells required to build a **foetus**.
Pluripotent	Stem cells that can differentiate into multiple cell types.	**Embryonic stem cells**, which are found in the early stages of a developing embryo. These cells can differentiate into all cell types of the body (except the placenta) via three distinct germ layers of cells called the mesoderm, endoderm, and ectoderm.
Multipotent	Stem cells that can differentiate into a limited number of specialised cell types belonging to a specific tissue or organ.	The **bone marrow** contains blood stem cells (also known as haematopoietic stem cells) that can differentiate into a variety of different blood cells including red blood cells, white blood cells, and platelets (Figure 1). Mesenchymal stem cells, which are also located in the bone marrow, are capable of differentiating into bone cells, cartilage cells, muscle cells, and fat cells.

totipotent stem cells which can differentiate into any cell type

zygote the diploid cell formed by the combination of two haploid gamete cells

foetus a human embryo after 8 weeks of development

pluripotent stem cells that can differentiate into multiple cell types

embryonic stem cell a pluripotent stem cell present during the early stages of human development

multipotent stem cells which can differentiate into a limited number of specialised cell types belonging to a specific tissue or organ

bone marrow semi-solid tissue found within bones. Serves as the primary site of the creation of red blood cells and leukocytes

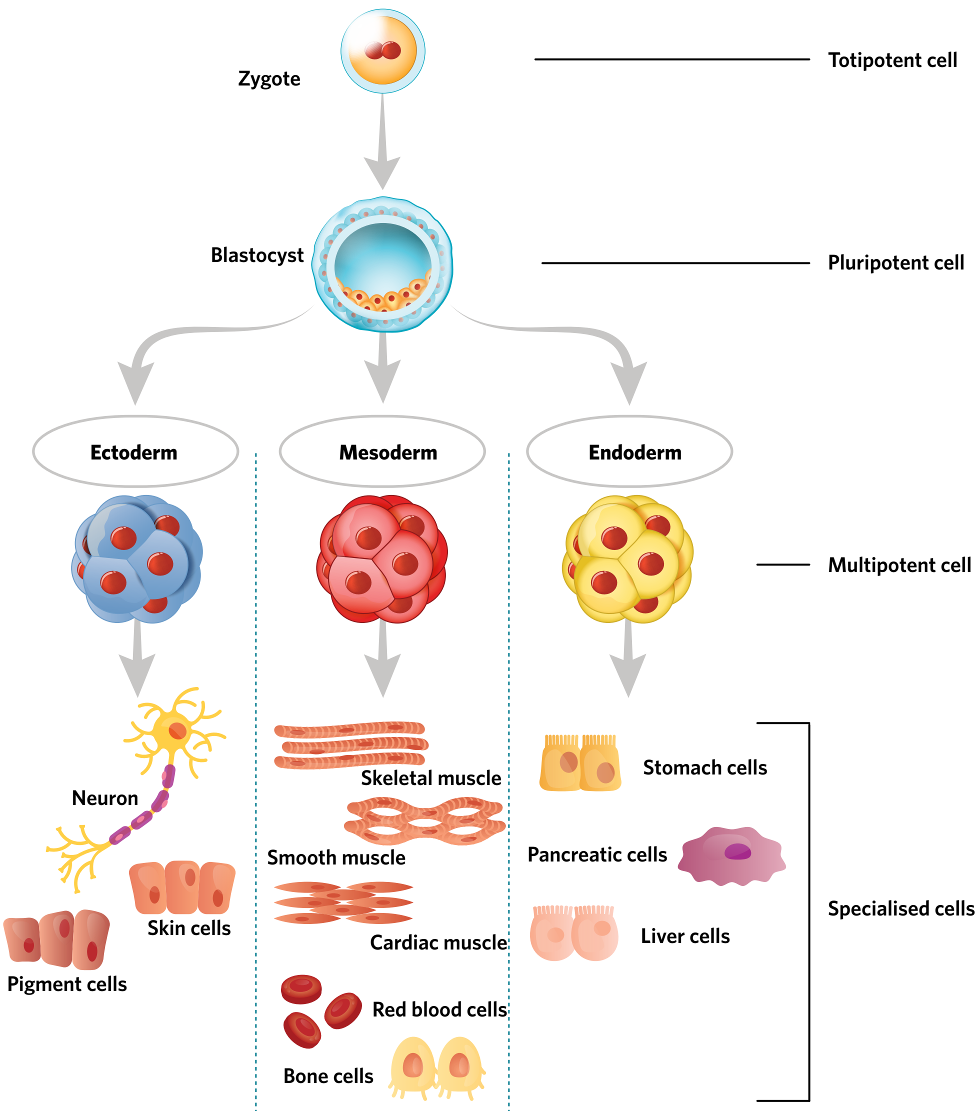


Image: Designua/VectorMine/Shutterstock.com

Figure 3 A diagrammatic representation of stem cell potency

Theory in context

INDUCED PLURIPOTENT STEM CELLS

In 2006, Shinya Yamanaka and his fellow researchers at Kyoto University in Japan discovered a method to genetically reprogram specialised somatic cells such as skin cells into pluripotent stem cells. By introducing four specific segments of DNA into these cells, Yamanaka was able to reverse the process of differentiation. These cells became known as induced pluripotent stem cells. While there are still many challenges with induced pluripotent stem cells, including the low success rate of undifferentiation and the tendency to form tumours, induced pluripotent stem cells are very promising in the field of regenerative medicine.

Theory summary

Stem cells are undifferentiated cells with the capability of specialising into cells with a specific function. Stem cells can undergo differentation and create more stem cells through the process of self-renewal.

Their ability to differentiate into different cell types can be measured using potency. Totipotent cells can differentiate into any cell type, pluripotent cells can differentiate into many cell types, and multipotent cells can differentiate into a limited number of cell types belonging to a specific tissue or organ.

In our bone marrow, there are blood stem cells which differentiate into the various components of our blood including red blood cells, white blood cells, and platelets. Interestingly, red blood cells die at a rate of around two million cells per second and are constantly replenished at an equal rate. Therefore, our bodies are well equipped to handle a simple nosebleed!

4D QUESTIONS

Theory review questions

Question 1

Stem cells are

A undifferentiated cells that can differentiate into unspecialised cells.
B differentiated cells that can differentiate into unspecialised cells.
C undifferentiated cells that can differentiate into specialised cells.
D differentiated cells that can differentiate into specialised cells.

Question 2

A stem cell's ability to produce both a differentiated cell and a copy of itself is known as

A self-renewal.
B specialisation.
C differentiation.

Question 3

Stem cells with a greater potency can differentiate into

A more cell types.
B less cell types.

Question 4

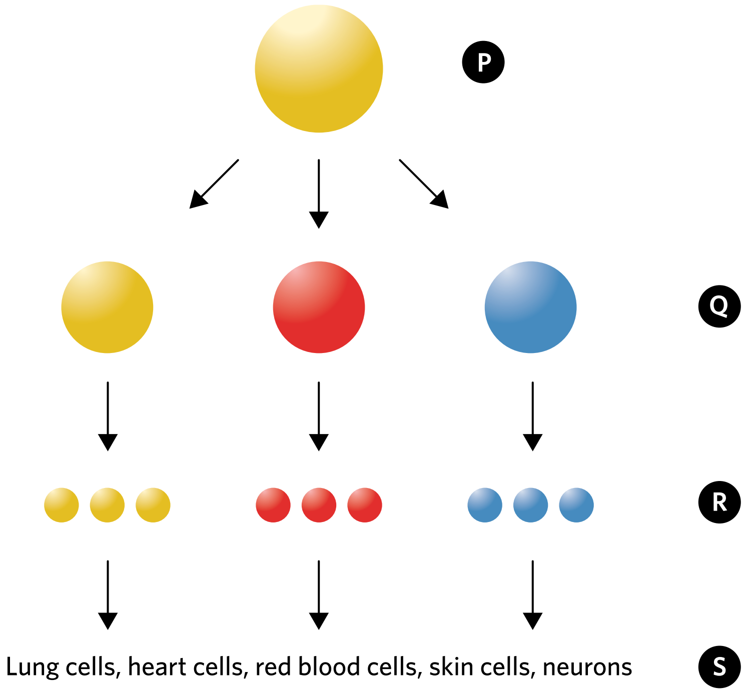
Match each potency to its description.

Cell type	**Potency**	
• pluripotent	**I**	________ stem cells that can differentiate into any cell type
• totipotent	**II**	________ stem cells that can differentiate into several specialised cell types within a particular organ or tissue
• multipotent	**III**	________ stem cells that can differentiate into multiple cell types

Question 5

Label the parts of the diagram from the list of terms.

- multipotent stem cells
- pluripotent stem cells
- totipotent stem cells
- specialised cells



Question 6

Scientists are interested in stem cells because

A all diseases can only be treated using stem cells.

B the only way to repair cells is with stem cells.

C they can be used to regenerate tissue.

SAC skills questions

Bioethical deep dive

Use the following information to answer Questions 7–12.

The potential for stem cells to differentiate into any cell has interested scientists for decades. In particular, researchers are interested in the application of stem cells in regenerating damaged tissues, which could be used to help people suffering from untreatable conditions such as paraplegia (paralysis of the lower body). However, scientists are still many years from developing effective treatments. Bone marrow transplants are currently the only clinically approved stem cell transplant.

Despite a lack of clinical approval and scientific evidence, many clinics have surfaced offering stem cell therapies promising 'miracle' cures. Often, these clinics coerce patients by withholding important information, masking the dangers of stem cell therapy with the hope for a cure. Typically, these clinics will even cite circumstantial research papers detailing successful attempts in small groups of animals, claiming that these successes can be seen in humans as well. The widespread misinformation about the effectiveness of unproven stem cell therapies is also increasing due to journals failing to publish negative research papers, which has led to a seemingly greater amount of evidence in favour of stem cell therapy.

Question 7

Stem cell therapies are

A well-developed with the capability to treat a variety of different illnesses.

B still relatively new and unproven.

Question 8

Widespread misinformation about stem cell therapy is accelerated by

A research papers detailing unsuccessful stem cell therapies in animals.

B journals which refuse to publish negative data.

Question 9

Bone marrow transplants involve blood stem cells which can only differentiate into a limited number of blood cells. Therefore, blood stem cells are

A totipotent.

B pluripotent.

C multipotent.

Question 10

Stem cell therapy involves the use of cells which are capable of

A replicating into both a differentiated and undifferentiated cell.

B only replicating into differentiated cells.

Question 11

Withholding information about a specific treatment

A violates the ethical principle of respect as the patient can no longer make an autonomous and informed decision.

B is justified based on the ethical principle of beneficence because withholding information offers false hope to the patient.

Question 12

Publishing only positive research papers violates the ethical principle of

A integrity, as all results should be communicated whether favourable or unfavourable.

B non-maleficence, because researchers should only be focused on maximising benefits.

Exam-style questions

Within lesson

Question 13 (1 MARK)

A zygote is a stem cell produced by the fusion of an egg cell with a sperm cell. Because zygotes differentiate and give rise to every cell in the body, zygotes are a

A multipotent stem cell.

B pluripotent stem cell.

C totipotent stem cell.

D unipotent stem cell.

Question 14 (1 MARK)

In organ transplants, recipients are often at risk of organ rejection. This is because when cells from another individual are introduced into the body, the body can sometimes recognise the cells as foreign, thereby launching an immune response. To reduce this risk, researchers hope to develop organs from an individual's own differentiated skin cells by reprogramming them into pluripotent stem cells. In order to achieve this, scientists must

A know how binary fission works.

B know how to remove organs from an adult.

C be able to reverse the process of differentiation.

D insert DNA from the desired organ into skin cells.

Multiple lessons

Question 15 (8 MARKS)

Often, cancerous stem cells can evade the effect of death signalling molecules, allowing them to rapidly proliferate and produce large tumours.

a Describe how scientists could differentiate between cancerous stem cells and normal cancer cells. (2 MARKS)

b Describe the process which normally prevents the formation of tumours. (3 MARKS)

c Suggest how a cancerous stem cell may evade the effect of death signalling molecules. (1 MARK)

d Explain why cancerous stem cells may need to form new blood vessels. (2 MARKS)

Key science skills and ethical understanding

Question 16 (13 MARKS)

Embryonic stem cells (ESCs) are cells which are harvested from a growing embryo. Unfortunately, by harvesting ESCs the embryo perishes, which has sparked a lot of controversy over research into ESCs. Scientists are particularly interested in ESCs because they are pluripotent, meaning they can differentiate into many different types of cells, such as muscle cells or neurons.

a Describe the differences between totipotent, pluripotent, and multipotent stem cells. (1 MARK)

b A researcher's decision to harvest embryonic stem cells is heavily influenced by bioethical principles.

  i Suggest how the decision to harvest embryonic stem cells might be influenced by the ethical principle of beneficence. (2 MARKS)

  ii Suggest how the decision to harvest embryonic stem cells might be influenced by the ethical principle of non-maleficence. (2 MARKS)

c In a clinical trial, scientists decided to investigate the potential for a new stem cell treatment to regenerate damaged muscle tissue. To conduct this trial, they established two groups of five people, all with the same health status. In the first group, they injected the treatment of stem cells. In the second group, they only injected a 0.9% saline solution, which is not expected to yield the regeneration of tissue. To determine whether the treatment was successful, scientists measured the growth of muscle tissue after treatment.

  i Identify the hypothesis of the experiment. (1 MARK)

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

  iii Explain why the scientists injected the second group with a 0.9% saline solution. (2 MARKS)

  iv Suggest how the scientists could improve the accuracy of this experiment. (1 MARK)

d Recently, scientists have discovered a method to harvest adult somatic cells such as skin fibroblast cells and reverse the process of differentiation to produce stem cells called induced pluripotent stem cells.

  i Describe the process of differentiation. (1 MARK)

  ii Suggest an advantage of using induced pluripotent stem cells compared with embryonic stem cells. (1 MARK)

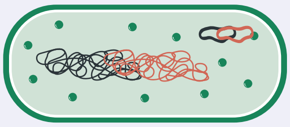
CHAPTER 4 SUMMARY

Cell replication

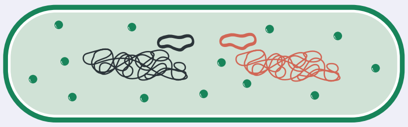
Cell type	Purpose of replication	Method of replication
Eukaryote	• Reproduction • Growth and development • Maintenance and repair	Mitosis and meiosis
Prokaryote	• Reproduction	Binary fission

Binary fission

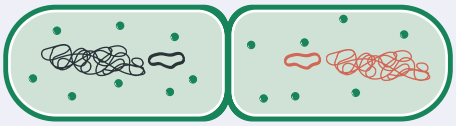
1 DNA replication – the circular chromosome uncoils and replicates



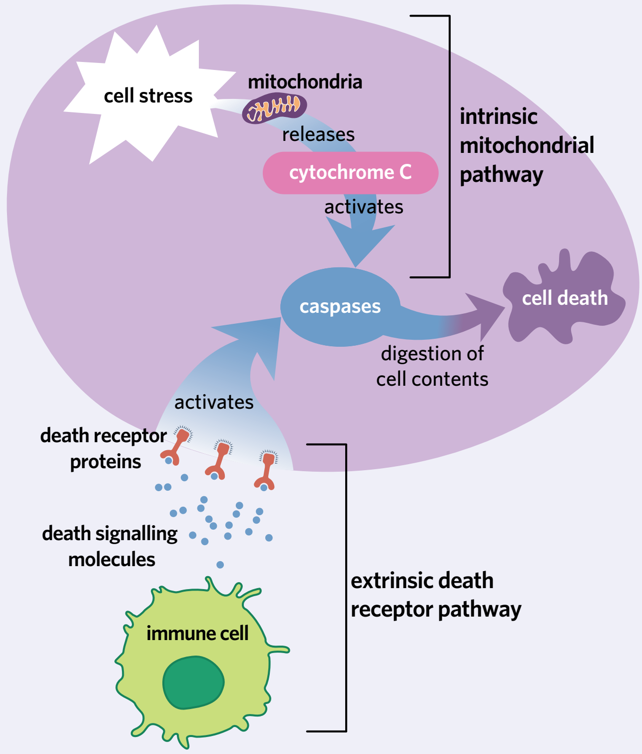
2 Cell elongation – the duplicated chromosomes and plasmids migrate to opposite ends



3 Cytokinesis – a septum, new cell wall and membrane, form down the middle resulting in the creation of two new daughter cells.



Apoptosis



Stages of apoptosis

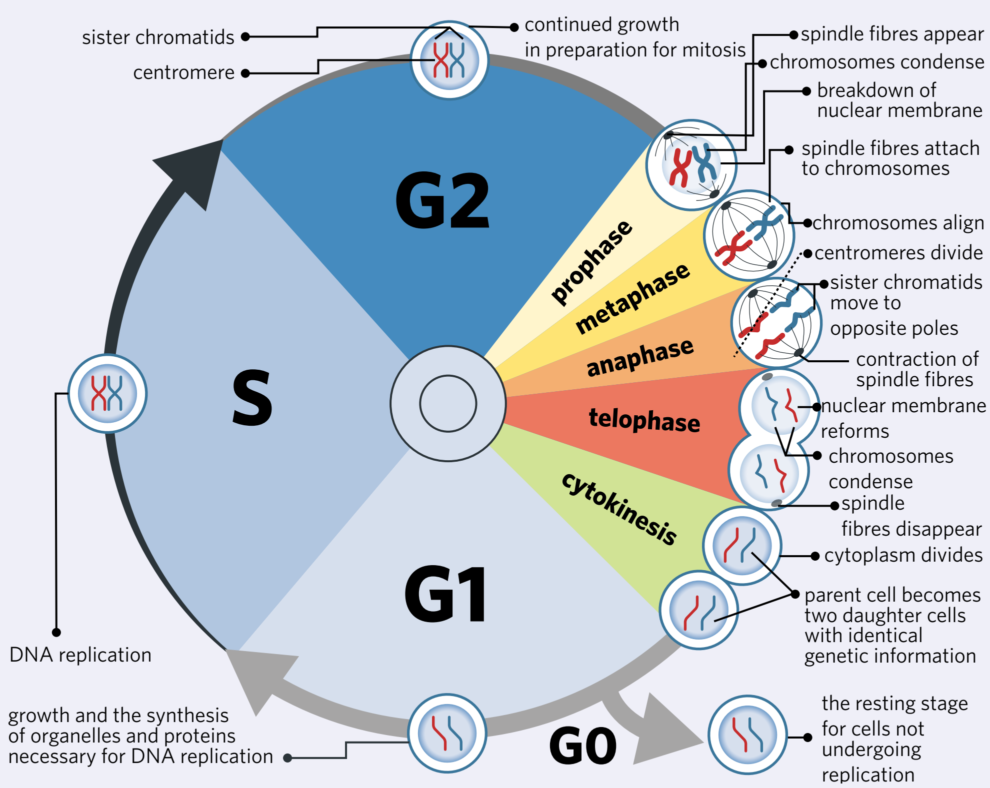
1 Caspase activation – activated by either the mitochondrial or death receptor pathway

2 Digestion of cell contents – caspases cleave proteins and digest organelles

3 Cell shrinkage – cell shrinks due to digestion

4 Blebbing and breakage – organelles and cytoskeleton are digested, apoptotic bodies detach from the cell

Eukaryotic cell cycle



Properties of stem cells

- Self-renewal – stem cells can replicate into both a differentiated and undifferentiated cell
- Differentiation – stem cells are undifferentiated cells which can give rise to differentiated cells with specialised functions

Potency of stem cells

- totipotent- stem cells that can differentiate into any cell type (e.g. a zygote)
- pluripotent- stem cells that can differentiate into multiple cell types (e.g. embryonic stem cells)
- multipotent- stem cells that can differentiate into a limited number of specialised cell types belonging to a specific tissue or organ (e.g. adult stem cells)

CHAPTER 4 SAC PRACTICE

SAC skills covered in this section:

✓ Case study analysis ✓ Data analysis ✓ Bioethical deep dive

THE CELL CYCLE (25 MARKS)

Acute myeloid leukaemia

Leukaemia is one of the most common cancers in the world. It is estimated that in 2019, over 4 200 individuals in Australia were diagnosed with leukaemia and over 2 000 people died as a result of it. While there are many different types of leukaemia, the most common is acute myeloid leukaemia (AML).

AML is caused by an alteration to the DNA of one type of stem cell (called a myeloblast) located in our bone marrow. Normally, these stem cells differentiate via a carefully regulated process into a variety of white blood cells which help fight infections and keep us healthy. This alteration leads to the overproduction of white blood cells. As the production of white blood cells increases, the body cannot produce as many red blood cells or platelets. Red blood cells are responsible for carrying oxygen around the body, and platelets are responsible for the clotting of blood. Without sufficient oxygen, both the rate of aerobic cellular respiration and the production of energy (ATP) decreases. Symptoms of AML include fatigue, easy bleeding and bruising, bone and joint pain, and weight loss.

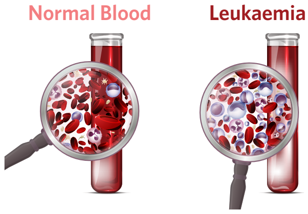


Image: Double Brain/Shutterstock.com

1 Myeloid stem cells can differentiate into myeloblasts, platelets, and red blood cells. Name and describe the potency of myeloid stem cells. (2 MARKS)

2 Identify the regulatory process that occurs when irreparable DNA damage occurs in a normally functioning cell. (1 MARK)

3 DNA damage often occurs in the S phase of the eukaryotic cell cycle. Explain why this is the case. (1 MARK)

4 Explain why fatigue is a symptom of AML. (1 MARK)

Prevalence of AML

The graph shows the incidence of AML by age at diagnosis.

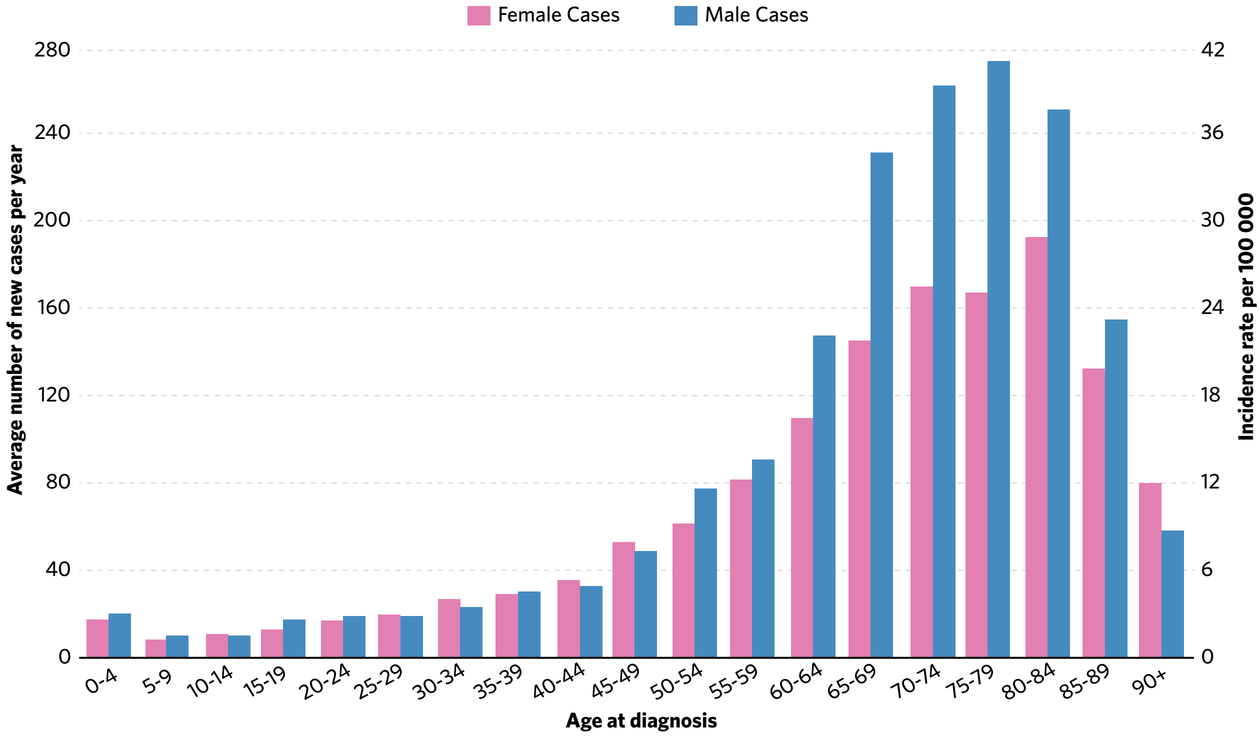


Image: adapted from Cancer Research UK (2020)

5 Identify the group with the greatest number of new cases. (1 MARK)

6 Using data from the graph, describe the general trends for both females and males. (2 MARKS)

Treatment for AML

One possible treatment for AML is chemotherapy. Chemotherapy is a treatment regimen composed of toxic drugs with the aim of killing cancerous cells. In AML, chemotherapy targets leukaemia cells – the cancerous cells – by inducing apoptosis. Many drugs used in chemotherapy are large hydrophilic molecules. This means that they cannot pass through the plasma membrane.

At the end of each regimen of chemotherapy, doctors typically take a biopsy or a sample of the patient's bone marrow to assess whether the number of leukaemia cells is increasing or decreasing. Other diagnostic tools doctors use include blood tests and various imaging tests such as CT scans and PET scans. In the event that leukaemia cells are still increasing, the doctor will either proceed with more chemotherapy, or they can recommend a peripheral blood stem cell transplant.

In peripheral blood stem cell transplants, doctors use high doses of chemotherapy or total body irradiation to kill cancerous cells. Doctors then collect peripheral blood stem cells from a donor and transfuse them into the patient's bloodstream using a drip. These stem cells then migrate to the patient's bone marrow and start producing normal blood cells. However, in more severe cases, doctors may instead opt for a bone marrow transplant instead of a peripheral blood stem cell transplant, directly transplanting a donor's bone marrow into the patient.

7 How do doctors assess whether a patient requires a stem cell transplant? (1 MARK)

8 Outline how a large hydrophilic chemotherapy drug could induce apoptosis in cells. (1 MARK)

9 Suggest how chemotherapy may sometimes be ineffective at killing leukaemia cells. (1 MARK)

10 In some cases, chemotherapy can irreversibly damage terminally differentiated cells. Explain whether these cells have the ability to naturally regrow. (2 MARKS)

New research

On the surface of most cells in the body, there is a group of proteins which form a complex known as the major histocompatibility complex (MHC). This complex identifies cells belonging to the body, and if a foreign cell does not have the same MHC proteins as the body, the immune system is primed to destroy it. Therefore, to ensure the success of stem cell transplants, both the donor and patient must have cells with similar MHC proteins. Because of this, it can sometimes be very difficult to find donors with compatible MHC proteins on their stem cells.

Recently, scientists have been researching the possibility of altering the MHC proteins on stem cells to match the patient. In doing so, they discovered a special chemical with this ability. As part of their research, they conducted a clinical trial.

First, they established two large volunteer groups (around 50 people each) with similar health statuses. A stem cell sample was taken from every individual, to analyse their unique MHC proteins. In the first group, researchers administered the volunteers with stem cells which had been converted to match their MHC proteins. In the second group, researchers simply reintroduced the volunteer to their own stem cells. Throughout the trial, the scientists monitored whether the volunteers developed an immune response against the transplanted stem cells.

11 State a hypothesis the scientists could be testing. (1 MARK)

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

13 The day before releasing the treatment to the open market, researchers discovered that the converted stem cells caused adverse reactions within 1% of patients. Scientists were worried that this could delay the release of the treatment, negatively impacting thousands of patients on waiting lists.

Discuss whether the scientists should proceed with the release of the treatment to the public with reference to one relevant bioethical concept. (2 MARKS)

Complications of treatment

Following total irradiation or high doses of chemotherapy, the number of white blood cells decreases. This results in an increased chance of developing a bacterial, viral, or fungal infection due to the body's decreased immune strength. A common infection during chemotherapy is pneumonia, where fluid can form in the lungs making it difficult to breathe. Pneumonia is caused by the bacteria *Streptococcus pneumoniae*.

14 Describe how *Streptococcus pneumoniae* would replicate in a patient's lungs. (2 MARKS)

15 *Streptococcus pneumoniae* does not replicate in the same way as human cells. Describe two differences between the modes of replication. (2 MARKS)

Prevalence of pneumonia

The graph shows the death rate from pneumonia by age around the world.

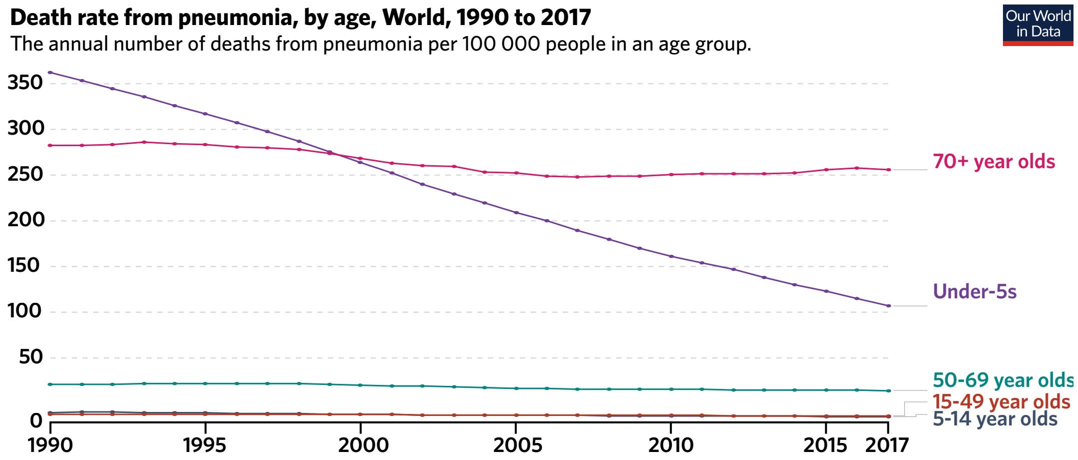


Image: Global burden of disease study (2017) and Health metrics and evaluation (2018), adapted by Dadonaite and Roser (2019)

16 Identify the year where people over 70 and under 5 years old had the same number of annual deaths per 100 000 people. (1 MARK)

17 Describe the downward trend in death rate for people under five-years-old and suggest a reason for this trend. (2 MARKS)

CHAPTER 4 EXAM PRACTICE

30 min

Section A (5 MARKS)

Question 1 (1 MARK)

Quiescent cells are

A stuck in the G1 phase of the eukaryotic cell cycle.

B capable of re-entering the eukaryotic cell cycle.

C terminally differentiated cells.

D cancer cells.

Question 2 (1 MARK)

Specialised mammalian cells such as red blood cells

A are unable to further differentiate.

B can differentiate into cells with an even more specialised function.

C are multipotent because they can differentiate into a variety of different cells.

D can produce both an undifferentiated cell and a copy of itself during replication.

Question 3 (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 blunt trauma applied to the skin, causing cells to swell and burst.

B an increase in the production of death signalling molecules.

C a decrease in the production of cytochrome c.

D decreased production of caspases.

Question 4 (1 MARK)

Apoptosis can be initiated by damage to intracellular contents such as DNA or organelles. Following such damage

A specific proteins will puncture the cell membrane, causing the cell contents to leak out.

B the cell will immediately be engulfed by phagocytes.

C cytochrome c is released into the cytosol.

D the cell will immediately shrink.

Question 5 (1 MARK)

In order to survive, cancer cells produce signals called angiogenic factors which can stimulate the growth of blood vessels. Cancer cells require blood vessels to

A deactivate mechanisms preventing cell replication.

B produce chemicals that initiate cell replication.

C receive oxygen and nutrients to survive.

D increase the rate of apoptosis.

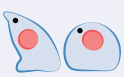
Section B (15 MARKS)

Question 6 (3 MARKS)

There are three checkpoints in the cell cycle responsible for detecting errors during cell replication. These are the G1 checkpoint, the G2 checkpoint, and the metaphase checkpoint.

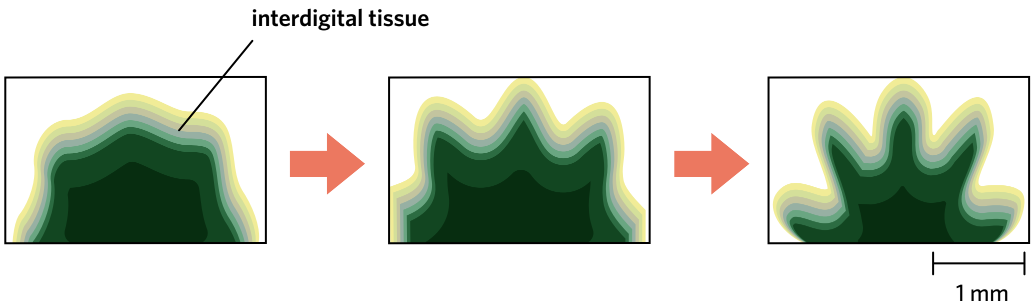
a Describe the changes to a cell during metaphase. (2 MARKS)

b Explain why a cell would undergo apoptosis at the metaphase checkpoint. (1 MARK)



Question 7 (4 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 time 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)

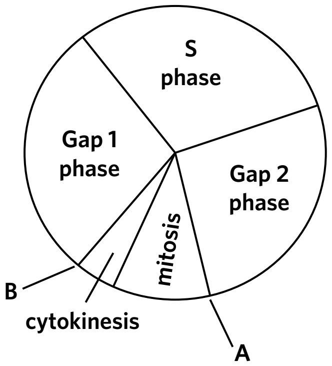
Adapted from VCAA 2018 Section B Q2b

c What is the role of caspases in apoptosis? (1 MARK)

Adapted from VCAA 2017 Sample Exam Section B Q4a

Question 8 (3 MARKS)

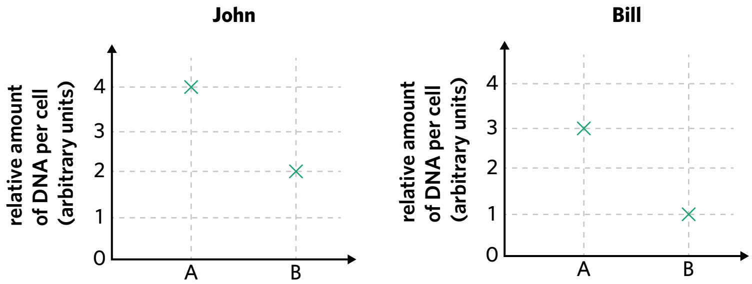
When a cell replicates it goes through a series of events that are summarised in the diagram. The cycle moves in a clockwise direction. Note the two points, labelled A and B.



Given that two daughter cells are formed during the cycle, at some point, the cell must replicate its DNA.

a Describe the changes in the structure of the chromosomes during DNA replication. (1 MARK)

b Two students, John and Bill, used crosses to mark the relative amount of DNA present in each cell at points A and B in the cycle.



Identify which student is correct. Explain. (2 MARKS)

Adapted from VCAA 2008 Exam 2 Section B Q1

Question 9 (5 MARKS)

Clostridium perfringens is a bacterium often associated with food poisoning, causing diarrhoea and abdominal cramps. It replicates through binary fission at a rapid rate. Symptoms usually develop 6–24 hours after the initial infection.

a What evidence supports the idea that *Clostridium perfringens* is a prokaryote? (1 MARK)

b Identify two possible cellular characteristics of *Clostridium perfringens*. (2 MARKS)

c Identify two differences between the cellular processes of binary fission and mitosis. (2 MARKS)

UNIT 1

AOS2

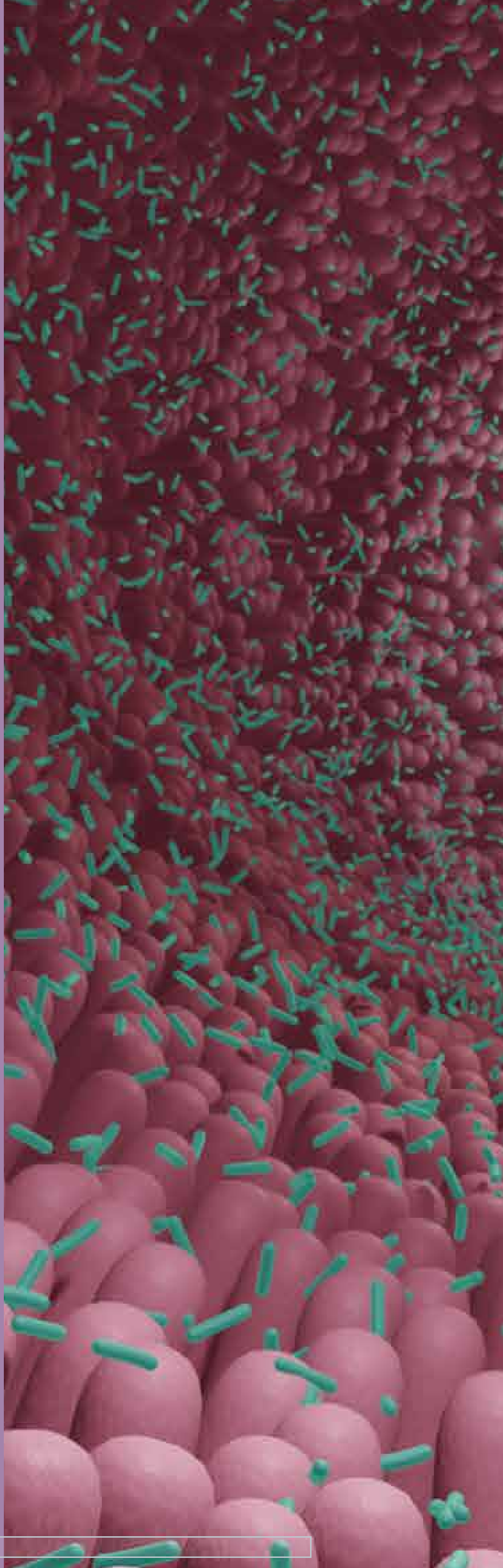
How do plant and animal systems function?

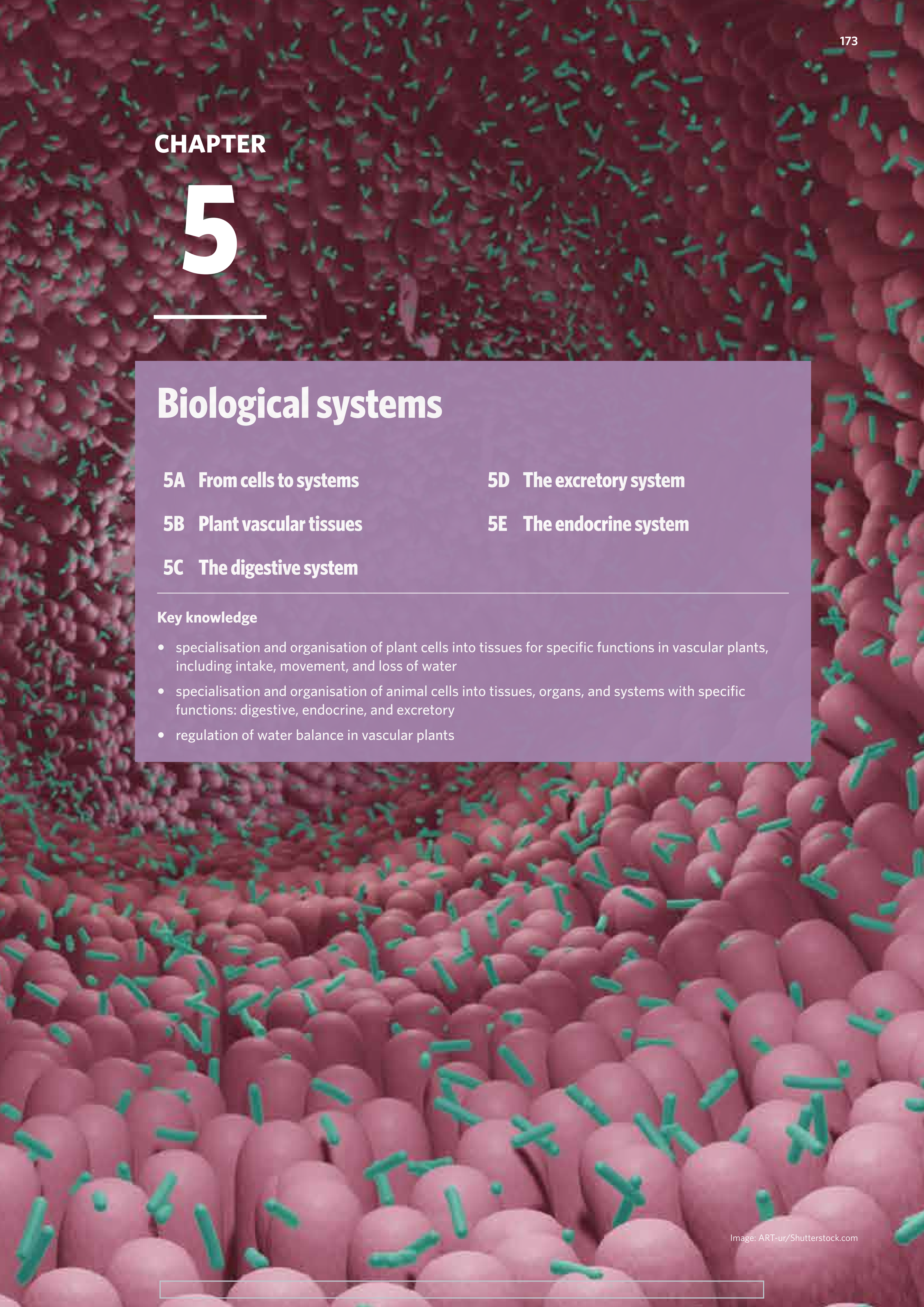
In this area of study students explore how systems function through cell specialisation in vascular plants and in digestive, endocrine and excretory systems in animals, focusing on regulation of water balance in plants, and temperature, blood glucose and water balance in animals. Students examine how homeostatic mechanisms in animals help maintain their internal environment within a narrow range of tolerance levels, and consider malfunctions in homeostatic mechanisms.

Outcome 2

On completion of this unit the student should be able to explain and compare how cells are specialised and organised in plants and animals, and analyse how specific systems in plants and animals are regulated.

Reproduced from VCAA VCE Biology Study Design 2022-2026





CHAPTER

5

Biological systems

Key knowledge

- specialisation and organisation of plant cells into tissues for specific functions in vascular plants, including intake, movement, and loss of water
- specialisation and organisation of animal cells into tissues, organs, and systems with specific functions: digestive, endocrine, and excretory
- regulation of water balance in vascular plants

Image: ART-ur/Shutterstock.com

5A CELLS TO SYSTEMS

They are the five words that send a chill down every student's spine – 'This is a group assignment.' But really, your body and every single complex living organism you can see around you is an example of a group assignment done right. How do individual biology students (cells), that separately are not capable of much (no offence), come together to make an amazing project (organism)?

Image: paulista/Shutterstock.com

Lesson 5A

In this lesson you will learn how plant and animal cells are organised in order to carry out complex processes needed for survival.

◀ *Prerequisite knowledge* | *Future applications* ▶

Years 7–10
Complex organisms such as humans are made up of trillions of specialised cells.

Chapter 5
In the rest of chapter five, you will learn about the two major systems in plants and three of the major systems in animals.

Chapter 6
This chapter will explore how each animal system is maintained to provide a stable internal environment.

Study design dot points

- specialisation and organisation of plant cells into tissues for specific functions in vascular plants, including intake, movement, and loss of water
- specialisation and organisation of animal cells into tissues, organs, and systems with specific functions: digestive, endocrine, and excretory

Key knowledge units

Cells, tissues, organs, systems	1.2.1.1
Organisation of plants	1.2.1.2
Organisation of animals	1.2.2.1

Cells, tissues, organs, systems 1.2.1.1

OVERVIEW

Cells are organised into tissues to carry out functions that can't be performed by single cells alone. Tissues are further organised into organs, which function in synchrony with other organs to make a system. Each system is vital for the whole organism to survive.

THEORY DETAILS

Multicellular **organisms** are composed of **cells**. Complex organisms, such as plants and animals, can survive because their cells are **specialised**, which means that they perform specific individual functions. However, each of these specialised cells must interact and work together with all other cells of the body to survive.

To function, a cell needs to obtain nutrients and oxygen, remove waste and toxic substances, and requires the stable regulation of conditions such as temperature and pH. Such a request is hard to deliver, especially when an organism is composed of trillions of cells, many of which demand completely different requirements and conditions.

organism a living thing made up of one or more cells

cell the smallest functional unit of a living organism

specialised cells which serve a unique, particular function

As an organism increases in size and complexity, greater cooperation and coordination of cells is required to survive, and cells begin to arrange into four different levels of increasing complexity:

- cells
- **tissues**
- **organs**
- **systems**.

tissue a cluster of cells which perform a shared function

organ the combination of tissues and cells into a distinct structure that performs a specific function

system a collection of organs and tissues that perform specific functions necessary for survival

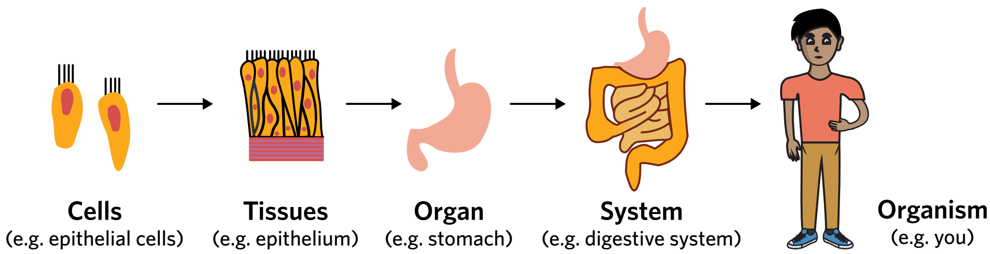


Figure 1 The increasingly complex arrangement of cells in the human body

Simple unicellular life is composed of a single cell (e.g. bacteria), whilst multicellular organisms are made up of specialised cells that contribute to the formation of tissues. These tissues are groupings of cells that work together to carry out particular functions. It is important to note that for some organisms (such as jellyfish and corals), tissues represent the greatest level of organisation required to meet survival and reproduction needs.

Organs are composed of multiple tissues and perform specialised tasks. They are easily recognisable structures inside the body (e.g. heart, kidneys, and lungs). It is rare for a single organ to function independently – instead, organs and tissues form larger systems. Systems perform vital tasks essential for the survival of an organism.

Organisation of plants 1.2.1.2

OVERVIEW

Plant cells are organised into dermal tissue that lines the outside of plants, vascular tissue that is responsible for transporting water and nutrients around the plant, and ground tissue which describes all other tissues in a plant. Plant tissues are organised into many distinct organs and two different systems. The root system contains the roots, whereas the shoot system contains the leaves, stems, flowers, and fruit.

THEORY DETAILS

Plant cells

Plants are complex multicellular organisms that require the organisation of cells into tissues, organs, and systems. Vascular plants are plants that contain **vascular tissue**, which is responsible for transporting water and minerals throughout the plant. Non-vascular plants, such as moss, do not contain vascular tissue and only require simplified tissues to function.

vascular tissues conducting tissues that transport water and nutrients throughout a plant. An encompassing term for the xylem tissue and phloem tissue

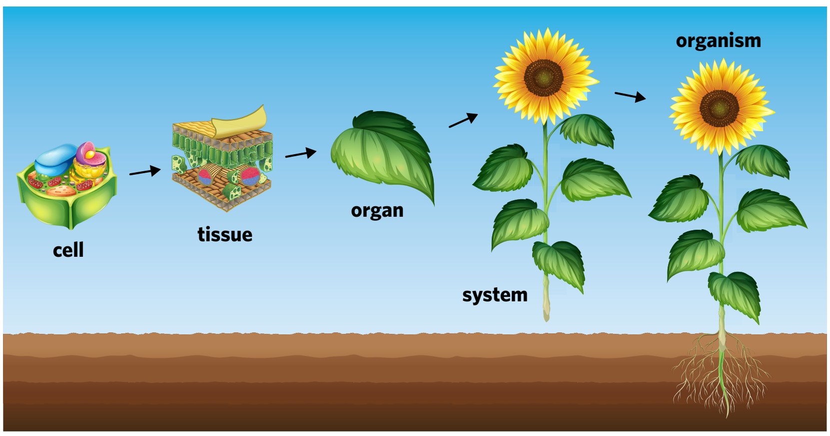


Image: BlueRingMedia/Shutterstock.com

Figure 2 Overview of the organisation of cells in plants

In vascular plants, specialised cells carry out specific functions such as the transport of nutrients and water, and acquiring energy via photosynthesis. The major types of vascular plant cells are summarised in Table 1.

Table 1 Some of the major vascular plant cells and their functions

Cell type	Function
Parenchyma cells	The major cells of plants, responsible for photosynthesis and other metabolic activity.
Sclerenchyma cells	Provide support to the plant
Collenchyma cells	Provide support to the plant
Xylem cells	Cells of the xylem are responsible for the transport of water and minerals from the roots to the leaves of the plant.
Phloem cells	Cells of the phloem are responsible for the transport of sugars and other nutrients throughout the plant.

Plant tissues

Cells of complex plants combine to form several different types of tissue. **Dermal tissue** refers to the single layer of cells covering the outside of a plant. Dermal tissue secretes a waxy film called a cuticle to form a physical barrier between a plant and its environment and to reduce water loss and physical damage. **Ground tissues** make up the majority of the interior of the plant and carry out metabolic functions. Vascular tissues run through the ground tissue of vascular plants, carrying water and nutrients.

Plant organs

The major organs of vascular plants and their functions are outlined in Table 2 and Figure 3.

Table 2 Major plant organs and their functions

Organ	Function
Leaves	Sites of gas exchange and responsible for photosynthesis. In most species, leaves are organised to increase sunlight exposure.
Flowers	The sexual reproductive organs of flowering plants (angiosperms). Following the fertilisation of male and female gametes which are contained in pollen, seeds develop and the ovary of a flower grows into a fruit.
Fruits	Grown from a flower post-fertilisation. Fruits protect seeds and are often specialised to attract animals that aid with seed dispersal.
Stems	Support the leaves, flowers, and fruits, as well as transport water and nutrients between the roots and shoots.
Roots	Absorption and storage of water and nutrients from the soil. Roots are also responsible for anchoring the plant to the ground and providing structural support.

Plant systems

Vascular plants have two major organ systems – the **root system** and the **shoot system**. The root system is typically underground. It absorbs water and nutrients from the soil and provides the plant with support and structure. The shoot system of angiosperms is made up of the reproductive and non-reproductive sections. The reproductive sections include the flowers and fruit, and the non-reproductive sections include the leaves and stems.

Lesson link

The two types of vascular tissue, xylem tissue and phloem tissue, will be explored in ***lesson 5B***.

dermal tissue collection of cells that form the outer linings of a plant

ground tissues an encompassing term for many different plant tissue types, which are involved in metabolism and support

leaves the plant organs that are responsible for photosynthesis

flowers the reproductive organ of angiosperms. Grows into fruit following fertilisation

fruit the seed-bearing structures that are responsible for the protection of developing seeds and seed dispersal

stem the main body of the plant that provides support and connects the whole plant

roots the plant organ embedded in the ground. Absorbs water and nutrients from soil, and provides support for the plant

root system organ system in plants that is responsible for providing support to the plant and water and nutrient absorption from soil

shoot system organ system in plants made up of reproductive organs, stems, and leaves

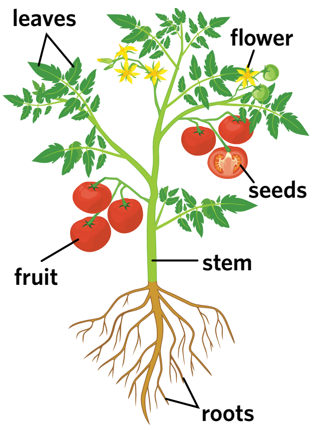


Image: Kazakova Maryia/Shutterstock.com

Figure 3 The organs of a tomato plant

Lesson link

The reproductive strategy of angiosperms and the individual components of a flower are covered in detail in ***lesson 9A***.

Organisation of animals 1.2.2.1

OVERVIEW

Animal cells combine to form the four major animal tissue types – muscle, nerve, connective, and epithelial. Tissues are further organised into organs which make up systems such as the digestive system, respiratory system, and the immune system.

THEORY DETAILS

Animal cells

Complex animals are made up of hundreds of different cell types, each responsible for a specialised function. Common types of animal cells include skin, muscle, blood, nerve, and fat cells.

Animal tissues

In animals, tissues are grouped into the four types seen in Table 3.

Table 3 The four types of tissues in animals

Tissue type	Function
Muscle tissue	Contracts to exert a force. The three major types are skeletal, cardiac, and smooth muscle tissue.
Nervous tissue	Detects stimuli and transmits electrical signals Composed of neurons that detect stimuli and carry electrical signals and glia that assist neuron signal transmission.
Connective tissue	Connects and supports other tissues and organ structures of the body
Epithelial tissue	Composes the external and internal layers of the body. These tissues assist in protection, secretion, and absorption.

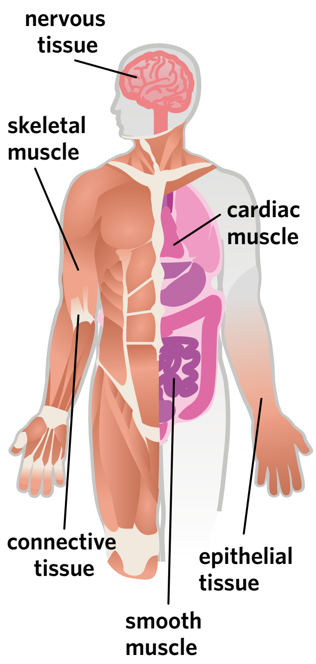


Figure 4 Muscle, nervous, connective, and epithelial tissue in animals

muscle tissue collection of animal cells that are capable of contraction. Includes skeletal, cardiac, and smooth muscle

nervous tissue collection of animal cells that sense stimuli and initiate responses. Also known as **nerve tissue**

connective tissue collection of many different animal cells that bind and support the other major tissue types

epithelial tissue one of the basic tissue types in animals that line the outer surface of organs and blood vessels

Theory in context

MUSCLE TISSUE TYPES

There are three major types of muscle tissue: skeletal, cardiac, and smooth muscle. Most skeletal muscle tissue is attached to the bones via connective tissues called tendons. Skeletal muscles are under voluntary control, and contract to assist movement. Cardiac muscle tissue is found entirely in the heart, where cardiac muscle contracts to pump blood around the body. Smooth muscle tissue is found in the linings of hollow organs and structures throughout the body, including the stomach, intestines, and blood vessels. Smooth muscle tissue contracts slowly to change the shape and size of these structures. The movements of both cardiac and smooth muscle are involuntary, meaning they are not regulated by conscious control.

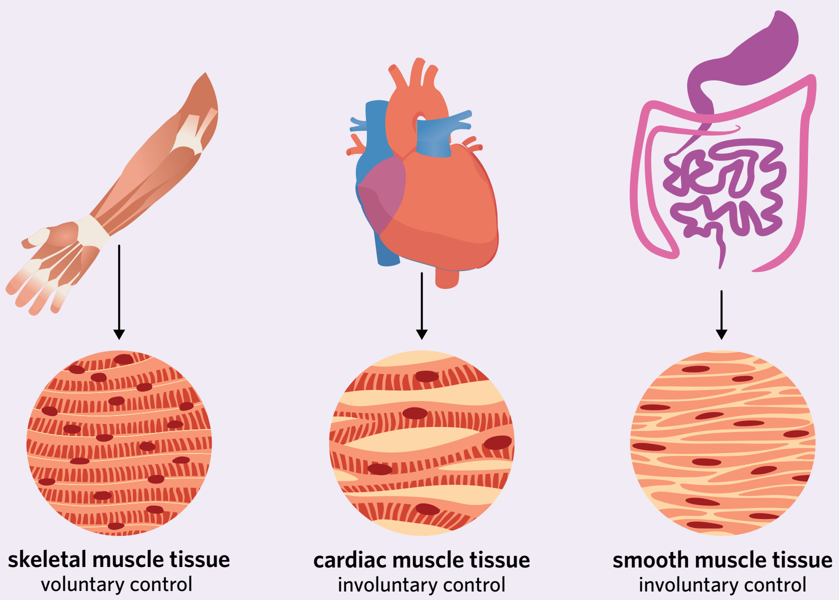


Image: udaix/Shutterstock.com

Figure 5 The three types of muscle tissue

Animal organs

Some of the major organs in humans are shown in Figure 6. It is important to note, however, that there are many more organs in the human body than those shown.

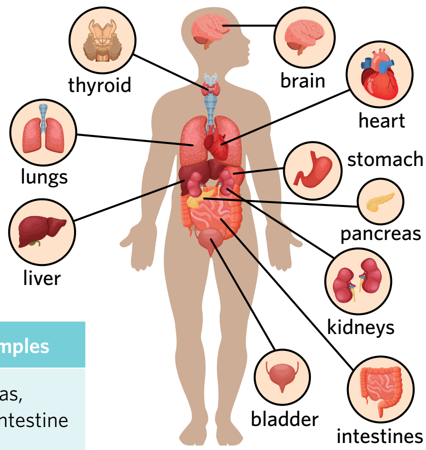


Image: ideyweb/Shutterstock.com

Figure 6 Some of the major organs of the human body

Animal systems

The major systems in complex animals are seen in Table 4 and Figure 7.

Table 4 The 11 major systems in humans. Systems denoted by a * will be explored in later lessons.

System	Function	Organ and tissue examples
Digestive system*	Breaks down and processes food to be used by the body. Eliminates food waste that is not digested via egestion.	Stomach, liver, pancreas, small intestine, large intestine
Excretory system*	Removes waste substances from the blood via excretion. Also assists in the control of water balance in the body.	Kidneys, bladder, lungs
Endocrine system*	Responsible for the production and secretion of **hormones** which control and regulate bodily processes.	Hypothalamus, pituitary gland, thyroid gland, thymus, pancreas, adrenal glands
Skeletal system	Provides an internal structure to support the body. Works in tandem with the muscular system to enable movement of the body.	Bones, joints, cartilage
Muscular system	Responsible for contractions in skeletal muscle, the heart, and other contractions throughout the body. Works in tandem with the skeletal system to enable movement of the body.	Skeletal muscles, cardiac muscles, tendons
Integumentary system	Protects internal body structures from the external environment.	Skin, hair, nails, subcutaneous fat
Nervous system	Detects and processes sensory information to activate responses in the body.	Brain, spinal cord, peripheral nerves
Immune system	Defends the body against infection. Contains the lymphatic system which transports lymph fluid around the body.	Bone marrow, spleen, thymus, tonsils, lymph nodes
Respiratory system	Responsible for removing carbon dioxide from the body and delivering oxygen to the blood via respiration.	Lungs, nasal passage, trachea
Blood circulatory system	Delivers oxygen and nutrients to the tissues of the body via blood.	Heart, blood vessels (arteries, veins, and capillaries)
Reproductive system	In males, regulates the production of sperm and certain hormones. In females, regulates the production of egg cells, certain hormones, ovulation, and nurturing offspring during development. In both males and females, the reproductive system coordinates action for the purposes of reproduction.	Testes, penis, ovaries, vagina, uterus, mammary glands

digestive system the collection of specialised tissues and organs responsible for the breakdown of food and absorption of nutrients

excretory system the collection of organs and tissues that removes excess fluid and waste materials from the body

endocrine system the collection of glands in animals responsible for producing hormones that can be transported in the bloodstream to regulate distant organs/cells

hormone a signalling molecule released from endocrine glands that regulates the growth or activity of target cells

skeletal system the organ system comprised of bone and cartilage that supports the body and the muscular system to enable movement

muscular system collection of muscle tissues that circulate blood and enable movement

integumentary system the organs and tissues responsible for protecting the body from the external environment

nervous system the network of nerve tissue that receives, transmits, and responds to stimuli

immune system collection of organs and tissues that provide resistance to and protection from infection and diseases

respiratory system the organ system that allows an organism to breathe and exchange gases with the external environment

blood circulatory system the network of blood vessels and the heart that pumps blood around the body

reproductive system the sex organs responsible for sexual reproduction

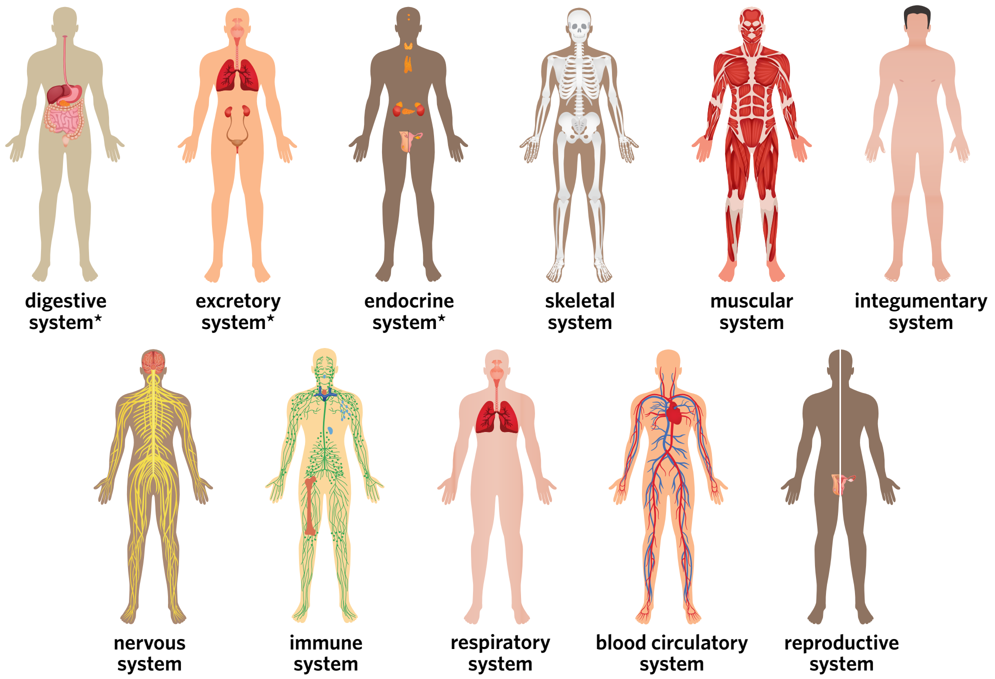


Image: Macrovector/Shutterstock.com

Figure 7 The 11 major systems in humans. Systems denoted by a * will be explored in later lessons.

Lesson link

The VCAA specifies that you need to learn about the digestive, excretory, and endocrine systems. The digestive system is explored further in ***lesson 5C***, the excretory system in ***lesson 5D*** and the endocrine system in ***lesson 5E***.

Lesson link

In ***chapter 6***, you will learn about how the body maintains a stable internal environment. In these lessons, the hormones of the endocrine system are vital signalling molecules that communicate messages between tissues and organs.

Theory in context

GAS EXCHANGE IN ANIMALS

All animals need to absorb oxygen for aerobic cellular respiration and to expel carbon dioxide to prevent a toxic buildup. This process is known as respiration and is typically carried out by an animal's respiratory and blood circulatory systems. Very simple animals, however, such as sponges, coral, and flatworms can exchange gases directly with the environment, they neither require a respiratory system to exchange gas nor a blood circulatory system to transport these gases throughout their body.

Complex animals are often too large to passively exchange gases with the environment, and therefore require more advanced respiratory systems and blood circulatory systems. In humans, the primary organs of the respiratory system are the lungs which carry out gas exchange, and the trachea which carries gas between your lungs and the environment.

In an insect's respiratory system, air (and oxygen) enters the body through tiny holes called spiracles. Spiracles attach to a network of internal tubes called trachea. This network, combined with an insect's open blood circulatory system, allows oxygen to reach all the cells of the body.

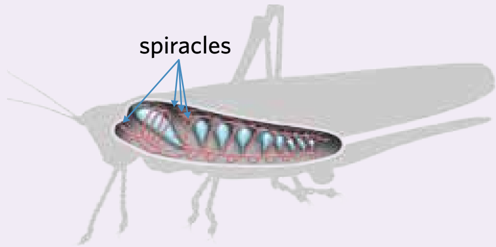


Image: Aldona Griskeviciene/Shutterstock.com

Figure 8 Insect spiracles

Fish live in water, a liquid that generally only contains about 1% O_2, compared to the 21% of O_2 in air. To compensate for this, fish have evolved extremely efficient gas exchange and respiratory systems. The primary organ of the respiratory system in fish are the gills, located on the side of their throat. Gills are made of several gill arches composed of specialised rows of filaments, which in turn are made of tightly packed lamellae. Fish breathe in water through the mouth and push it out between the gill arches and the lamellae. Because of the high surface area of the lamellae, oxygen and carbon dioxide can quickly and efficiently diffuse into and out of the gills. Oxygen is then transported from the gills around the body via the fish's blood circulatory system.

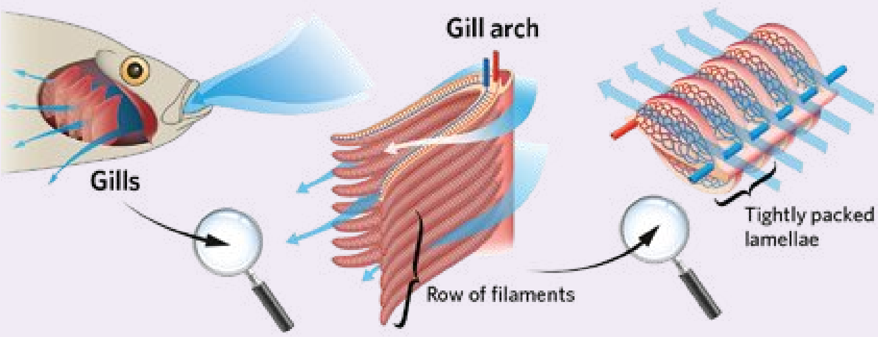


Image: Aldona Griskeviciene & Kraska/Shutterstock.com

Figure 9 Water is exposed to a large surface area of fish gills to increase respiration.

Theory summary

In order to coordinate sophisticated functions, specialised cells are organised into tissues, organs, and systems in complex organisms. With increased organisation, cells, tissues, organs, and systems are able to perform specific and vital body functions.

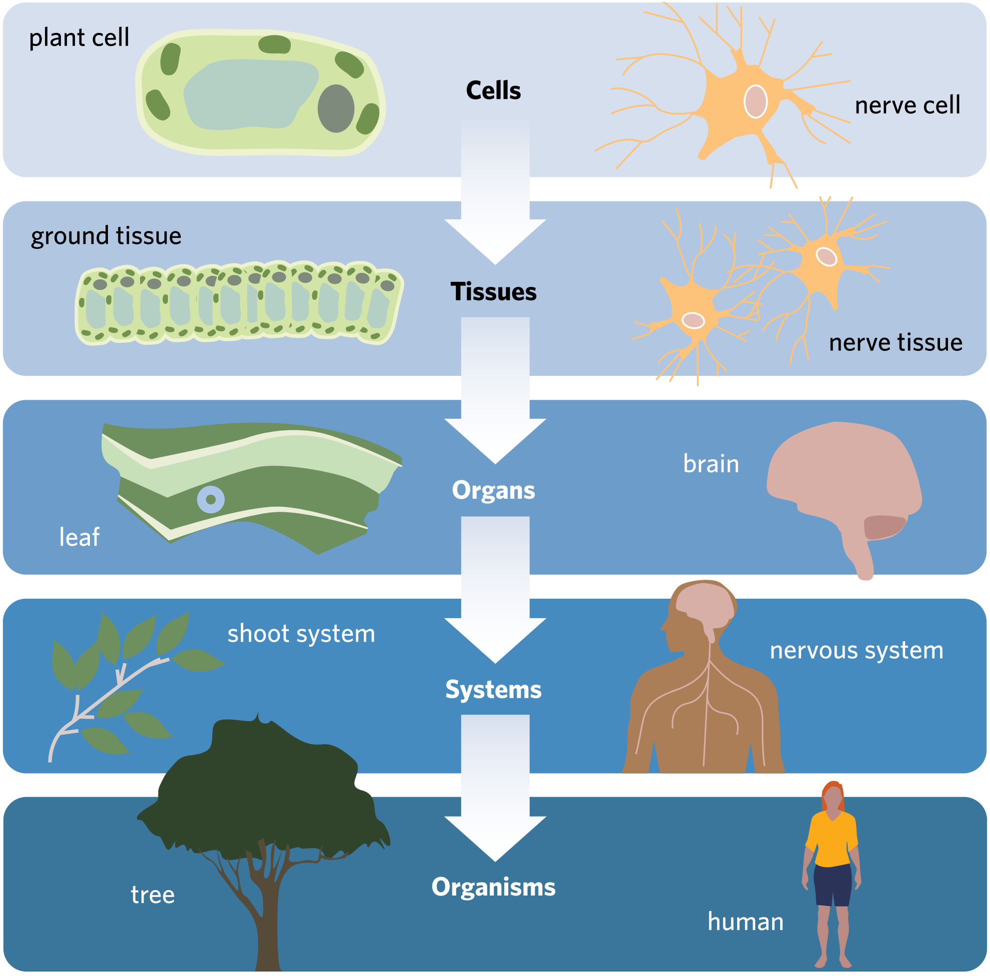


Figure 10 Summary of cell organisation in plants and animals

Just like a group working on an assignment together, the cells in your body work together to make up all the different parts of you. They break off into smaller groups to form tissues and organs, and then the night before the assignment is due they meet and join all their hard work together to make up an amazing organism. Teamwork not only makes the dream work – it literally makes you work!

5A QUESTIONS

Theory review questions

Question 1

Cells are organised into tissues, organs, and systems to

A perform functions that cannot be carried out by single cells.

B allow for cells to exchange oxygen and carbon dioxide directly between one another.

Question 2

The two organ systems of vascular plants are the

A stem and leaf systems.

B root and shoot systems.

Question 3

Match the plant organ to the organ function.

Plant organ		Organ function
• flowers	I	__________ undergo fertilisation in the presence of pollen to produce seeds
• leaves	II	__________ protects developing seeds and aids seed dispersal
• stems	III	__________ absorb water and nutrients from ground soil
• roots	IV	__________ site of photosynthesis
• fruit	V	__________ provide support and also stores and transports nutrients and water

Question 4

Fill in the blanks with the following terms.

- muscle tissue
- nervous tissue
- epithelial tissue
- connective tissue

There are four major animal tissue types. __________ consists of tightly packed cells that line the internal and external surfaces of an organism. Neurons are the cells found in __________. Skeletal, cardiac, and smooth are all types of __________. __________ connects the different tissue types and structures of the body.

Question 5

Which of the following are major systems of the human body? *(Select all that apply)*

I integumentary system
II reproductive system
III intestinal system
IV nervous system
V brain system

Question 6

Match the animal system to the system function.

Animal system		System function
• immune system	I	__________ removes waste substances from the body
• excretory system	II	__________ protects the body against infection
• endocrine system	III	__________ delivers oxygen to the blood and removes carbon dioxide from the body
• respiratory system	IV	__________ delivers oxygen and nutrients to body tissues
• blood circulatory system	V	__________ produces and secretes hormones around the body

Question 7

Fill in the blanks in the following sentences

The __________ system is responsible for breaking down foods and absorbing their nutrients. Animals often consume __________, a plant organ that contains seeds. Plants have __________ that absorb water from the soil, and along with __________ provide support to the plant, helping it stand upright. Similarly, animals such as humans contain a __________ system that works in tandem with the muscular system to provide support and enable movement.

SAC skills questions

Bioethical deep dive

Use the following information to answer Questions 8–13.

Organ donation is the process of removing organs from one person (a donor) and transplanting them into someone who is in need of a replacement organ (a recipient). Tissue donation is also possible, and the majority of the time the recipient's body accepts the donated organ or tissue as part of their own body. While living donors can donate tissues or non-vital organs, most donors are recently deceased.

The decision to donate organs after death is one that raises many potential implications and requires the assessment of bioethical concepts. To be able to donate organs in Australia, a person over the age of 18 must 'opt-in' to record their consent to donation after their death. Other countries, such as Spain, have an 'opt-out' policy for post-death organ donation.

Following death, reasonable steps must also be taken by the designated doctor to determine if there were changes in the intent or wishes of the deceased. In Australia, the next of kin to the deceased must also consent to the organ transplant. Ethical issues arise if the deceased changed their consent prior to death, or if there is a difference in consent between the deceased donor and their next of kin.

Question 8

An 'opt-out' policy for post-death organ donation

A assumes a person consents to deceased donation unless they opt-out.

B means that people are required to actively record their consent to be eligible to donate.

Question 9

The organ donation law in England transitioned from an opt-in system to an opt-out system in May 2020. The law was changed to

A increase the number of consenting donor adults to increase the availability of organ donations.

B increase the respect placed on deceased individuals' bodies by only removing organs after they have declared their consent.

Question 10

Health officials want to raise the rate of deceased organ donation in Australia. One change that would increase the donation rate is

A the removal of the next of kin's approval of a willing deceased donor.

B including additional steps to uncover if a consenting deceased donor changed their consent after opting in.

Question 11

Consider the following scenario under the current Australian system. A deceased person consented to donate before death and a suitable recipient is available, but the next of kin to the deceased objects to the donation. Which bioethical concept does Australian law adhere to when influencing a doctor's decision to operate?

A Respect. Under the current Australian law the beliefs of the deceased next of kin's need to be followed and respected.

B Beneficence. The maximisation of benefits should be achieved by donating the deceased organ to the recipient to improve their life.

Question 12

Like all operations, there are risks and complications associated with organ donation procedures. Which bioethical concept should be followed when informing the potential recipient of the operation risks?

A Non-maleficence. Doctors and health professionals responsible for the recipient should ensure that harm is avoided at all costs.

B Integrity. Doctors and health professionals have a commitment to present all information on procedures for the patient to make their own informed decision, even if there are risks and dangers.

Question 13

Which approach to bioethics does the current Australian system most closely adhere to?

A A consequences-based approach. The central importance is placed on organ donation to achieve maximum benefits whilst minimising harms.

B A virtues-based approach. Central importance is placed on the values and beliefs of people rather than the actions and their outcomes of a procedure.

Exam-style questions

Within lesson

Question 14 (1 MARK)

The digestive system plays an important role within the body.

Which of the following is true of the digestive system?

A All organisms possess a digestive system.

B Organs of the digestive system include the pancreas and stomach.

C There are no cells or tissues within the digestive system, only organs.

D The primary role of the digestive system is to defend the body against infection.

Question 15 (1 MARK)

Which of the following is a type of plant tissue?

A connective

B muscular

C vascular

D nervous

Question 16 (1 MARK)

What cells are responsible for the transport of water from the root of a plant to its leaves?

A xylem cells

B phloem cells

C parenchyma cells

D collenchyma cells

Question 17 (1 MARK)

Not all organisms contain organs or systems.

One reason that could explain the absence of organs and systems in some organisms is that

A organs and systems are only present in intelligent organisms.

B organs often cease functioning and are removed and replaced by new organs.

C these organisms are plants, which don't contain as complex an organisation as animals.

D the functions required for the survival of these organisms do not require the level of coordination of organs or systems.

Question 18 (1 MARK)

The role of the excretory system in animals is to

A detect the presence of stimuli and activate responses in the body.

B remove waste substances from the body.

C defend the body against infection.

D produce and secrete hormones.

Question 19 (1 MARK)

Identify the name of the animal organ system responsible for protecting the internal body environment from external factors.

A nervous system
B muscular system
C integumentary system
D blood circulatory system

Multiple lessons

Question 20 (5 MARKS)

Humans are made up of trillions of cells. By having many small cells, the transport of nutrients and waste removal is more efficient. The small cells are organised into tissues, organs, and systems to perform the functions vital for life.

a What is surface area to volume ratio? (1 MARK)

b Describe the effect of cell size on surface area to volume ratio. (1 MARK)

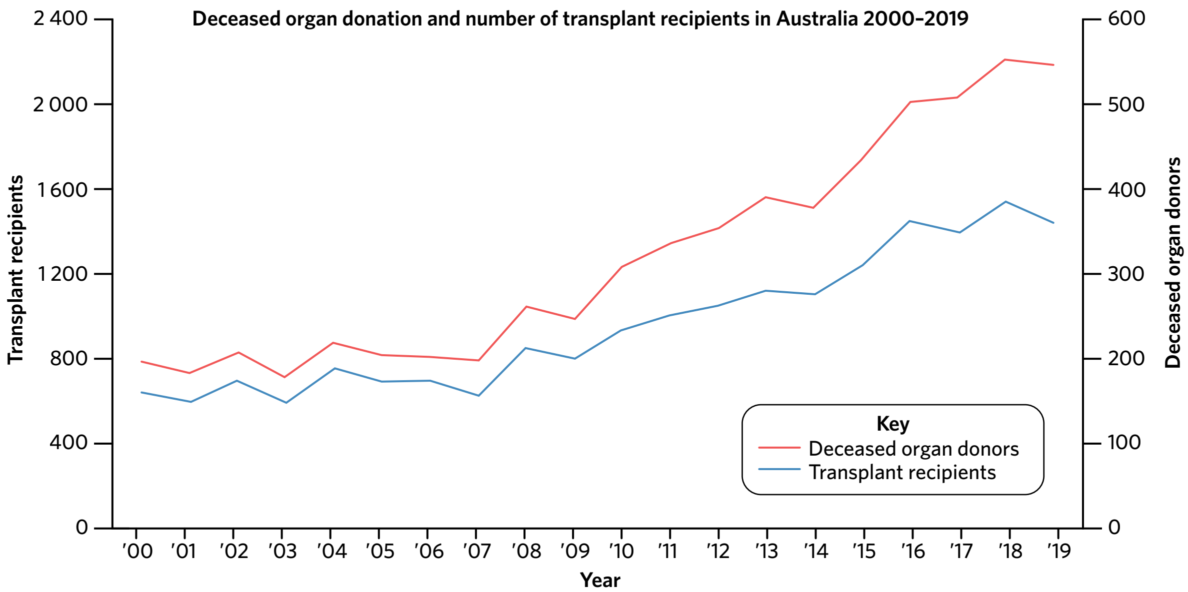
c What is the benefit of cells having a high surface area to volume ratio? (1 MARK)

d The small intestine is an organ of the digestive system. Its role is to absorb the nutrients from broken-down food as it passes through the digestive system. Cells lining the small intestine arrange into 'finger-like' projections to increase surface area. Briefly outline why the cells are arranged like this. (2 MARKS)

Key science skills and ethical understanding

Question 21 (8 MARKS)

Organ and tissue donation involves removing organs or tissues from a recently deceased person and transplanting them into someone who in many cases is very ill or dying. Donations of non-vital organs and tissues from living donors are also possible. The following graph shows the number of organ donations from deceased individuals and transplant recipients in Australia over a 20-year period.



Adapted from Organ and Tissue Authority, 2019.

a Describe the trends seen in both graphs. (2 MARKS)

b How many deceased donors were there in Australia in 2010? (1 MARK)

c How many people received a transplant in Australia in 2018? (1 MARK)

d Choosing to donate organs or tissues is an important decision to make and is considered an act of extraordinary generosity. The consideration of many ethical concepts is required in making such a decision and the procedure that follows.

- **i** Identify a bioethical concept that the doctor should be following when informing a potential donor of the risks associated with organ donation while still alive. Justify your response. (2 MARKS)
- **ii** Identify a bioethical concept that should be adhered to when a doctor is performing surgery on both a donor and recipient. Justify your response. (2 MARKS)

5B PLANT VASCULAR TISSUES

Every single plant on Earth requires water for photosynthesis, but would you believe me if I told you that it took 20 000 L of water to produce your cotton t-shirt? Where does all this water go? And why exactly is cotton such a thirsty crop species?

I really hope this shirt isn't made out of cotton...

Image: Bolakaretstudio/Shutterstock.com

Lesson 5B

In this lesson you will learn how vascular plants move water and essential nutrients, and how plants limit water loss.

◀ *Prerequisite knowledge* | *Future applications* ▶

Chapter 3
The transport of water and nutrients in plants relies on the ability of water and nutrients to cross the plasma membrane.

Lesson 5A
5A discussed the organisation of cells to systems. This lesson will discuss the cells, tissues, and organs involved in the movement of water and nutrients between the two plant systems, the root and shoot systems.

Lessons 10A & 10B
Evolved adaptations to vascular tissues and the root and shoot system enable plants to survive in a range of different environments.

Study design dot points

- specialisation and organisation of plant cells into tissues for specific functions in vascular plants, including intake, movement, and loss of water
- regulation of water balance in vascular plants

Key knowledge units

Introduction to vascular tissues in plants	1.2.1.3
Mechanisms of water and nutrient movement in plants	1.2.1.4
Regulating transpiration	1.2.3.1

Introduction to vascular tissues in plants 1.2.1.3

OVERVIEW

Vascular plants contain vascular tissues, which transport water from the roots to the leaves of a plant, and glucose and nutrients throughout the plant.

THEORY DETAILS

Everyone knows that plants can't live without water. But what is it about water that makes it so special? For a start, water is involved in:

- metabolic reactions like photosynthesis
- transporting nutrients and waste around the plant
- preventing plants from overheating through evaporation
- ensuring cells have the right tonicity
- preventing wilting and/or damage from dehydration in the plant.

Very simple plants, such as mosses or liverworts, can passively transport water, nutrients, and wastes without the need for complex transport systems. This is because they have a high surface area to volume ratio, and substances simply diffuse across the small distances around the plant. However, larger and more complex plants like trees and shrubs need nutrients and water to reach every cell in an organism that could be over 100 m long. To solve this problem, some plants – called **vascular plants** – have evolved specialised cells, tissues, organs, and systems that transport materials around, into, and out of the plant.

In lesson 5A, you learned that plants have two main systems, the **root** and **shoot** systems, which are composed of the three plant tissue types: dermal, ground, and **vascular tissues**. The vascular tissues of plants transport water, nutrients, and minerals between these two systems and throughout an entire plant. There are two main types of vascular tissue:

- **xylem tissue** – tubes that transport water, and minerals such as potassium, nitrogen, and phosphorus in one direction from the roots to the leaves of a plant
- **phloem tissue** – tubes that transport sugars and other nutrients around a plant in both directions.

The arrangement of vascular tissues is different between plant species. This lesson focuses on the vascular systems of a group of flowering plants called dicots, which includes eucalypts, fruit trees, and roses. For dicots, the vascular tissues are located in **vascular bundles** in the centre of roots and just below the bark of stems and trunks (Figure 1). In leaves, vascular bundles branch out and you can see them as 'veins'.

vascular plants a group of plants that contain vascular tissues

root system organ system in plants that is responsible for providing support to the plant and water and nutrient absorption from soil

shoot system organ system in plants made up of reproductive organs, stems, and leaves

vascular tissues conducting tissues that transport water and nutrients within a plant. An encompassing term for the xylem tissue and phloem tissue

xylem tissue transports water and minerals in one direction, from the roots to the leaves

phloem tissue transports sugars and other nutrients in two directions, to all the cells of the plant

vascular bundles the close arrangement of xylem and phloem tissues

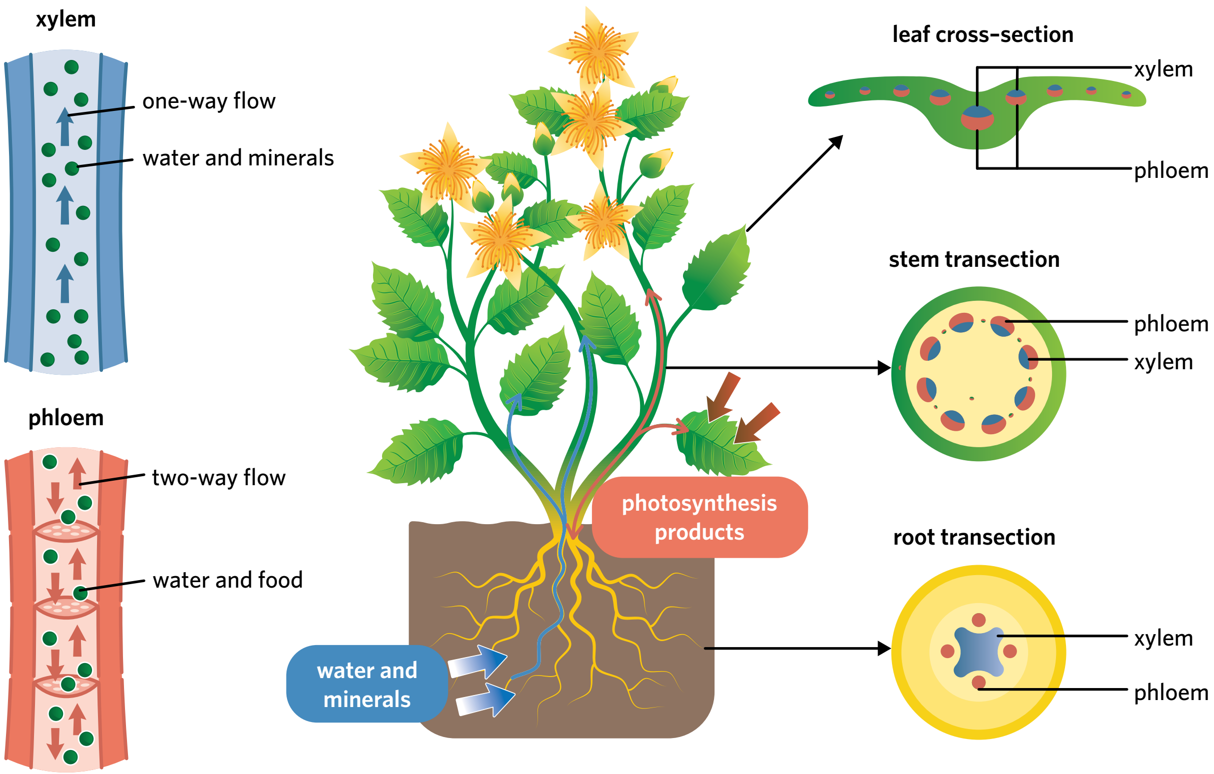


Image: VectorMine/Shutterstock.com

Figure 1 Water and nutrients in vascular plants are transported using the two vascular tissues, the xylem and the phloem. The arrangement of xylem and phloem vascular bundles is different in the roots, stems, and leaves of a vascular plant.

Mechanisms of water and nutrient movement in plants 1.2.1.4

OVERVIEW

In vascular plants, water and essential nutrients are absorbed from the groundwater and soil by the roots. The nutrients and water then travel up the xylem to the leaves, where water is used during photosynthesis or released from the plant. The product of photosynthesis (glucose), and other nutrients, are transported throughout the rest of the plant in the phloem.

THEORY DETAILS

This section will step you through the structures and mechanisms of water movement in vascular plants. Firstly, you will consider the intake of water and minerals by the roots. Secondly, the cellular structure of the xylem and phloem will be explained and contrasted. Thirdly, you will learn how water and minerals travel through the xylem. And finally, you will learn how sugars and other nutrients travel through the phloem.

Intake of water and nutrients

The root system has two major functions – to provide stability and support to a plant, and to absorb the water and minerals from the soil that are required for complex plant life. How the root system provides structure is relatively simple – the roots act as an 'anchor' in the ground, preventing the plant from toppling over during strong winds.

How the roots absorb water and nutrients from the soil is slightly more complex. Firstly, we know that diffusion occurs at a greater rate in structures with a high surface area to volume ratio. Therefore, roots aren't simply one large, lumpy structure. The root system has many different branches which increase the overall surface area for absorption. Additionally, **root hair cells** have finger-like projections which extend outwards, further increasing the surface area of roots (Figure 2).

root hair cell a cell with hair-like extensions that absorbs water and minerals from the soil into the root

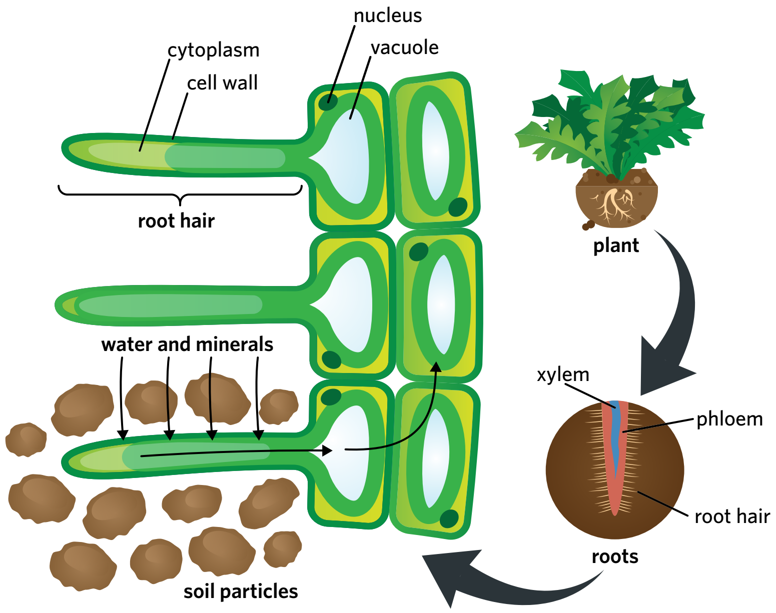


Image: VectorMine/Shutterstock.com

Figure 2 The structure of root hair cells and their location in a plant

extracellular pathway the pathway by which roots absorb the majority of water from the soil. Also known as the **apoplastic route**

cytoplasmic pathway the pathway by which roots absorb the majority of nutrients and essential minerals from the soil. Also known as the **symplastic route**

Casparian strip the impermeable barrier between the root cells and vascular tissue that forces water and solutes travelling by the extracellular pathway into the cytoplasm of cells

Secondly, there are two different pathways of water and nutrient absorption in roots – the **extracellular pathway** and the **cytoplasmic pathway**:

- extracellular pathway – water (and the solutes dissolved within it) diffuses into the roots in the gaps between cells. Once the water reaches the hydrophobic **Casparian strip**, the water and solutes are forced to enter cells, so plasma membranes can selectively transport specific substances into the xylem. The extracellular pathway is represented by the blue line in Figure 3.
- cytoplasmic pathway – mineral ions (and a small amount of water) either passively diffuse into the cytoplasm or are taken up via active transport in root hair cells. Because of uptake via active transport, the concentration of ions within the cytoplasm of root hair cells is often 100x greater than the concentration of similar ions in the groundwater and soil. The cytoplasmic pathway is represented by the red line in Figure 3.

Lesson link

Chapter 3 describes the plasma membrane and transport across the plasma membrane. Facilitated diffusion is a form of passive transport down a concentration gradient, whilst active transport uses energy to transport a substance across the plasma membrane.

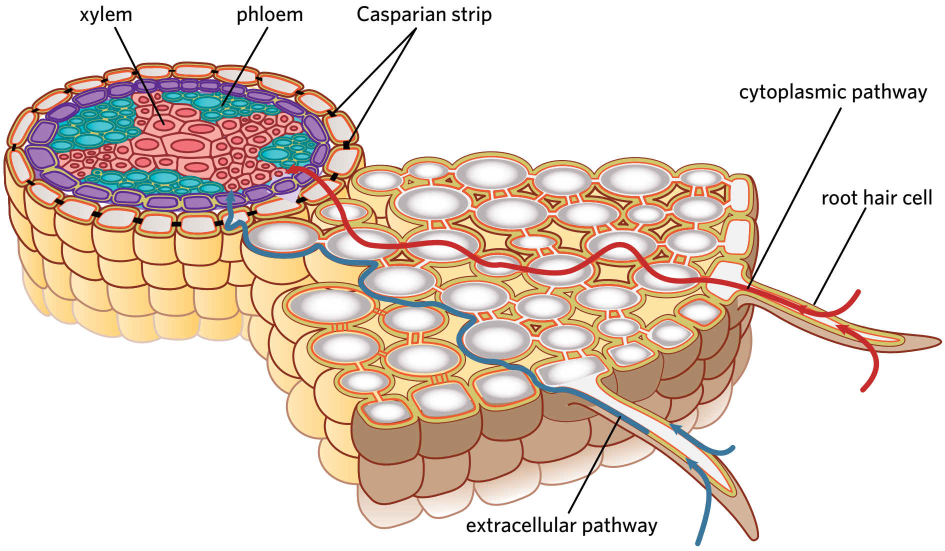


Image: Emre Terim/Shutterstock.com

Figure 3 Water and nutrients enter the xylem of the roots by either the extracellular or cytoplasmic pathways.

Structure of the xylem and phloem

To fully understand how the xylem and phloem transport water, glucose, and nutrients, you will first need to understand their structures.

Table 1 Differences in the structures of xylem and phloem

Structure of the xylem	Structure of the phloem
Xylem tissue is composed of long, skinny tubes that run from the roots to the shoots of plants. The tubes are made from two cell types: **vessel elements** and **tracheids**. The three common characteristics of vessel elements and tracheids are: • hollow cells – as the cells mature their nucleus and cytoplasm disintegrate, leaving the cells hollow and dead. • **lignified cells** – as the cell develops, the cell wall becomes strengthened with woody lignin deposits. This provides strength and support to the entire plant. • pits between vessel elements and tracheids – these allow water to flow horizontally within the xylem. The differences between the vessel elements and tracheids are: • size – vessel elements are much larger than tracheids. • arrangement – the vessel elements join end-to-end, forming a tube that allows water to flow vertically through the xylem. Meanwhile, the tracheids have tapered ends that overlap, meaning water must travel horizontally through pits between tracheids before continuing vertically.	Phloem tissue is also composed of long, skinny tubes that run throughout a plant. It is made of two types of non-lignified living cells: **sieve cells** and **companion cells**. Key characteristics of sieve cells include: • hollow cells – as the cells mature, their nucleus and cytoplasm disintegrate, leaving the cells hollow. • tube-like structure – the cells join end-to-end, providing a hollow space for water to flow vertically within the phloem. • **sieve plates** – perforated/porous plates that connect stacked sieve cells, allowing water to flow vertically through the phloem. • pits between sieve cells – small horizontal tubes form between adjacent sieve cells, allowing water to flow horizontally within the phloem. Companion cells are next to sieve cells. They regulate the entry of nutrients into the phloem and perform functions to keep themselves and sieve cells alive.

vessel element the larger components of the xylem which stack end-to-end

tracheid the smaller elements of the xylem whose endings overlap with one another

lignified when a cell is strengthened by woody lignin deposits

sieve cell the living hollow tubes of the phloem which stack end-to-end

companion cell the cells of the phloem that ensure sieve cells remain alive and regulate entry into the phloem

sieve plates the porous plates separating adjacent sieve cells

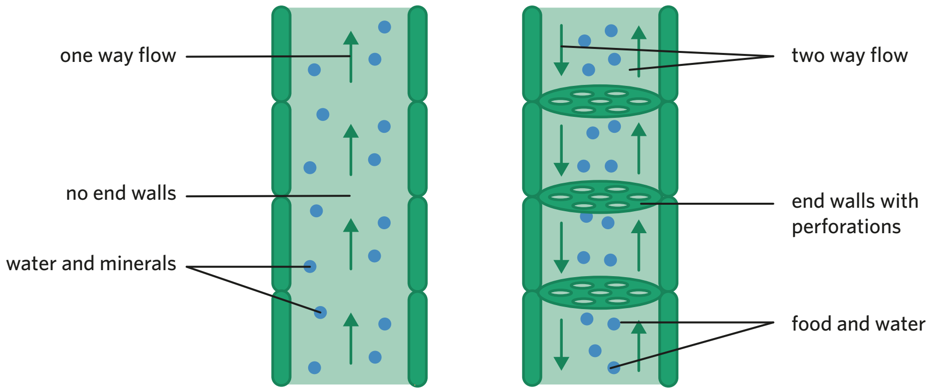


Image: gstraub/Shutterstock.com

Figure 4 The structure and direction of fluid movement in vessel elements and tracheids of the xylem (left) and sieve cells of the phloem (right)

Movement in the xylem

Transpiration

You already know that water and nutrients move up the xylem. What you might not know is that only about 1% of the water from the xylem is used during photosynthesis – the majority of the remaining water evaporates and exits a leaf via the **stomata** during gas exchange which involves the release of oxygen and the uptake of carbon dioxide. This movement of water up the xylem and its exit via the stomata is the passive process of **transpiration**. Apart from assisting photosynthesis, transpiration helps plants regulate heat and water balance, distribute nutrients throughout the plant, and prevent wilting and cell damage.

stoma (pl. stomata) small pore on the leaf's surface that opens and closes to regulate gas exchange

transpiration the evaporation of water from leaves and movement of liquids up the xylem

Image: Yuris/Shutterstock.com

Figure 5 Leaves have lots of branching veins. Their high vascularisation supplies them with high volumes of water from the xylem and enables them to transport large amounts of glucose throughout the rest of the plant via the phloem.

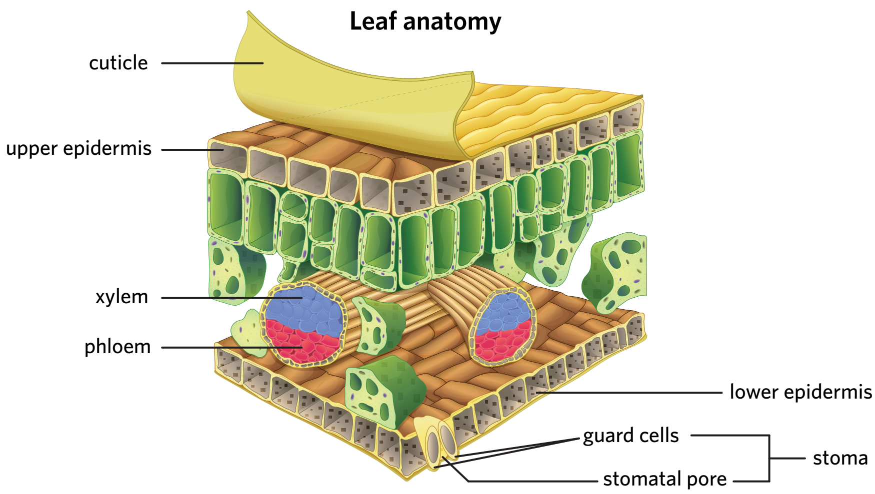


Image: BlueRingMedia/Shutterstock.com

Figure 6 Water enters the leaves via the xylem and exits the leaves by gas exchange through the stomata.

How transpiration works

When water evaporates from the leaf and exits through the stomata, the air pressure in the leaf becomes lower than the pressure in the roots. The lower pressure in the leaf creates a force that draws water up from the xylem. Because water likes to stick together (a characteristic called cohesion), even more water is drawn up than would be expected. This works the same way as when you 'suck' liquid up a straw – you create a lower pressure in your mouth compared to the atmospheric pressure, so water moves up the straw.

Another force, called **capillary action**, also helps water flow in the xylem. Capillary action is caused by the adhesion of water molecules to the surface of the xylem. This is the same force that causes a meniscus to crawl up the side of a test tube. In small enough tubes, this force of adhesion is large enough to basically 'pull the water up a tube'. These two forces working together enable transpiration and help deliver the small amount of water required for photosynthesis to the leaves.

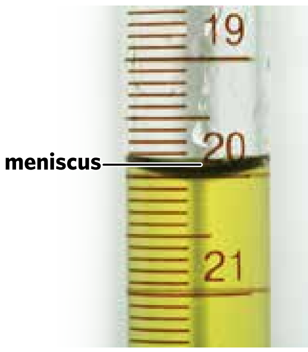


Figure 7 Meniscus in a small test tube

capillary action when a liquid, such as water, flows in narrow tubes due to the adhesion of the liquid to the surface of the tube

Theory in action

HOW EXACTLY DO STRAWS WORK? WHAT IS THE LONGEST POSSIBLE STRAW?

Materials

- 13 m of 8 mm clear vinyl tubing
- A 10 m diving board (or a 10 m high structure and a bucket filled with water)

Method

1. Stand up the top of the 10 m diving board and lower the tube into the water.
2. Attempt to suck the water through the straw.
3. Record the maximum water rise in the straw.

Questions

1. What was the maximum rise in water levels in the straw?
2. Using the equation $(P_{atmosphere} - P_{inhale}) = p_{water} \times g \times h$, calculate the maximum P_{inhale}.

   P_{inhale} = the pressure in your mouth from inhaling/sucking

   $P_{atmosphere}$ = atmospheric pressure (101 325 Pa)

   p_{water} = the density of water (1 000 kg/m^3)

   g = the gravitational constant (9.8 m/s^2)

   h = water rise (m)

Explanation

It is likely that you only managed to make the water rise up the tube by about 6 m, but don't be ashamed. Even the strongest vacuum in the world wouldn't be able to fill the straw all the way. This is because we aren't actually sucking water up through the straw – sucking forces don't actually exist. Rather, when you suck water through a straw you are lowering the pressure in your mouth cavity compared to the atmospheric pressure, and this difference in pressure pushes water up through the straw. The difference in pressure is at its absolute maximum when the P_{inhale} term is 0 kPa, otherwise known as a perfect vacuum. By plugging this P_{inhale} term into the equation, we can calculate that the maximum possible recorded height is 10.3 m. This means that when the height of the water is 10.3 m, the weight of water due to gravity is equal to the pressure pushing water up the straw, and the two forces balance each other out. In other words, it is physically impossible to raise the water any higher than 10.3 m without some other force acting on the water.

So, this begs the question, 'How can trees taller than 10.3 m transport water from their roots to their leaves?' The answer: capillary action!

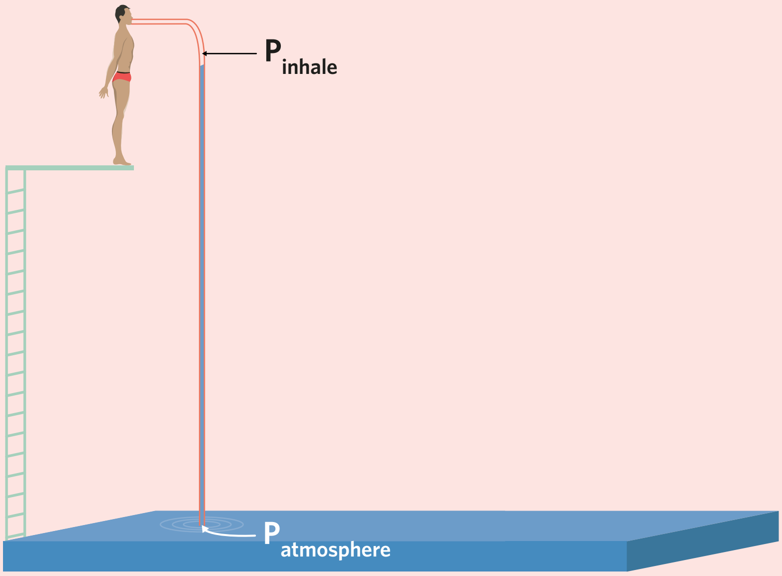


Image: Inspiring/Shutterstock.com

Figure 8 I don't care who you are, you can't suck enough to raise the water more than 10.3 m.

Theory in action

WHAT EXACTLY IS CAPILLARY ACTION? AND HOW DOES IT WORK?

Materials

- Capillary tubes with different diameters e.g. 0.5 mm, 1 mm, 1.5 mm, 2 mm
- Petri dish
- Food dye
- Water

Method

1. Fill the Petri dish with water, and add food dye until coloured.
2. Place one end of each capillary tube into the Petri dish.
3. Record the rise in water height in each capillary tube.

Question

Which capillary tube had the highest rise in water level? Which capillary tube had the smallest rise?

Explanation

The water rising in the capillary tubes is caused by the force of capillary action. Because water molecules are polar, they are attracted to each other and other polar substances. Adhesion – the 'sticking' of water molecules to the capillary tube or xylem wall – draws water up the edges of the tube. Meanwhile, cohesion – the 'sticking' of water molecules to each other – pulls other water molecules up the tube too. Skinnier tubes have less xylem wall and therefore fewer adhesive forces in total, but have more adhesive forces relative to the size of the tube. In contrast, larger tubes have more xylem walls but have lots of water in the middle of the tube where no adhesive forces exist. This means that water can climb to greater heights in tubes with small diameters. The average radius of a xylem vessel in most plants is 20 µm (0.00002 m), or thinner than a human hair.

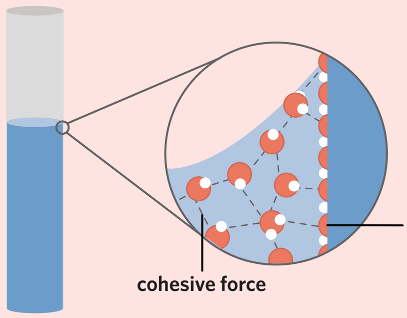


Figure 9 Adhesive and cohesive forces drag water up through capillary tubes

Theory in context

THE THEORETICAL MAXIMUM TREE HEIGHT

The main factor which determines the maximum height of a tree is whether the xylem can deliver water to cells located at the top. The action of transpiration that causes a pressure differential which 'sucks' the water up through the xylem, combined with the effects of capillary action within the xylem, are the main two forces that cause water and dissolved solutes to be drawn up through the xylem. Unfortunately these two forces can't drag water up against gravity forever. For instance, 10.3 m is the maximum height water can be raised due solely to the difference in pressure between Earth's open atmosphere and a perfect vacuum, and at very small radii or with thick liquids like sap, capillary action can be inefficient.

Using mathematical modelling, direct observations of water pressure within the xylem of tall trees, and other morphological characteristics, current estimates suggest that the largest possible height of a tree is anywhere between 122 and 130 m high.

Image: Lucky-Photographer/Shutterstock.com

Figure 10 The tallest species of tree in the world, the Californian redwood (*Sequoia sempervirens*) tops out at 115.55 m, not too far off the theoretical maximum height of trees.

Want to read the study this is based on? Find the free article by searching: "Koch, G. W., Sillett, S. C., Jennings, G. M., & Davis, S. D. (2004). The limits to tree height. *Nature*, 428, 851–854."

Translocation is the movement of nutrients created in the leaves to other areas of the plant. This tends to take place in the phloem from a **source** to a **sink**. Translocation of glucose in the phloem can be broken up into four different steps:

1 Glucose is produced in the leaf cell (the source) and pumped into the companion cells, where they diffuse into the sieve cells of the phloem.

2 Increased concentration in the sieve cells causes water to diffuse in from the xylem, increasing turgor pressure in the sieve cells.

3 The increase in turgor pressure pushes the liquid in the phloem throughout the plant, where glucose will be actively transported into required cells (the sinks). In Figure 11, the sink cells are the fruit cell and root cell.

4 Once glucose is unloaded into the sink cells, the concentration in the phloem is reduced and water will diffuse back into the xylem.

Other solutes, such as amino acids or important minerals, travel through the phloem in a similar manner to glucose.

translocation the movement of substances from a source to other tissues in the plant via the phloem. Also known as **source and sink movement**

source a tissue of a plant where substances are produced or enter the plant

sink a tissue of a plant where substances are stored

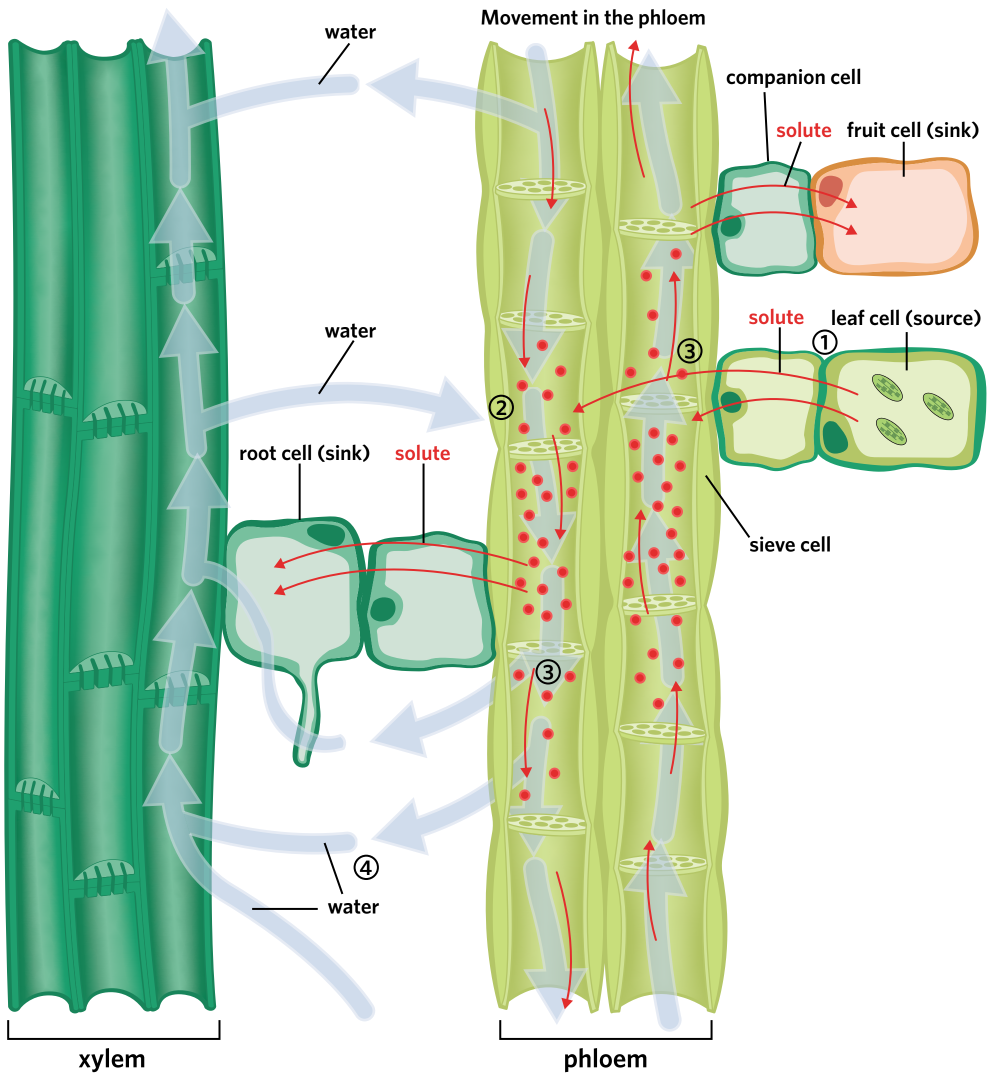


Figure 11 Translocation in the phloem vascular tissue of a plant

Regulating transpiration 1.2.3.1

OVERVIEW

Plants lose water more in hot, dry, and windy environmental conditions as a part of transpiration. Water loss via transpiration can lead to wilting, drying up, or the eventual death of the plant. In response, plants have developed mechanisms to regulate the rate of transpiration.

THEORY DETAILS

Factors affecting transpiration rate

Water vapour is lost by plants during transpiration. While transpiration is an essential process for all vascular plants, it does represent a significant and dangerous avenue of water loss. Water loss leads to high solute concentrations and a reduction in turgidity, which in turn can damage the plant or cause it to wilt. The amount of water lost to transpiration is largely dependent on the environmental conditions surrounding a plant. Environmental conditions that affect transpiration rates include:

- temperature – at higher temperatures, more water evaporates from the leaves.
- light – in high light conditions, stomata can open to increase the amount of CO_2 absorbed for photosynthesis, further increasing the amount of water lost to transpiration.
- humidity – at any temperature, air has a maximum amount of water vapour that can remain dissolved within it (or 'saturation point'). As the humidity increases, less water can evaporate into the air, and at 100% relative humidity, water cannot evaporate at all and transpiration cannot occur.
- wind – on calm days, the water released from stomata stays near the leaf, creating a humid layer of air on the leaf surface. On windy days, this humid layer is blown away, encouraging water vapour to exit the leaf.
- water availability – when water availability is high the roots absorb more water. The plant can then afford to increase the rate of transpiration and lose more water.

Lesson link

The effects of humidity on the rate of transpiration can also be explained by osmosis. In ***lesson 3B***, you learned that in osmosis, water moves from an area of high water concentration to an area of low water concentration. When the humidy is low, the air outside of the stomata has low water concentration so water will move out of the stomata, increasing the rate of transpiration.

Theory in action

Check out scientific investigation 5.1 to put this into action!

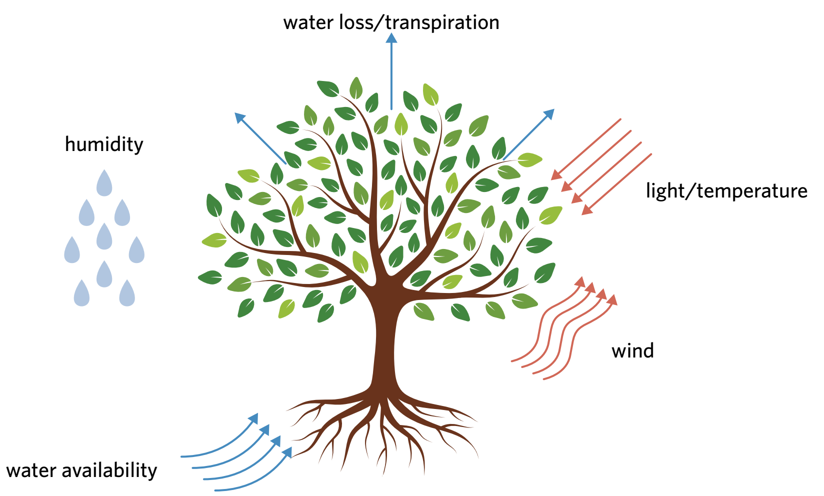


Image: Alazur/Shutterstock.com

Figure 12 Factors that affect the rate of transpiration in plants

Guard cells regulate transpiration

Two **guard cells** that surround the **stomatal pore** regulate the opening and closing of stomata. Stomata allow a plant to exchange gases with the environment. The main gases exchanged with the environment are CO_2, O_2, and H_2O.

- When stomata are open, water vapour can freely leave the leaf as part of transpiration, CO_2 can freely enter the leaf as an input of photosynthesis, and O_2 can exit the leaf after it is produced during photosynthesis.
- When stomata are closed, gases cannot freely leave or enter a leaf, thereby reducing the rate of photosynthesis, transpiration, and water loss.

To increase the rate of transpiration, plants:

- actively pump potassium ions into guard cells, greatly increasing the concentration of solutes
- water then diffuses into the guard cells via osmosis, which causes the vacuoles to increase in size, and each guard cell becomes turgid
- turgid guard cells are shaped like beans, which leaves the stomata open.

guard cell a pair of curved cells that surround a stoma. When hot they lose turgor pressure and become flaccid, closing the stomata to limit water loss

stomatal pore the opening in the centre of a turgid stoma, where gases freely enter or exit a leaf

To reduce the rate of transpiration, plants:

- actively pump potassium ions out of guard cells
- water then diffuses out of the vacuoles and guard cells
- each guard cell becomes flaccid, closing the stomata (Figure 13).

epidermal cells the plant's outermost cells which separate the plant from the external environment. These cells coat the leaves, fruits, stems, flowers, and roots of a plant. Also known as **epidermis**

Lesson link

Some plants, especially those living in hot environments, have developed unique adaptations to minimise water loss via transpiration. You can learn more about this in ***lesson 10A***.

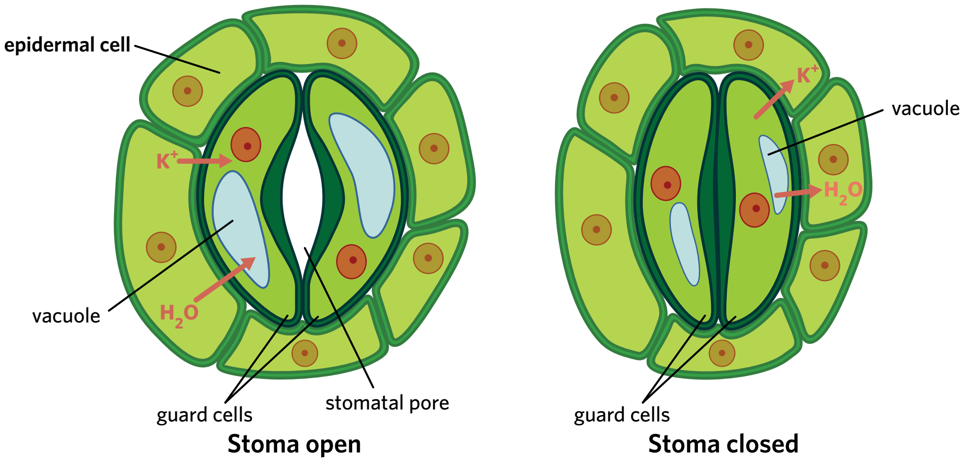


Image: Kazakova Maryia/Shutterstock.com

Figure 13 The guard cells surrounding a stoma become turgid and open when there is plenty of water. During hot temperatures as the availability of water decreases, guard cells become flaccid and close, limiting transpiration.

Theory summary

Vascular plants have two types of vascular tissue – the xylem (which transports water from the roots to the leaves), and the phloem (which transports nutrients throughout the plant). Water and nutrients are absorbed from the soil by the roots: water enters via the extracellular pathway, whilst nutrients and minerals enter via the cytoplasmic pathway.

Water is transported up the xylem through its lignified vessel elements and tracheids, which are the hollowed-out husks of dead cells. Nutrients are transported throughout the plant using live sieve cells and companion cells, according to the source and sink theory.

The majority of water loss in vascular plants is caused by transpiration, which drags water up through xylem via capillary action, low pressures in the leaves, and cohesion of water molecules. Transpiration is limited by the opening and closing of stomata – when stomata are open, transpiration is greatest, allowing the exchange of gases with the environment; when the stomata are closed, transpiration cannot occur, which limits water loss and glucose production. The fastest rates of transpiration occur on hot, dry, and windy days with bright light.

It takes approximately 20 000 L of water to grow 1 kg of cotton – the amount of material required to produce one shirt and a pair of jeans. This is enough water to fill your bathtub 100 times over, and the reasons why cotton requires so much water mainly comes down to two factors. Firstly, cotton is a particularly water inefficient species with a high inherent rate of transpiration, meaning that it loses a bunch of water to evaporation. Secondly, most cotton is grown in more arid environments, so cotton crops cannot rely on natural rainfall. An inherently high transpiration rate, high temperatures, low humidity, and low rainfall increase the transpiration rate of cotton crops, causing their water requirements to shoot through the roof.

If the amount of water surprised you, don't worry, there are less water-intensive options – for instance, growing and harvesting bamboo uses less water. Unfortunately, being environmentally friendly doesn't just boil down to how much water something takes to make – emissions, pesticides, and waste all need to be considered. Ultimately, the two most reliable methods to reduce your fashion-based environmental impact are 1) visit the op shop and buy pre-loved clothing, and 2) buy fewer clothes.

Image: Phillip Minnis/Shutterstock.com

5B QUESTIONS

Theory review questions

Question 1

Vascular plants

A are generally smaller than non-vascular plants.

B transport dissolved nutrients, minerals, and water using vascular tissues.

C contain three organ systems: the root system, the shoot system, and the vascular system.

Question 2

Label the parts of the vascular plant from the list of terms. Terms may be used multiple times or not at all.

- xylem
- phloem
- root system
- shoot system
- vascular bundle

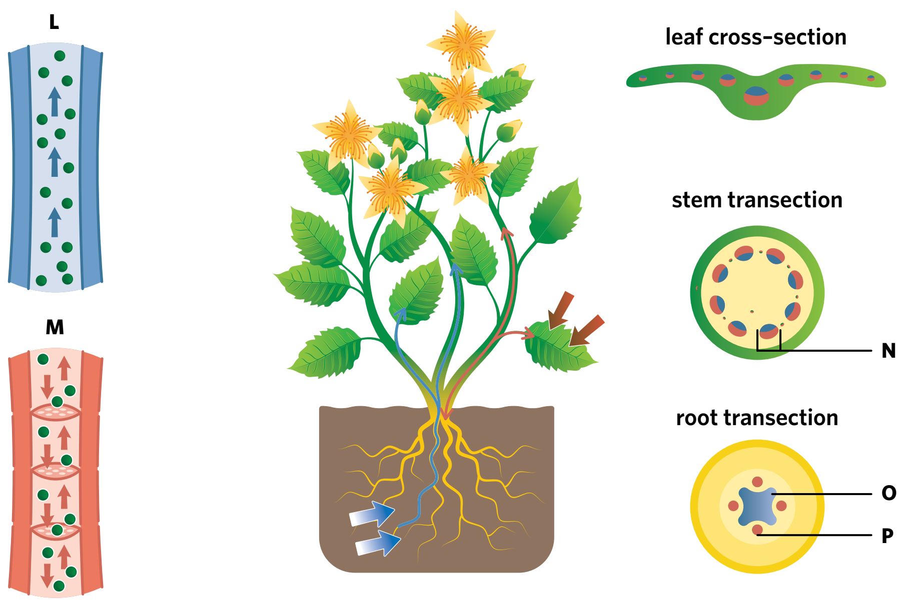


Image: VectorMine/Shutterstock.com

Question 3

Fill in the blanks in the following sentences.

The __________ is vascular tissue that allows water to flow in two directions, and is used to transport __________ using __________ movement. The __________ is vascular tissue that allows water to flow in only one direction, and transports water, minerals, and nutrients from the __________ to the shoot system.

Question 4

Which of the following are environmental factors which affect the rate of transpiration in plants? (*Select all that apply*)

I oxygen concentration

II nutrient availability

III water availability

IV groundwater pH

V light availability

VI temperature

VII humidity

VIII wind

Question 5

Fill in the blanks in the following sentences.

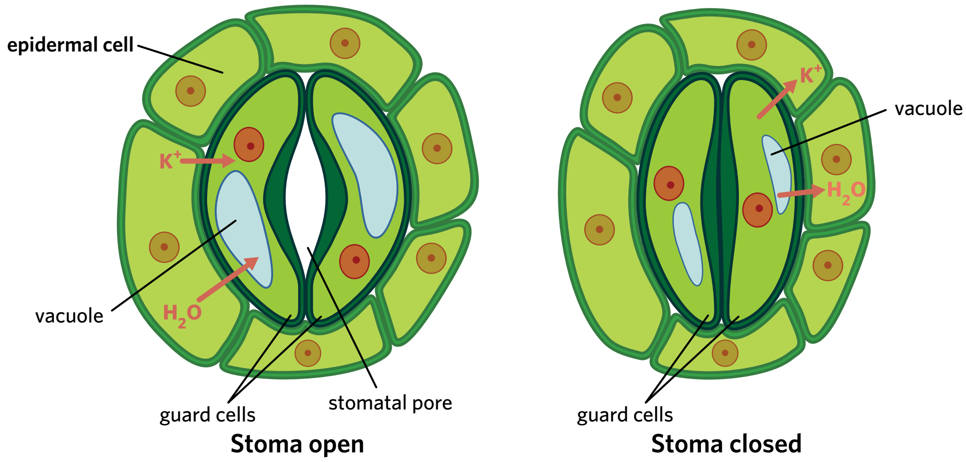


Image: Kazakova Maryia/Shutterstock.com

When temperatures are high the plant will lose __________ amounts of water due to gas exchange. This causes the __________ around the stoma to become flaccid and the stomatal pore will close, limiting water lost by the plant. When temperatures are low the guard cells around the __________ will become __________, as water diffuses into the vacuoles. This will cause the stoma to open, increasing the rate of __________.

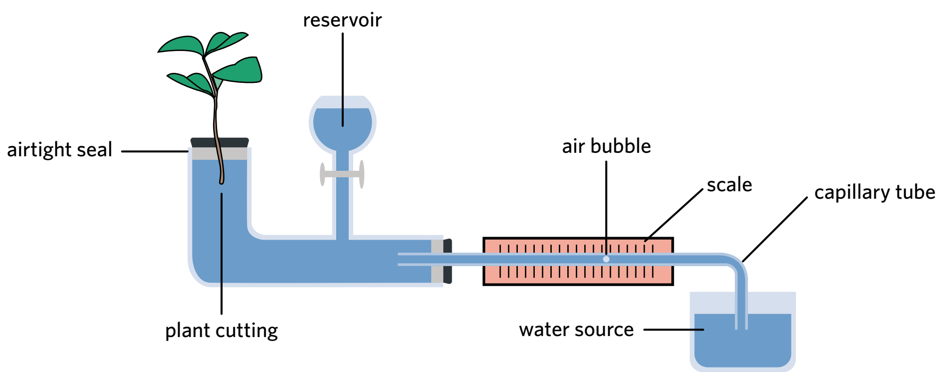
SAC skills questions

Scientific methodology comparison

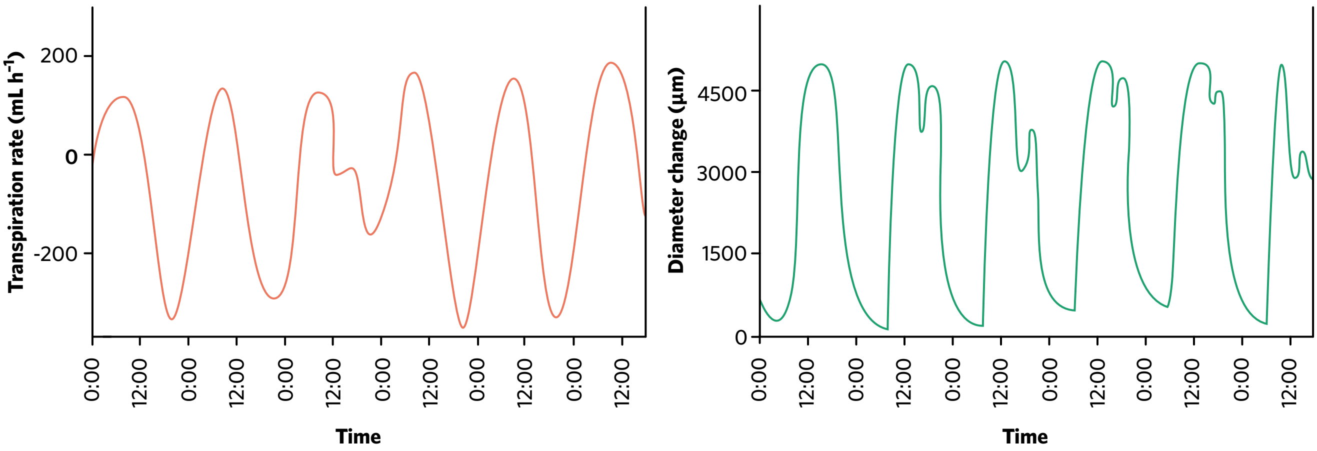
Use the following information to answer Questions 6–13.

The rate of transpiration of a plant does not remain constant over the course of a day. Generally, as temperatures become warmer, water evaporates faster and the potential for plants to lose water increases. Therefore, in high-temperature environments with low water availability, the stomata of a plant will close, significantly limiting the transpiration rate. While transpiration rate is near impossible to measure directly, many methods have been devised which can indirectly measure the rate of transpiration. Many of these methods may be considered better than others, but generally each method has positives and negatives associated with its use.

Potometers estimate the rate of transpiration of a plant cutting submerged in water. The rate of transpiration can be estimated by looking at the position of the bubble on the scale, which is influenced by water flow rate through the capillary tube. The further the bubble moves, the more the cutting is transpiring.



Dendrometers are measuring devices attached to metal bands encircling the trunk or branch of a tree. They measure the expansion and contraction of a tree's diameter over the course of a day. When the diameter of the tree increases, we can assume that the rate of water consumption by the tree is elevated. When the diameter decreases, we can assume that the rate of water consumption has decreased.



Question 6

As the temperature increases, the stomata of a plant will

A close.

B open.

Question 7

Each method measures

A total water use to estimate transpiration rate.

B transpiration rate to estimate total water use.

Question 8

According to the dendrometer, the rate of transpiration is highest

A when the diameter of the tree is lowest.

B between 6:00 pm and 12:00 am each day.

C between 10:00 am and 4:00 pm each day.

Question 9

Which of the following explains why the tree diameter increases with water consumption?

A As the water consumption increases, the cells of the trunk begin to replicate more quickly.

B As the water consumption increases, the cells in the trunk of the tree swell and become turgid.

C As the water consumption decreases, the cells actively transport more water from the trunk of the tree to the leaves.

Question 10

The peak rate of transpiration calculated using the potometer was found to be less than 100 mL h^{-1}. Proponents of the potometer method of measuring transpiration rate used this to argue that dendrometers cannot accurately determine transpiration rate in trees. Which of the following could account for the lower readings of the potometer?

A The air surrounding the potometer plant cutting had a far lower humidity than the air surrounding the plants measured by the dendrometer.

B The potometer and dendrometer were measuring the transpiration rate of the same species of plant.

C The capillary tube had a larger diameter than the volume scale was calibrated to.

Question 11

An advantage of the potometer over the dendrometer would be that the potometer

A requires a single plant cutting, as opposed to an entire tree.

B directly measures the rate of transpiration, whereas the dendrometer does not.

C provides a more accurate measurement of the transpiration rate of an entire tree.

Question 12

An advantage of the dendrometer over the potometer would be that the dendrometer

A is cheaper to run and maintain than a potometer.

B enables the tracking of water use over extended periods of time.

C provides a more accurate measurement of the transpiration rate of an entire tree.

Question 13

A common criticism for both of these methods is that transpiration rate is not simply equal to the water use of a plant. What avenues of water use are ignored when suggesting transpiration is equal to water use?

A aerobic respiration

B photosynthesis and water uptake by non-photosynthesising cells

Exam-style questions

Within lesson

Question 14 (1 MARK)

Vascular plants are any plant that

A produces seeds.

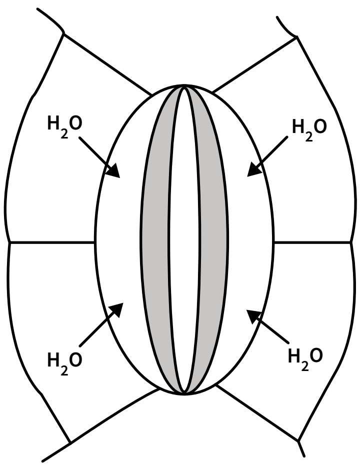
B can grow taller than 10 m.

C contains xylem and phloem.

D passively absorbs water from the environment.

Use the following information to answer Questions 15 and 16.

The figure represents two guard cells, with surrounding epidermal cells, in the leaf of a plant. The plant is in bright light.
The arrows on the diagram indicate the direction of the net movement of water from the epidermal cells into the guard cells.



Question 15 (1 MARK)

In this situation

A the stomatal pore will decrease in diameter.

B photosynthesis will decrease in the guard cells.

C the rate of water movement in the vascular tissue of the plant will decrease.

D the concentration of solutes within the guard cells is greater than in the surrounding epidermal cells.

Adapted from VCAA 2002 Exam 1 Section A Q2

Question 16 (1 MARK)

A plant wilted but later recovered. The stoma represents cells of the plant during recovery. As the plant recovered, the rate of photosynthesis increased because

A the stomatal pore opened, allowing carbon dioxide to enter the leaf.

B the wilting prevented the entry of water into the leaves.

C chlorophyll within the leaf now had access to O_2 gas.

D the temperature of the leaf was reduced.

Adapted from VCAA 2002 Exam 1 Section A Q2

Question 17 (1 MARK)

Transpiration in a well-watered potted plant would be expected to be lowest when environmental conditions included

A moving air and bright sunlight.

B moving air and high humidity.

C still air and high humidity.

D still air and low sunlight.

Adapted from VCAA 2002 Exam 1 Section A Q11

Question 18 (1 MARK)

Pieces of leaf epidermis were peeled from the plant *Commelina communis*. The pieces were then placed in a solution of a dye that binds to potassium ions. You would expect that most of the dye would be concentrated in the

A sieve cells when the stomata are closed.

B guard cells when the stomata are closed.

C epidermal cells when the stomata are open.

D epidermal cells when the stomata are closed.

Adapted from VCAA 2005 Exam 1 Section A Q6

Multiple lessons

Question 19 (1 MARK)

Certain non-plant species, including the water mould species *Saprolegnia ferax*, have evolved the ability to maintain high turgor pressures in their hyphae to break through strong substances such as plant cell structures and lignin. The ability of *S. ferax* to maintain turgor pressure suggests that they possess

A a cell wall.

B chloroplasts.

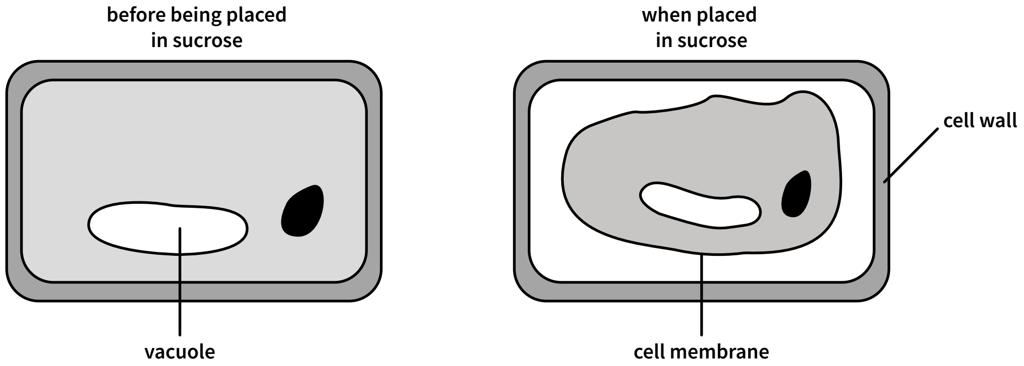
C vascular tissues.

D one large vacuole.

Adapted from VCAA 2005 Exam 1 Section A Q6

Use the following information to answer Questions 20 and 21.

The root cells of a plant were placed in a sucrose solution and changes within the cell were observed.



Question 20 (1 MARK)

From the information in the diagrams it can be concluded that

A the concentration of the sucrose solution was greater than that of the plant's cytoplasm.

B the plasma membrane of the plant is impermeable to water.

C glucose molecules passed through the cell membrane.

D sucrose molecules are nonpolar.

Question 21 (1 MARK)

If a plant of the same species as the submerged root cells was continuously watered using the sucrose solution, you would expect that

A the plant would begin to wilt.

B the rate of photosynthesis in the plant to increase.

C the rate of transpiration in the plant would increase.

D the concentration of sucrose in the root cells would decrease.

Question 22 (7 MARKS)

Ring-barking is the removal of a ring of bark and phloem around the circumference of a woody trunk, branch, or stem. Girdling is similar to ring-barking, but removes the bark, phloem, and xylem.

a Solutes enter a root hair cell via active transport.

- **i** Identify the pathway of nutrient absorption taken by solutes when entering a plant. (1 MARK)
- **ii** Using your understanding of vascular tissue, predict and justify the effects of ring-barking and girdling on the trunk of an oak tree. (4 MARKS)

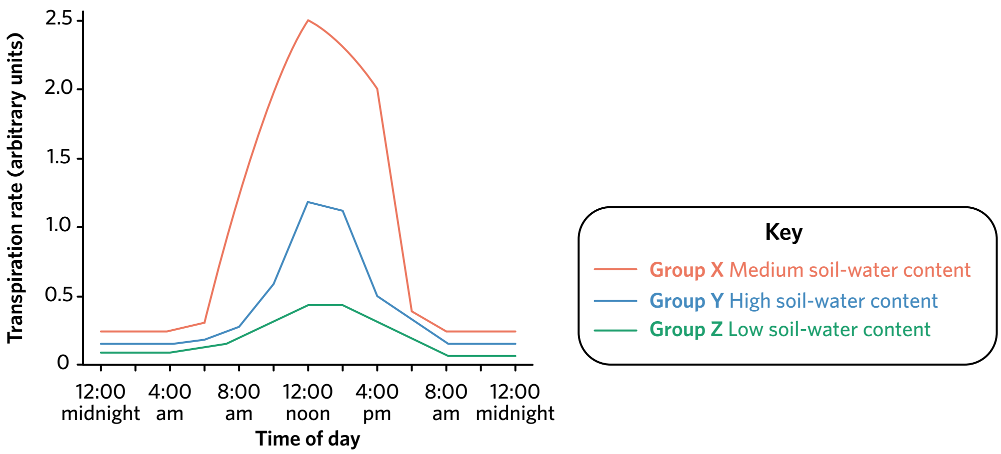
b Identify the two major cell types of the xylem and describe their structure and purpose. (2 MARKS)

Key science skills and ethical understanding

Question 23 (10 MARKS)

Transpiration rate was measured in the bean, *Phaseolus vulgaris*. Three groups were tested at varying soil-water contents.

The graph shows the results of the experiment.



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

b Does the graph display qualitative or quantitative data? Describe the difference between the two types of data. (1 MARK)

c A key component of the scientific method is the analysis of results.

- **i** Do the results of the experiment align with the theory of transpiration? Explain your answer. (2 MARKS)
- **ii** Identify one factor that could account for the results seen in the experiment. (1 MARK)

d Outline the steps involved in moving glucose from source cells to sink cells. (4 MARKS)

5C THE DIGESTIVE SYSTEM

You hear about the digestive system in the media all the time; 'Eating our product helps you digest', 'Taking this pill will help you digest', 'Drinking our fermented tea helps digestion'. So, can anything really 'help' you digest?

Image: Syda Productions/Shutterstock.com

Lesson 5C

In this lesson you will learn how cells and tissues of the digestive system are specialised to perform specific functions.

◀ Prerequisite knowledge

Years 7–10
Remember how cells make up tissues, and tissues make up organs? The digestive system is made up of a variety of cells that combine to form tissues and organs such as the oesophagus, stomach, and small intestine.

Lesson 3B
Nutrients that are digested from food travel across the plasma membrane of cells.

Future applications ▶

Lesson 6C
Glucose is absorbed from the digestion of food and enters the bloodstream which is regulated by homeostasis.

Year 12
Our cells get the energy they need from the food we eat. To obtain usable energy from food molecules, cells undergo cellular respiration.

Study design dot point

- specialisation and organisation of animal cells into tissues, organs, and systems with specific functions: digestive, endocrine, and excretory

Key knowledge units

Purpose of the digestive system	1.2.2.2
Cells, tissues, and organs of the human digestive system	1.2.2.3
The digestive systems of other animals	1.2.2.4

Purpose of the digestive system 1.2.2.2

OVERVIEW

The digestive system breaks down the food we eat into manageable pieces that we can absorb into cells and utilise.

THEORY DETAILS

Unlike plants, animals are **heterotrophs** that have to consume other organisms or their products to obtain organic molecules. These organic molecules provide chemical energy to the animal to be able to live, survive, and reproduce. They include **carbohydrates**, **lipids**, **proteins**, **vitamins**, and **minerals** (Table 1).

heterotroph an organism that cannot produce its own food and instead gains nutrition by eating plant or animal matter

carbohydrate a class of biomacromolecule made from monosaccharide monomers consisting of carbon, hydrogen, and oxygen. Also known as **saccharides** or **sugars**

lipid the class of biomacromolecule typically made from fatty acids and glycerol monomers consisting of C, H, and O. Characterised by their nonpolar nature

Table 1 A brief description of the importance of organic molecules in the body

Organic molecule	Importance
Carbohydrates	Provide a source of immediate energy
Lipids (such as fats)	Energy storage in animals
Proteins	Structural components of cells, cell receptors, enzymes
Vitamins	While required in small amounts, many vitamins are used to make enzymes
Minerals	While required in small amounts, minerals are used in many structural components of organisms

Food molecules are too large for animals to simply absorb into their bodies. For most animals, food molecules must be made small enough before they can be transported across plasma membranes and into cells. **Digestion** is the breakdown of large food molecules into smaller forms that can cross plasma membranes and be used by the body. The system of specialised tissues and organs responsible for digestion is the **digestive system**.

There are two methods of food digestion, which are both employed by humans:

- **Physical (or mechanical) digestion** – to be absorbed, food must first be broken into smaller pieces as smaller pieces provide a relatively large surface area for digestion. Physical digestion describes the processes whereby the mechanical movement of organs and tissues causes this breakdown of food into smaller pieces. These movements include chewing, muscle contractions, and the stirring of food and digestive juices by muscle movements.
- **Chemical digestion** – food pieces undergo chemical digestion by enzymes and stomach acid, producing smaller molecules that are capable of being absorbed. Most digestive enzymes split food molecules in hydrolysis reactions, by adding water molecules. The three major types of digestive enzymes are amylases (which act on carbohydrates), proteases (proteins), and lipases (lipids).

Overall, digestion occurs via the following four steps:

- Ingestion – the first step of the process is when food is taken into the body. For vertebrates such as humans, the teeth, saliva, and tongue play an important role in ingestion. The teeth physically break down food into smaller pieces, whilst enzymes in the saliva chemically break down the food pieces into a soft mass that can be swallowed.
- Digestion – occurs along the **digestive tract**, where the soft mass travels from the mouth into the body of the organism and continues to be broken down both physically and chemically by a variety of organs.
- Absorption – once the food macromolecules are broken down into smaller molecules, they are absorbed across the plasma membrane of cells in the digestive tract into the bloodstream. It is here when the energy from food is ready to be used by the body.
- Elimination/egestion – the final step is the elimination of undigested food content that has travelled along the digestive tract and has not been absorbed. Undigested food is eliminated from the body as faeces.

Now that you know about the overall purpose and general mechanism of digestion, we'll now take a closer look at the specialised organs and tissues involved to see exactly how the digestive system fulfils its function.

Cells, tissues, and organs of the human digestive system 1.2.2.3

OVERVIEW

In humans, the digestive system is made up of a number of organs including the stomach, liver, pancreas, and small and large intestines. Each organ is a collection of cells forming specialised tissues.

protein a class of biomacromolecule made of amino acid monomers folded into a 3D shape, consisting of C, H, O, N, and sometimes S

vitamins organic compounds that the body requires in small amounts to perform a variety of functions

minerals inorganic compounds that are essential for regular growth and nutrition

digestion the process of breaking down a substance into its basic components

digestive system the collection of specialised tissues and organs responsible for the digestion of food and absorption of nutrients

physical digestion the breakdown of food into smaller pieces by processes such as chewing and peristalsis. Also known as **mechanical digestion**

chemical digestion the breakdown of food into smaller molecules by digestive enzymes and stomach acid

digestive tract the pathway of organs that food and liquids travel through after being swallowed, leading to digestion and elimination. Also known as the **gastrointestinal tract** or **alimentary canal**

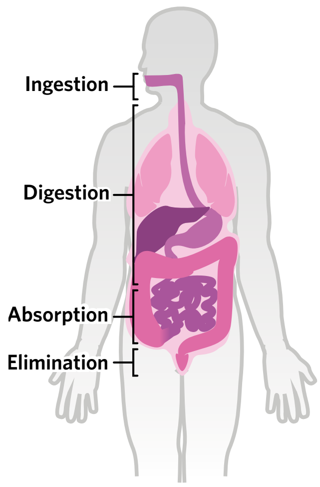


Figure 1 Consuming food involves ingestion, digestion, absorption, and elimination.

THEORY DETAILS

1. Oral cavity
The beginning of the digestive system and the site of ingestion. Teeth mechanically break food into small pieces, digestive amylase enzymes in saliva start the breakdown of carbohydrates, and lipase enzymes in the mouth start the breakdown of fats. The chewing of food occurs here. The pH of the mouth ranges from 6–8.

2. Salivary glands
Glands that produce and release saliva into the mouth and oesophagus.

3. Oesophagus
A hollow tube connecting the oral cavity to the stomach which food travels down after being swallowed. Saliva continues to mix with the food. The movement of the food is aided by waves of muscular contractions of the tube, known as **peristalsis**.

4. Stomach
A temporary storage tank where food is mixed by muscular movements known as churning. Protease enzymes are secreted by the stomach and begin the digestion of protein materials. Digestive juices are released by the stomach membrane, which creates an acidic environment of pH 1–3. Peristalsis of the stomach muscles helps push food along to the small intestine. Partially digested food that leaves the stomach is known as **chyme**.

5. Liver
The liver is the site of bile production. Bile is important in the physical breakdown of fats – smaller fat particles are then more readily broken down by lipase enzymes. The liver also has important roles in regulating metabolism, toxin removal, and processing nutrients.
The liver stores excess glucose in the form of glycogen, which can be converted back to glucose when needed for energy.

6. Gallbladder
After being produced in the liver, bile is stored and further concentrated in the gallbladder before it is released into the small intestine.

7. Pancreas
Digestive enzymes are produced in the pancreas and are released when food reaches the first part of the small intestine.
The pancreas also regulates blood sugar levels and is responsible for secreting bicarbonate, which neutralises acids in chyme.

8. Small intestine
The main function of the small intestine (divided into three sections: the duodenum, the jejunum, and the ileum) is to absorb nutrients from food. Enzymes produced in the small intestine, enzymes from the pancreas, and bile from the gallbladder aid the breakdown of food in chyme. Continued breakdown of carbohydrates and proteins occurs in the small intestine, as well as the majority of fat breakdown.
The cells lining the small intestine absorb nutrients and certain waste products of digestion and deliver them to the circulatory system.

9. Large intestine
The final absorption of water, vitamins, and minerals occurs in the large intestine which is made up of the cecum, colon, and rectum. The junction between the small and large intestines is called the cecum.
As water is reabsorbed from undigested food, food becomes more solid and compact, eventually turning into faeces ready for egestion. The large intestine has a large number of bacteria.

10. Appendix
Sits at the junction between the small and large intestines and is believed to play a role in immune functions.

11. Rectum
Final area of the large intestine that stores faeces for elimination.

12. Anus
The end of the digestive tract where faeces are expelled from the body.

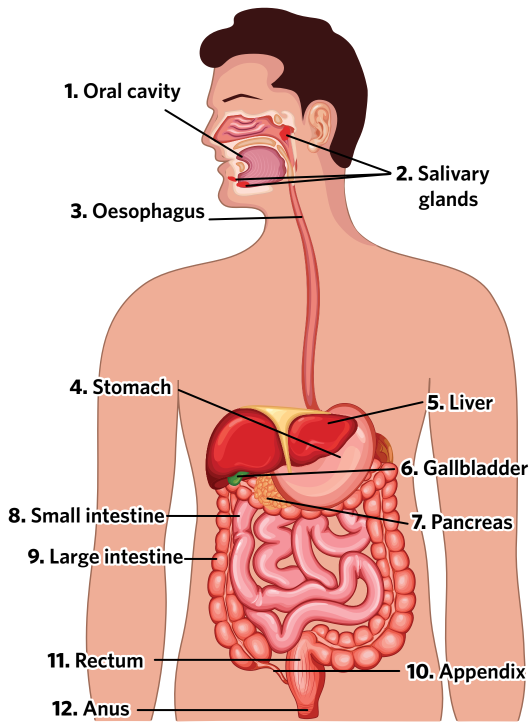


Image: Vecton/Shutterstock.com

Figure 2 The organs of the human digestive system

oral cavity beginning of the digestive tract where food is prepared for the stomach. Also known as the **mouth**

salivary glands collection of cells that produce saliva and secrete it into the oral cavity

oesophagus muscular tube lined with mucus that connects the mouth and stomach

peristalsis coordinated muscular contractions and relaxations of the digestive tract wall that move food along the system

stomach a muscular organ that receives food from the oesophagus and temporarily stores it, where it is broken down by stomach acids, enzymes and peristaltic movements

chyme mixture of partially digested food and digestive juices that passes from the stomach to the small intestine

liver a large organ found in the abdomen that is involved in many metabolic processes including the breakdown of toxins

gallbladder bile-storing organ that releases bile into the small intestine

pancreas an organ of the digestive and endocrine system that releases both digestive juices and hormones, namely insulin and glucagon which regulate blood glucose levels

small intestine connects the stomach to the large intestine and is a major site of nutrient absorption during digestion

large intestine the final area of absorption along the digestive tract and the site of faeces production

appendix a small sac of tissue that sits at the junction between the small and large intestines

rectum the final section of the large intestine that delivers faeces to the anus

anus the opening at the end of the digestive tract that releases faeces

Theory in context

CELLS AND TISSUES OF THE OESOPHAGUS

The alimentary canal is the name given to the muscular tube that runs from the mouth to the anus through the digestive system. It is composed of different parts, including the mouth, oesophagus, and intestines. Within the walls of the alimentary canal, such as in the oesophagus, epithelial cells combine with goblet cells and enteroendocrine cells. Goblet cells secrete mucus and fluid into the **lumen** of the canal, and enteroendocrine cells secrete hormones. These cells combine to form the **epithelial tissue** of the oesophagus.

The epithelial tissue combines with connective and muscle tissues to form the mucosa tissue. This mucosa is surrounded by three other layers of tissue, including the submucosa, the muscular layer, and the serosa layer. Together, these tissues form the wall of the alimentary canal. The inner layers secrete mucus, while the muscles of the outer layers contract and relax in a way that pushes food along the canal. The organ we refer to as the oesophagus, then, can be seen to be a hollow tube composed of four layers of tissue.

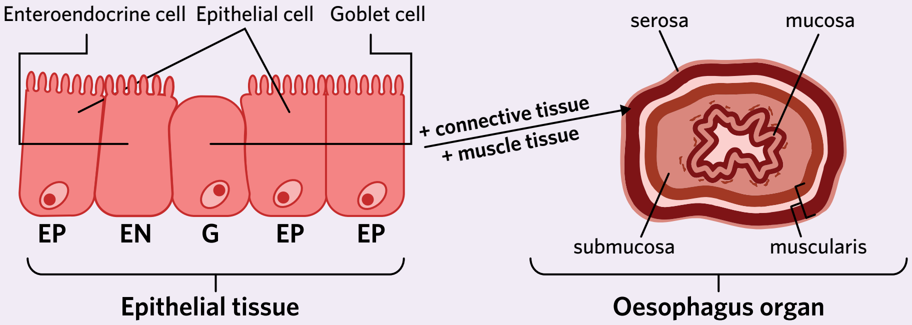


Image: Timonina /Shutterstock.com

Figure 3 Epithelial cells combine with goblet and enteroendocrine cells to form epithelial tissue. Epithelial tissue combines with connective and muscle tissue to form mucosa tissue. Mucosa tissue in combination with other tissues forms the oesophagus of the alimentary canal.

lumen the inside space of a tubular structure

epithelial tissue one of the basic tissue types in animals that lines the outer surface of organs and blood vessels

Theory in context

PERISTALSIS

Peristalsis is a series of wave-like muscular contractions of the digestive tract wall that move food along the digestive system. These contractions occur right along the digestive tract, pushing food down the oesophagus, through the stomach, and along the length of the small and large intestines.

In addition to propelling food through the digestive system, peristalsis also helps to mix the chyme in the intestines with digestive enzymes and bile to break down nutrients and aid their absorption.

You've probably heard people saying how it's important to eat fibre in your diet. There are two kinds of fibre – soluble and insoluble. Insoluble fibre increases the bulk of chyme in the intestines which makes it easier for it to be pushed along the digestive tract, whilst soluble fibre increases the amount of water absorbed by the chyme creating a softer stool that is easier to excrete.

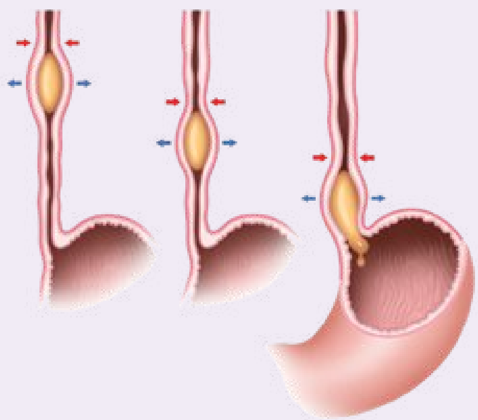


Image: Aldona Griskeviciene/Shutterstock.com

Figure 4 Demonstration of peristalsis

Theory in context

SURFACE AREA AND ABSORPTION IN THE SMALL INTESTINE

The small intestine is responsible for the majority of absorption of organic molecules in the digestive system. To maximise absorption, the small intestine is long and contains a specialised surface, giving it a large surface area. The surface of the small intestine contains millions of tiny folds called **villi**. On top of that, the epithelial cells lining the small intestine and its villi contain **microvilli** on their exposed surface, increasing the surface area even more (Figure 5).

As it is also part of the alimentary canal that food passes through, the small intestine is composed of the same four layers of tissue as the oesophagus. Villi and microvilli are part of the mucosa tissue layer that is exposed to the chyme. The increased surface area allows for greater exposure of digested food to the intestinal lining, where broken-down proteins, carbohydrates, and fats are absorbed through the tissue and put into circulation in the body.

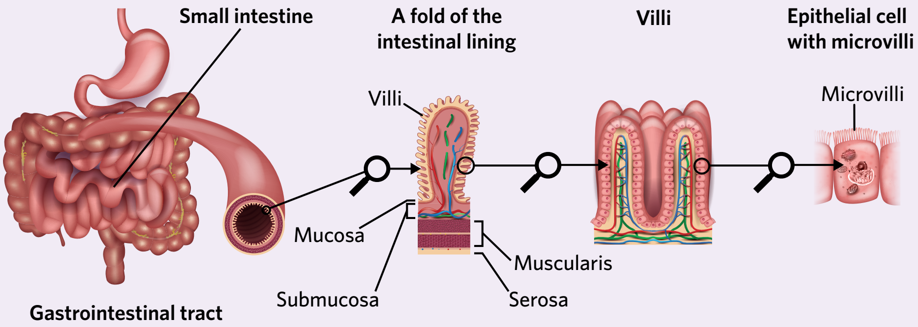


Image: Tefi/Shutterstock.com

Figure 5 The small intestine is made up of specialised tissues and cells that all serve to increase the surface area of the organ.

villus (pl. villi) finger-like projections from the surface of membranous structures to increase the surface area

microvillus (pl. microvilli) microscopic projections on the surface of cells that increase cellular surface area

The system in action

To bring it all together, imagine you have just eaten a delicious slice of cheesy pepperoni pizza.

- Ingestion – the pizza begins in your mouth where chewing physically breaks down the pizza and saliva starts the process of chemically breaking down the carbohydrates in the pizza base and fats in the cheese. Upon swallowing, saliva and peristaltic muscular contractions aid the movement of the pizza pieces down your oesophagus to your stomach.
- Digestion – in the stomach, the pizza pieces are exposed to protease enzymes that chemically break down the protein in the meat. Acidic juices and the churning of the solution aids digestion further. Following the stomach, the partially digested pizza is now called chyme which travels to the small intestine. When the chyme reaches the duodenum of the small intestine, it triggers the secretion of substances into the small intestine. Bile that was produced in the liver and stored in the gallbladder is secreted into the small intestine to break down fat molecules, as well as a variety of digestive enzymes from the pancreas. Additionally, bicarbonate is secreted by the pancreas to neutralise the chyme by increasing its pH.
- Absorption – the pizza is now completely digested as all carbohydrates, proteins, and fats are broken down. Within the small intestine, the majority of the absorption of the nutrients from the food occurs. Villi and microvilli increase the surface area to maximise the absorption of the nutrients from the food.
- Elimination/egestion – at the large intestine, the final absorption of nutrients and water occurs, and what is left of the undigested food is pushed to the rectum where it solidifies and becomes faeces, ready for elimination.

The digestive systems of other animals 1.2.2.4

OVERVIEW

Just as the human digestive system has evolved over thousands of years to suit our diet and feeding habits, different animals have evolved different digestive systems based on their environment and diet.

THEORY DETAILS

Different animal species have different food requirements and feeding behaviours. A key determinant of the structure and specialisation of an animal's digestive system is its diet. **Herbivores**, **omnivores**, and **carnivores** contain different digestive systems due to their differences in diet.

herbivore an animal that almost exclusively feeds on plant material

omnivore an animal that eats a variety of food from plants to other animals

carnivore an animal that almost exclusively eats meat

Omnivores

Humans are omnivores, meaning they consume a wide variety of food types when compared to the diet of other animals like a domesticated cat or a sheep. Humans and other omnivores have populations of microorganisms living along their digestive tract known as gut microbiota. Humans and their natural microbiota both benefit from one another. The microbiota have somewhere to live and a supply of food, and human digestion is aided by the microbiota's fermentation and breakdown of undigested food. The large intestine in particular is home to a large amount of microbiota in omnivores.

Omnivores typically have a combination of both sharp and blunt teeth that reflect a diet that is both animal and plant-based. Figure 6 shows a comparison between the digestive system of humans, cats, and sheep. In humans, you can see that food travels from the stomach to the tightly folded small intestine, before travelling through the large intestine prior to elimination.

Carnivores

Cats are carnivores, and as such their digestive system is comparatively simple overall. They have sharp teeth, including large canine teeth, that rip and tear flesh off prey, and their jaws chew up and down. Carnivore digestive systems still contain gut microbiota, although because meat is dense and relatively easy to digest, it allows carnivores to have relatively short digestive tracts. Similar to humans, food is still exposed to acid in the stomach, the majority of absorption occurs in the small intestine, and the large intestine serves to reabsorb water.

Herbivores

In general, plant matter is harder to digest than animal matter. This is because digesting cellulose, the main molecule in plant cell walls, is long and difficult. This is why herbivores have much longer digestive systems and far greater concentrations of gut microbiota compared to carnivores and omnivores. In fact, herbivores have a fermentation site within their digestive system that contains an extremely high concentration of microbiota and is responsible for massive amounts of fermentation that aids digestion. There are two distinct types of herbivore digestive systems: hindgut fermenters and foregut fermenters. Hindgut fermenters contain single-chambered stomachs and extremely large cecums, which is the fermentation site. Foregut fermenters have multi-chambered, more complex stomachs and their fermentation site is the very large first stomach chamber.

Herbivores have large flat teeth and their jaws move side to side which allows them to grind their food. Because it is so difficult to break down cellulose, herbivores browse and graze all day long in order to take in enough energy. The lengthy digestive tract provides enough time for the system and microbes to break down the tough plant material.

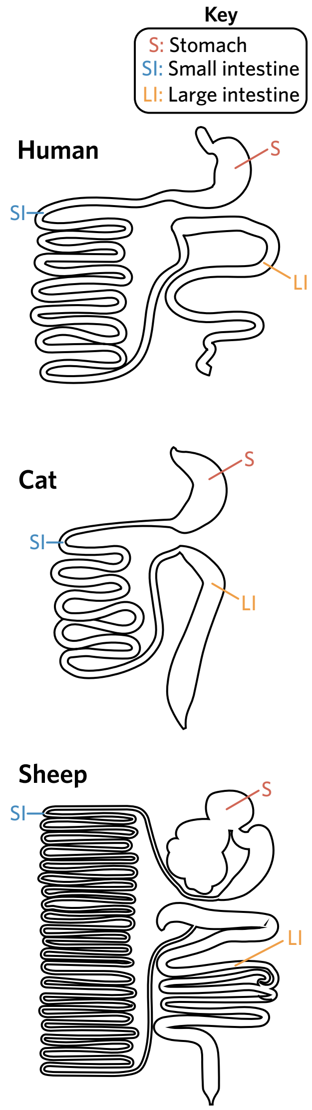


Figure 6 Animals contain different digestive systems depending on their diet.

Theory in context

AVIAN ANATOMY

Birds face a number of special challenges when it comes to digesting food. First, as they don't have teeth, birds' digestive systems must be able to process unchewed food. Secondly, birds need to keep their weight low so that they can fly effectively. This means that they need to digest food very quickly, as having a full stomach wouldn't be very favourable for taking off!

Many of the components of a bird digestive tract are very similar to that of a human as they are omnivorous, however, there are a few key differences to combat the challenges they face when it comes to digestion:

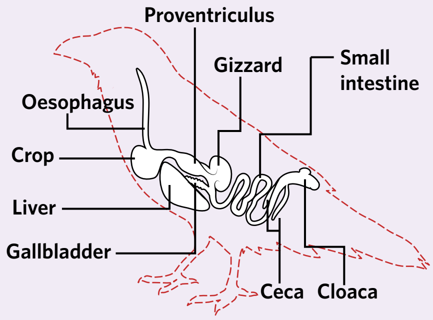


Figure 7 Bird digestive systems are specialised to help digest unchewed food and to keep body weight low.

- The crop is an area before the stomach where food is temporarily stored until it is ready for digestion.
- There are two chambers of the stomach; the proventriculus and the gizzard:
  - Gastric juices aid digestion in the proventriculus
  - Within the gizzard, food is stored, and mechanically ground. This mechanical breakdown in many birds is aided by the presence of gastroliths, which are rocks and stones deliberately swallowed by the bird to store and help grind food. You read that right – many birds are walking and flying around with rocks inside their digestive system!
- Waste is eliminated out of the cloaca.
- Digestion occurs much faster in birds than in other animals as the metabolic rate of birds needs to be significantly higher to provide sufficient energy to fly.

Theory summary

The purpose of the digestive system is to rapidly break down food into small molecules that can be absorbed by the small intestine and transported to cells throughout the body. Digestion takes place via physical and chemical processes. The digestive tract is comprised of the alimentary canal that transports food through the body and accessory organs that aid digestion. In different animals, digestive systems are specialised to suit their diet and feeding habits.

Now that you know how the digestive system works in both humans and other animals, you can understand why certain foods help or hinder digestion. Ways to improve your digestion include eating lean (low-fat content) meat and fish as they are easier to digest, and drinking plenty of fluids to encourage the passage of waste. Fruits and vegetables are high in vitamins and minerals that aid digestion and fibre that aids the movement of waste. Regular exercise is also important as the muscles around the abdomen are responsible for physical digestion.

To help digestion, it is best to limit fatty foods as fats take longer to break down and can lead to digestive issues like cramping and diarrhoea. The same can be said for sugary foods as unused sugar can be converted into fats. Avoiding binge eating and heavily processed foods is critical to maintain digestive functioning. Lastly, caffeine and alcohol should be limited as they can upset stomach acids.

Image: magic pictures/Shutterstock.com

5C QUESTIONS

Theory review questions

Question 1

The digestive system

A is made up of organs such as the stomach, kidneys, and liver.

B is responsible for converting food to smaller, more absorbable molecules.

Question 2

Which of the following are organs of the digestive system? *(Select all that apply)*

I small intestine

II oesophagus

III gallbladder

IV bladder

V lungs

VI mouth

Question 3

Label the parts of the digestive system from the list of terms.

- gallbladder
- pancreas
- rectum
- liver

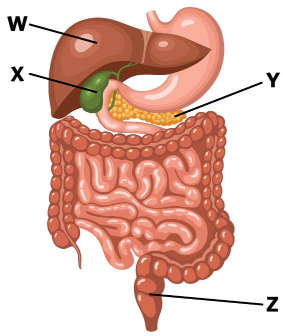


Image: Olga Bolbot/Shutterstock.com

Question 4

The pancreas

A produces digestive enzymes that are released into the small intestine.

B is the site of bile production, and releases bile into the gallbladder to be stored.

Question 5

Fill in the blanks with the following terms. Terms may be used multiple times or not at all.

- small intestine
- large intestine

The __________ is composed of the cecum, colon, and rectum, whereas the __________ is made up of three parts called the duodenum, jejunum, and ileum. The __________ directly connects to the anus, which is where faeces are eliminated from the body. The __________ is where the final absorption of water and minerals occurs along the gastrointestinal tract.

Question 6

The alimentary canal in humans consists of the

A mouth, oesophagus, stomach, small and large intestines, and anus.

B mouth, salivary glands, oesophagus, stomach, pancreas, and small intestine.

Question 7

Within the small intestine, epithelial cells that line the surface contain villi and microvilli. What is the purpose of the villi and microvilli?

A to aid the movement of chyme along the tract to push it through as quickly as possible

B to increase the surface area of the intestine allowing for greater absorption of nutrients

Question 8

Compared to herbivores, the digestive system of carnivores is

A shorter, contains a single stomach with a small cecum, and utilises teeth that pierce and rip food.

B longer, contains multiple stomachs or a single stomach, a large cecum, and utilises teeth that grind food.

SAC skills questions

Case study analysis

Use the following information to answer Questions 9–14.

Have you ever noticed that your bowel movements are an unusual colour? Faeces are usually a shade of brown due to the presence of a bile pigment called stercobilin, which is added during the formation of faeces. It is surprisingly common, however, particularly in children and babies, for faeces to be a different colour.

For example, many individuals experience green stools. This is caused by the individual's faeces having more bile acids than in normal faeces. If food is moving through the digestive system quickly, there isn't enough time for the green-coloured bile released into the small intestine to completely break down, resulting in green faeces.

Consuming large amounts of certain foods can also alter faeces colour. Some food dyes, additives, and natural colours can't be fully broken down and colour faeces. Eating loads of green leafy vegetables containing large amounts of chlorophyll can cause green faeces, as can baby formulas that are high in iron. The antioxidant called anthocyanin in blueberries can lead to blue faeces, beta carotene in carrots can cause orange faeces, whilst beetroot can colour faeces red. Typically, these colour changes are temporary but if they persist, your stool is white, or there is blood in your stool it is important to consult your GP.

Question 9

Green-coloured faeces could be caused

A at night as digestion is slowed during sleep.

B by diarrhoea as food passes through the digestive system too quickly.

Question 10

Bile is important in the breakdown of

A fats.

B carbohydrates.

Question 11

Before it is released into the small intestine, bile is stored in the

A liver.

B gallbladder.

Question 12

Stercobilin is present in the

A large intestine.

B small intestine.

Question 13

Consuming large amounts of plants is typically hard for humans to digest as

A cellulose in plant cell walls is difficult to digest.

B the chlorophyll responsible for photosynthesis stops chemical digestion.

Question 14

Why is it important to consult a GP if the discolouration lasts several days?

A A GP will be able to design and implement a dietary plan that avoids colourful foods responsible for the discolouration.

B Discolouration from indigestible pigments consumed in food are only temporary, however an ongoing discolouration may be a sign of an underlying health problem.

Exam-style questions

Within lesson

Question 15 (1 MARK)

The pancreas is part of the body's digestive system. Which of the following is a correct statement about the pancreas?

A The pancreas is part of the alimentary canal of the body.

B The pancreas is involved in the physical breakdown of food.

C The pancreas produces digestive enzymes that are released into the small intestine.

D Bile is not produced by the pancreas; instead, it is stored in the pancreas until secretion.

Adapted from VCAA 2018 Northern Hemisphere Exam Section A Q5

Question 16 (1 MARK)

Which of the following organs is not involved in the physical breakdown of food?

A small intestine

B gallbladder

C stomach

D mouth

Question 17 (1 MARK)

The majority of fats are broken down in the

A mouth.

B stomach.

C small intestine.

D large intestine.

Question 18 (10 MARKS)

The diagram shows the human digestive system.

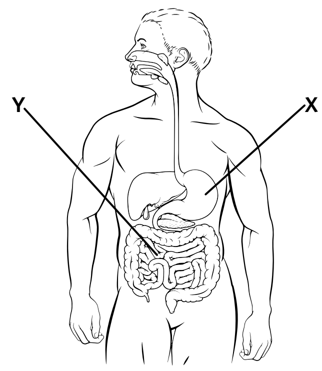


Image: Christos Georghiou/Shutterstock.com

a What organ is represented by X? (1 MARK)

b Describe the digestion that is occurring within organ X. (3 MARKS)

c State the name given to the substance that leaves organ X and continues along the gastrointestinal tract. (1 MARK)

d Structure Y is the small intestine. It is called the small intestine because the lumen of the small intestine has a smaller diameter than that of the large intestine. The lumen is the inside space of a tubular structure. In humans, the small intestine is about six metres long, whereas the large intestine is only 1.5 metres long.

- **i** Name the three sections of the small intestine. (1 MARK)
- **ii** Explain how the cells of the small intestine are specialised to aid digestion. (2 MARKS)
- **iii** What steps occur to undigested food after leaving the small intestine? (2 MARKS)

Multiple lessons

Question 19 (1 MARK)

Which of the following organs does not play a major role in multiple systems within the human body?

A pancreas
B mouth
C anus
D liver

Question 20 (6 MARKS)

The diagram shows an overview of the digestive system of a dog

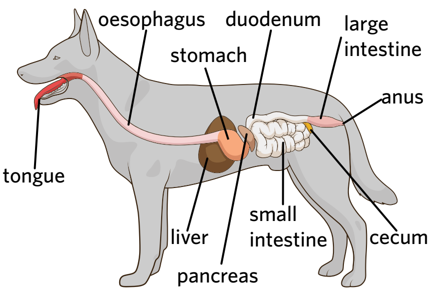


Image: Alexander_P/Shutterstock.com

a Explain how the digestive system and feeding behaviour of a dog is specialised for their diet and lifestyle. (2 MARKS)

b Nutrient absorption primarily occurs in one organ of the dog's digestive system.

i Identify this organ. (1 MARK)

ii Within this organ of the digestive system, cells lining the tract arrange into projections to alter the surface area. Briefly describe the relationship between cell shape and surface area to volume ratio, and discuss why cells lining the digestive tract arrange into projections. (2 MARKS)

c Give an example of a difference between the digestive systems of a carnivore and a herbivore. (1 MARK)

Key science skills and ethical understanding

Question 21 (8 MARKS)

The following tables display the nutritional information of two ready-to-heat meals, Meal A and Meal B, available for purchase at a local supermarket.

NUTRITION INFORMATION – MEAL A			
Servings per package: 1 Serving size: 400 g			
	Average quantities		
	Per serving	% DI per serve*	Per 100 g
Energy	2 783kJ (665Cal)	32%	696 kJ (166 Cal)
Protein	48.0 g	96%	12.0 g
Fat – total	35.2 g	51%	8.8 g
– saturated	20.7 g	86%	5.2 g
Carbohydrates	38.1 g	12%	9.5 g
– sugars	26.0 g	29%	6.5 g
Dietary fibre, total	2.2 g	7%	0.6 g
Sodium	755 mg	33%	189 mg
* Percentage daily intakes are based on an average adult diet of 8 700 kJ. Your daily intakes may be higher or lower depending on your energy needs. All nutrition values are averages.			

NUTRITION INFORMATION – MEAL B			
Servings per package: 1 Serving size: 350 g			
	Average quantities		
	Per serving	% DI per serve*	Per 100 g
Energy	2 378kJ (568Cal)	28%	679 kJ (162 Cal)
Protein	38.9 g	78%	11.1 g
Fat – total	27.1 g	43%	7.7 g
– saturated	13.8 g	58%	3.9 g
Carbohydrates	39.0 g	12%	11.1 g
– sugars	24.1 g	27%	6.9 g
Dietary fibre, total	6.4 g	21%	1.8 mg
Sodium	595 mg	26%	170 mg
* Percentage daily intakes are based on an average adult diet of 8 700 kJ. Your daily intakes may be higher or lower depending on your energy needs. All nutrition values are averages.			

a Which of the two meals, on average, provides the largest amount of energy when fully consumed? (1 MARK)

b Which meal contains more sugars per 100 grams? (1 MARK)

c What is the recommended daily intake of protein based on the average adult diet of 8 700 kJ? (1 MARK)

d After being consumed, briefly outline the pathway that Meal A travels through in the body from ingestion to elimination. (3 MARKS)

e Food companies must follow strict standards when presenting food data on their food labels. When companies misrepresent the data on their labels, which bioethical concept is not being adhered to? Justify your response. (2 MARKS)

5D THE EXCRETORY SYSTEM

It's 6 am. You've woken up before your alarm but can't get back to sleep because your bladder is so full. You lie in bed, tossing and turning, before finally giving in and staggering sleepily down the hall. By the time you arrive at the toilet, you have woken up a bit from the fright of tripping over the family cat. As you urinate, you notice that your pee is bright yellow and stinky. But before you went to sleep, it had been much paler. Why does your urine change colour? Is it always darker in the morning? And what is that smell?

Image: cliplab/Shutterstock.com

Lesson 5D

In this lesson you will learn how the excretory system removes waste materials from the body.

◀ *Prerequisite knowledge*

Years 7–10
Remember how cells make up tissues, and tissues make up organs? In the excretory system, cells make up nephrons and nephrons combined with other tissues make up the kidney.

Chapter 3
Active and passive transport are used to transport substances across nephron cell membranes.

Future applications ▶

Lesson 6D
The excretory system plays a role in osmoregulation.

Lesson 10A
Different species have evolved specialised excretory systems to conserve water.

Study design dot point

- specialisation and organisation of animal cells into tissues, organs, and systems with specific functions: digestive, endocrine, and excretory

Key knowledge units

Purpose of the excretory system	1.2.2.5
The kidneys and the urinary tract	1.2.2.6
Additional excretory organs of the body	1.2.2.7

Purpose of the excretory system 1.2.2.5

OVERVIEW

The purpose of the excretory system is to remove excess and unwanted substances from the body and to maintain a stable internal environment.

THEORY DETAILS

During cellular processes, the human body accumulates unwanted waste materials within its cells. These materials include carbon dioxide from respiration, toxins, and nitrogenous waste from protein breakdown. These substances need to be removed from the body, and when they are removed the body has to be careful not to destabilise ion and water concentrations in blood and tissues.

The body has a specialised system called the **excretory system** that removes waste substances and regulates water and ion concentrations. The excretory system comprises a number of organs and tissues, including the lungs, liver, kidneys, skin, and bladder (Figure 1).

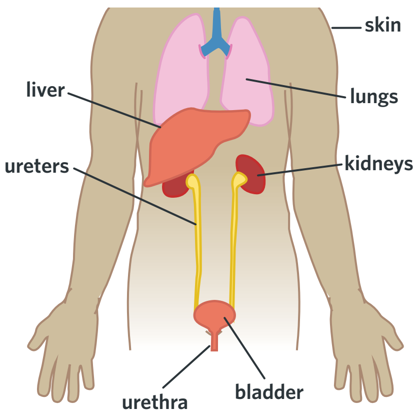


Figure 1 The excretory system of the body

If a part of the excretory system stopped working your body would fall apart pretty quickly. The buildup of toxins, nitrogenous waste, and other waste materials would poison your cells, interfere with metabolic reactions, and eventually kill you – simply because you are unable to **excrete** waste.

excretory system the collection of organs and tissues that remove excess, waste materials from the body

excrete to separate and eliminate waste from the body

The kidneys and the urinary tract 1.2.2.6

OVERVIEW

A major component of the excretory system is the urinary tract, which is responsible for filtering waste materials out of the blood and excreting these materials in urine.

THEORY DETAILS

Why do we urinate?

Mammals require protein in their diet to source amino acids, however the amino acids can't be stored so they must be immediately used or converted. In humans, when excess amino acids are consumed in the diet, they are transported from the small intestine of the digestive system to the **liver**.

In the liver, the amine group (NH_2) of amino acids is converted to ammonia (NH_3) in a process known as deamination. Ammonia is toxic to cells, so it is further broken down to less toxic **urea** (Figure 2). Like ammonia, urea must be removed from the body, but unlike ammonia, urea can be safely transported in the bloodstream.

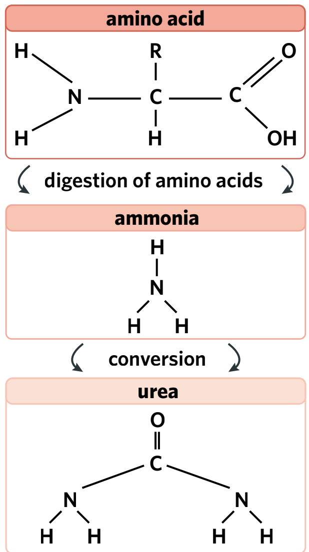


Figure 2 Nitrogenous waste produced from the digestion of amino acids needs to be excreted. The nitrogenous waste is not always in the form of urea, sometimes it is in the form of other molecules such as uric acid or creatinine.

This is where the excretory system comes in. The somewhat toxic urea in the blood is transported to the **kidneys**. Here, urea is mixed with water and solutes to form **urine**, which is then excreted from the body.

The collection of interconnected organs involved in the production and excretion of urine are known as the **urinary tract** (Figure 3). The urinary tract consists of:

- kidneys
- ureters
- bladder
- urethra.

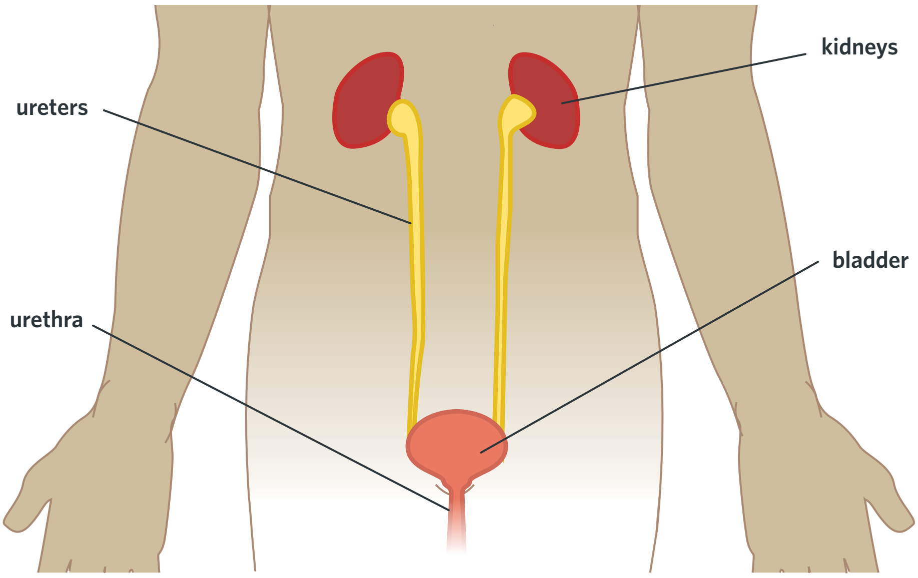


Figure 3 The urinary tract

Kidney structure

In humans, the kidneys are two bean-shaped organs located in the upper back on either side of the spinal column. The role of the kidneys is to **filter** blood, **reabsorb** the useful substances within the **filtrate**, and **secrete** the unwanted ones.

Blood is delivered to the kidneys by a pair of blood vessels called the **renal arteries** (Figure 4a). The supply is large and constant – kidneys can hold up to 25% of a person's blood volume at one time. The unfiltered blood entering the kidneys contains nitrogenous waste such as urea and uric acid, as well as creatinine.

liver a large organ found in the abdomen that is involved in many metabolic processes including the breakdown of toxins

urea the main nitrogenous product of protein breakdown in mammals. Excreted in urine

kidneys a pair of bean-shaped organs that are responsible for removing waste substances from the blood and the production of urine

urine a fluid formed by the kidneys and stored in the bladder. One of the body's major ways to remove excess water, solutes, and waste substances from the blood

urinary tract the series of channels in which urine is produced and excreted from the body

filter to pass a substance through a porous material

reabsorb to absorb a substance that has undergone filtration

filtrate the fluid filtered from blood that passes through the nephron

secrete to discharge a substance from a cell or tissue

renal arteries arteries that deliver blood from the heart to the kidneys

The renal artery branches into much smaller capillaries that deliver blood to small specialised tubes called **nephrons**. A kidney contains millions of nephrons; they are the functional unit of a kidney (Figure 4). The capillaries that deliver blood to nephrons are called the **afferent capillaries**, while the capillaries that take blood away from nephrons are called the **efferent capillaries**.

Nephron structure

Each nephron has the same structure (Figure 4b). First, the capillaries from the renal artery bunch together to form the **glomerulus** inside the **Bowman's capsule**. The Bowman's capsule connects to a long tube composed of the **proximal convoluted tubule**, the **loop of Henle**, the **distal convoluted tubule**, and the **collecting duct**. Multiple nephrons can feed into the same collecting duct.

You can see in Figure 4a that the kidney has two distinct regions: the cortex around the outside and the medulla on the inside. A single nephron spreads over both regions. The glomerulus, proximal convoluted tubule, and distal convoluted tubule are located in the cortex, while the loop of Henle and collecting duct are in the medulla.

nephron a functional unit of the kidney consisting of a glomerulus and tubule system through which filtrate passes and urine is produced

afferent capillary incoming capillaries that deliver blood to the glomeruli of nephrons

efferent capillary outgoing capillaries that carry blood away from the glomeruli of nephrons

glomerulus (pl. glomeruli) a network of capillaries that deliver blood to the Bowman's capsule

Bowman's capsule the first section of the nephron which collects filtered blood from the glomerulus

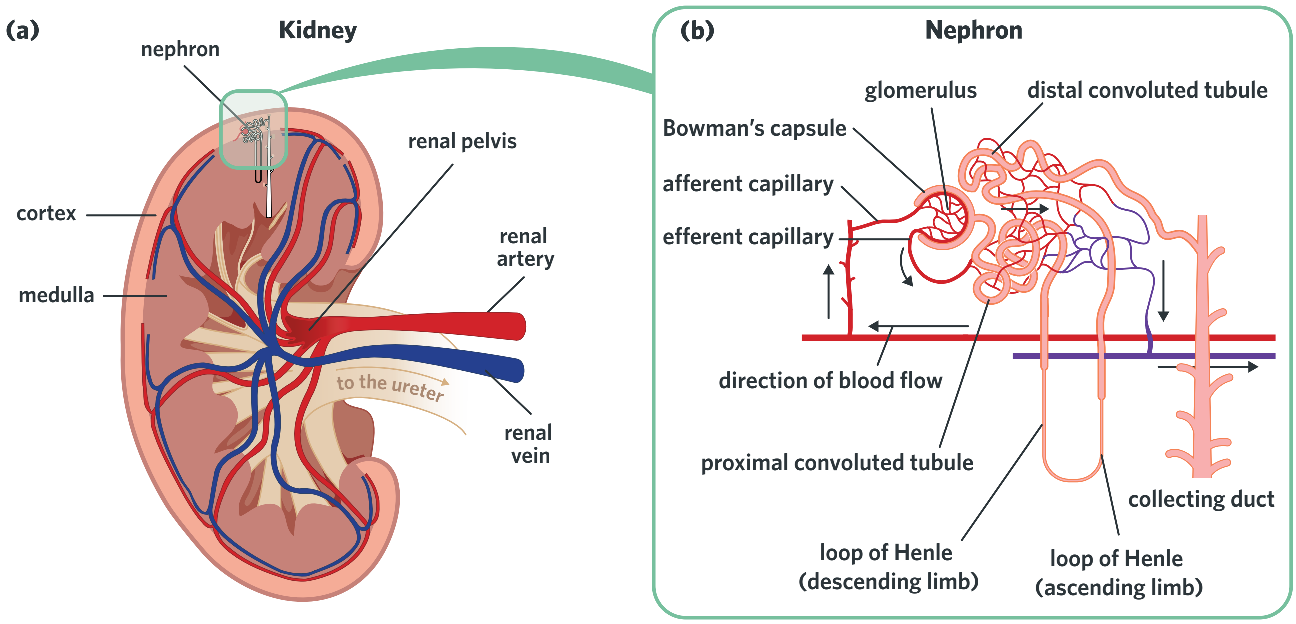


Image: Blamb/Shutterstock.com

Figure 4 The structure of **(a)** the kidney and **(b)** a nephron surrounded by capillaries

Nephron function in detail

Each part of the nephron helps with either filtration, reabsorption, or secretion. You can review the function of each part of the nephron in Table 1.

Table 1 The functions of each part of a nephron

Structure	Function	Details
Bowman's capsule	Filtration	• The high pressure of blood in the glomerular blood vessels forces fluid through the walls of glomerular capillaries and into the Bowman's capsule. • Only small molecules and water can pass through the glomerulus' membranes: blood cells and large proteins remain behind in the glomerular capillaries. • The fluid that crosses the glomerular walls is called the primary filtrate.
Proximal convoluted tubule	Reabsorption: ions, amino acids, water, glucose Secretion: ammonia, toxins	• Glucose, specific ions, and amino acids are reabsorbed into capillaries by active transport. • As solutes have left the filtrate, about 65% of water is reabsorbed via osmosis. • Some urea is incidentally reabsorbed by passive transport. • Ammonia and some drugs are secreted into the nephron. *cont'd*

proximal convoluted tubule the portion of the nephron tubule that lies between the Bowman's capsule and the loop of Henle

loop of Henle a u-shaped loop of the nephron that recovers water and salts from filtrate

distal convoluted tubule the portion of the nephron tubule that lies between the loop of Henle and the collecting duct

collecting duct the final section of the nephron tubule that collects urine and delivers it to the bladder for excretion

Table 1 Continued

Structure	Function	Details
Loop of Henle	Reabsorption: water Secretion: urea	• The ascending limb actively pumps ions out of the tubule. • This makes the tissue around the descending limb highly concentrated, so 1) water exits the descending limb via osmosis and 2) ions diffuse into the tubule down their concentration gradient. • Water cannot exit the ascending limb as the membrane is impermeable to water. • The ascending limb continues to pump ions out while the descending limb receives ions passively to maintain a concentration gradient that leads to water reabsorption. • Some urea is secreted into filtrate.
Distal convoluted tubule	Optional reabsorption: ions, water Secretion: ions, toxins	• Fine-tunes the composition of filtrate according to the body's requirements. • May reabsorb more water and ions. • May secrete more ions and toxins into filtrate.
Collecting duct	Optional reabsorption: water Secretion: urea, ions, ammonia, toxins	• Further fine-tunes filtrate composition. • May reabsorb more water. • Secretes waste like ammonia into the duct.

Note that the kidneys play an important role in the regulation of water balance as well as the excretion of wastes. If you drink lots of water, then the distal convoluted tubule and collecting duct do not reabsorb much water. Conversely, if you lose lots of water (e.g. via sweat) or don't drink enough, the distal convoluted tubule and collecting duct reabsorb lots of water into capillaries. This increases the concentration of urea in the urine. Because they filter the blood and dictate how much water is present in urine, kidneys also play a role in regulating blood pressure and blood pH. You'll learn more about the regulatory function of kidneys in lesson 6D.

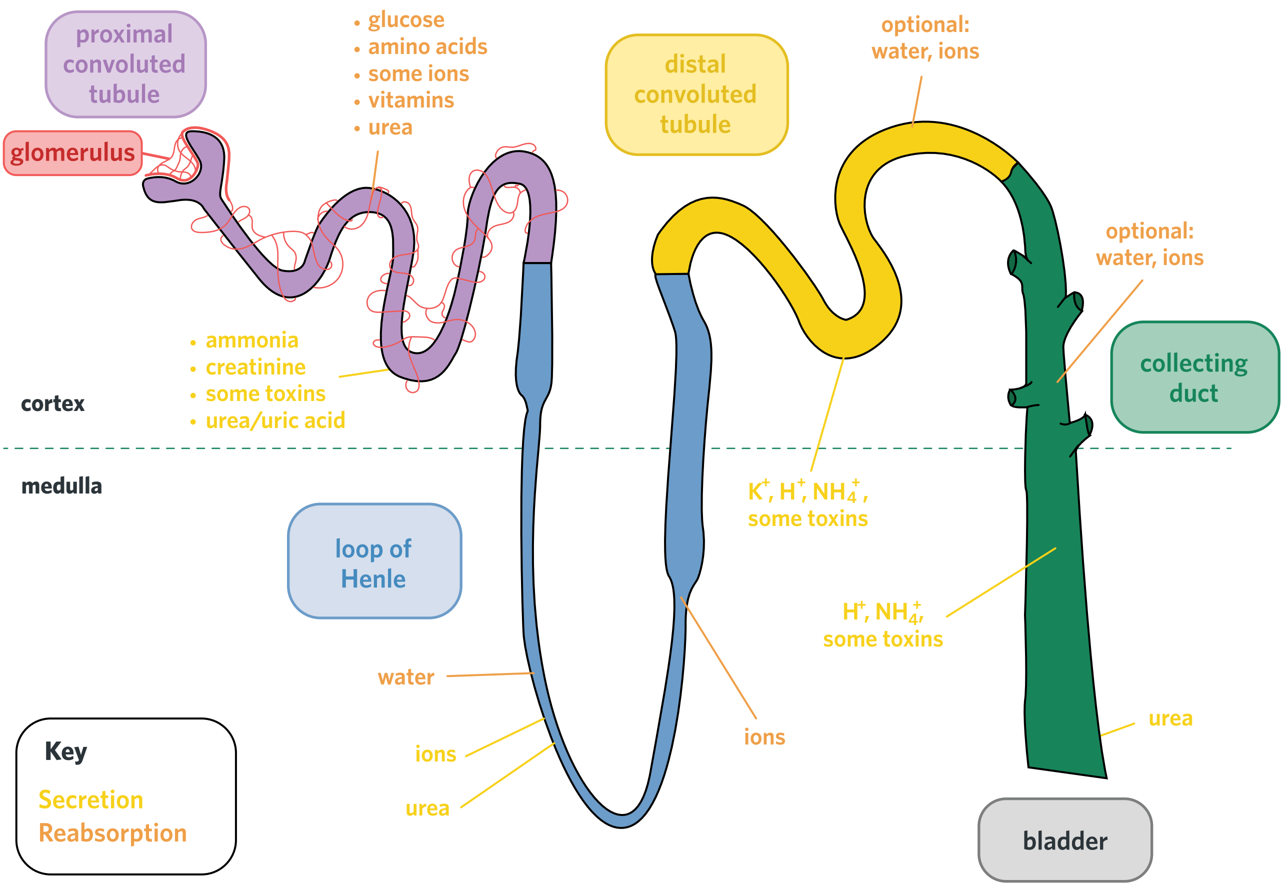


Figure 5 A representation of the movement of materials along a nephron

The bladder

After being produced in the kidneys, urine leaves each kidney via a tube known as a **ureter** (Figure 3). The ureters carry urine to the **bladder**, where it remains until it is ready to be emptied. Upon being emptied, urine exits the body via the **urethra**.

Additional excretory organs of the body 1.2.2.7

OVERVIEW

Although the urinary tract is the main component of the excretory system, other organs such as the lungs, skin, liver, and digestive tract can be considered excretory organs.

THEORY DETAILS

Traditionally, the excretory system is described by the urinary tract. However, if you think about it, other organs are involved in the release of waste products. For example, when cells undergo cellular respiration to release energy, carbon dioxide and water are produced. The water is incorporated into body fluids, and the carbon dioxide is released from the cells and travels through the bloodstream to the **lungs**, where it crosses respiratory membranes and is exhaled into the surrounding environment of the organism.

A small amount of nitrogenous waste and ions are removed from the body via sweating. Your **skin** can therefore be described as an excretory organ. It is important to remember, however, that sweating is mainly a method for controlling temperature rather than a way of removing waste. The liver can also be considered an organ of the excretory system as it breaks down toxins and other waste materials in the blood that are then carried through to the urinary tract and excreted. Sometimes waste material is released into the **digestive tract** and comes out in faeces. Because of this, the digestive tract can also play a role in excretion.

ureter the tube through which urine passes from the kidney to the bladder

bladder the hollow muscular organ that receives urine from the kidney and stores it for excretion

urethra the duct through which urine is excreted from the bladder and out of the body

lungs a pair of organs situated within the rib cage responsible for the process of oxygenation and excretion of carbon dioxide in humans

skin the thin layer of tissue covering the outer region of the body of vertebrates

digestive tract the pathway of organs that food and liquids travel through after being swallowed, leading to digestion and elimination. Also known as the **gastrointestinal tract** or **alimentary canal**

Theory summary

The purpose of the excretory system is to remove excess and unwanted substances from the body and maintain the ideal concentration of water and solutes. The major component of the system is the kidneys and the urinary tract. The nephrons of the kidneys filter blood and reabsorb the needed materials, and produce urine from the unwanted materials and water. Urine travels through the ureters to the bladder, where it is stored until it is excreted out of the body via the urethra. The lungs and skin are also part of the excretory system as they excrete carbon dioxide and some nitrogenous waste respectively.

Your urine is dark yellow in the mornings – or after exercise – because your kidneys have been working hard to conserve water. After all, sleeping means you don't drink for ~8 hrs and you lose water via sweat when you exercise. Conserving water means more concentrated waste products, making your urine a darker shade of yellow and more smelly.

The distinctive urine smell, though, is not urea – urea is odourless! It's probably ammonia (a harsh, chemical smell) and trimethylamine (a fishy smell) – the breakdown products of urea. The smell of your urine is also affected by your diet (just ask anyone who had asparagus for dinner).

Try it for yourself. Note the shade of your urine during your first urination in the morning in the chart, then compare it to subsequent urinations throughout your day. Think about how much water you are consuming between urinations and how it relates to the shade of colour.

5D QUESTIONS

Theory review questions

Question 1

The excretory system

A removes excess and unnecessary materials from an organism.

B is a collection of glands responsible for absorbing nutrients from food.

Question 2

Which of the following are a part of the excretory system? (*Select all that apply*)

I gallbladder

II pancreas

III kidneys

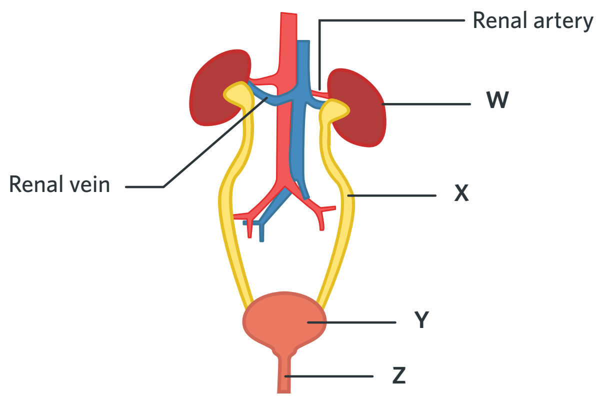
IV urethra

V lungs

Question 3

Label the parts of the excretory system from the list of terms.

- bladder
- urethra
- kidney
- ureter



Question 4

Fill in the blanks with the following terms.

- kidneys
- bladder

The role of the __________ in the excretory system is to store urine until it is ready to be emptied. The __________ filter blood, removing wastes and excess water to make urine.

Question 5

The tube that carries urine from the kidney to the bladder is

A a ureter.

B the urethra.

Question 6

A nephron is

A a tube system responsible for the collection of filtrate and the reabsorption of water.

B the functional unit of the kidney where blood is filtered into urine.

Question 7

Order the steps to correctly describe the production of urine.

I Where required, more water and ions are reabsorbed from the distal convoluted tubule. Some wastes may also be secreted into the filtrate.

II Where required, more water and ions are reabsorbed from the collecting duct. Some wastes may also be secreted into the filtrate.

III Blood is filtered under high pressure from the glomerulus into the Bowman's capsule.

IV The proximal convoluted tubule reabsorbs glucose, ions, urea, and water.

V Water and ions are reabsorbed in the loop of Henle.

Question 8

Fill in the blanks with the following terms.

- skin
- lungs
- the liver

Other organs are involved in excretion of waste other than urine, including __________ which removes water and salt via sweat, __________ which exhale carbon dioxide and the __________ which breaks down toxic substances in the blood.

SAC skills questions

Case study analysis

Use the following information to answer Questions 9–15.

The element phosphorus is essential to all living organisms. It forms part of the backbone of our DNA as well as the molecule adenosine triphosphate (ATP) that captures chemical energy from the food we eat. Phosphorus also plays an important role in fertilisers used for growing crops. Because of the green revolution, fertiliser production increased tenfold between 1961 and 2014. The cheapest way to cope with the rising demands for phosphorus fertiliser was to extract phosphorus from phosphate rocks. However, phosphate rocks are a finite and non-renewable resource, meaning the continuous extraction has caused concerns over future supplies.

There is one source of phosphorus that is renewable and non-finite: human urine. You excrete up to half a kilogram of phosphorus a year in your urine. There are 25 million people living in Australia. That means our country alone could generate 12.5 million kilograms of phosphorus annually. This makes urine an increasingly attractive resource, and scientists are developing methods to recover phosphorus from wastewater in urban areas. Already, farmers and companies are saying 'yes we can' to 'peecycling' and the race is on to find better technologies for converting smelly urine into a safe, non-odorous commercial fertiliser.

Question 9

The increased phosphorus-containing fertiliser use during the end of the twentieth century was possible due to

A phosphorus sources in phosphate rocks.

B phosphorus being sourced from people's urine.

Question 10

When looking at plants

A phosphorus is not required as plants do not exercise.

B phosphorus is required for metabolism, growth, and development.

Question 11

The green revolution was

A a period where crop production increased drastically due to fertiliser use.

B a time when no fertilisers were used and crops were picked by hand.

Question 12

A non-renewable resource is

A one that is used repeatedly and does not run out because it is naturally replaced.

B a substance that is being used up faster than it can be replaced.

Question 13

A concern with the continuous extraction of phosphorus from phosphate rocks is

A the need for phosphorus will decrease due to the rise of fertiliser-free crops.

B that phosphate rock sources are being depleted at a high rate.

Question 14

Why is phosphorus excreted in urine when it is important in processes such as the production of DNA and ATP?

A Humans consume more phosphorus than is required and the excess is excreted.

B Some phosphorus is unable to be broken down by the human digestive system because it comes from phosphate rocks.

Question 15

A farming company plans on using urine-derived fertiliser on crops destined for human consumption. Considering the bioethical concept of integrity, the company should

A sell the product at a lower price than the market to increase sales.

B ensure that the product is available to all socioeconomic classes.

C label the product package with information that urine-derived fertilisers have been used in production.

Exam-style questions

Within lesson

Question 16 (1 MARK)

The excretory system plays an important role in regulating water levels within the body.

Which one of the following is true of the excretory system?

A Urine always contains a large amount of water.

B The kidneys always produce urine that is extremely high in urea and low in water.

C Water levels are regulated by the bladder as it releases urine when it becomes full.

D The kidneys influence how much water is present in urine, regulating the water levels.

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q12

Question 17 (1 MARK)

Which of the following is false in regards to human kidney function?

A Kidneys filter blood and reabsorb the desired components.

B The amount of blood in the body is influenced by kidneys breaking down blood cells.

C Kidneys help to regulate blood pressure as they alter the amount of fluid in the body.

D The pH of the blood is regulated by kidneys controlling the ion concentrations in the blood.

Question 18 (1 MARK)

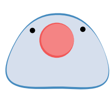
Which of the following is regulated by the kidneys?

A urea levels in the blood

B levels of proteins within cells

C carbon dioxide levels in the lungs

D water levels in the digestive system



Use the following information to answer Questions 19–21.

The image shows the structure of a nephron in a desert-dwelling mammal and a rainforest-dwelling mammal.

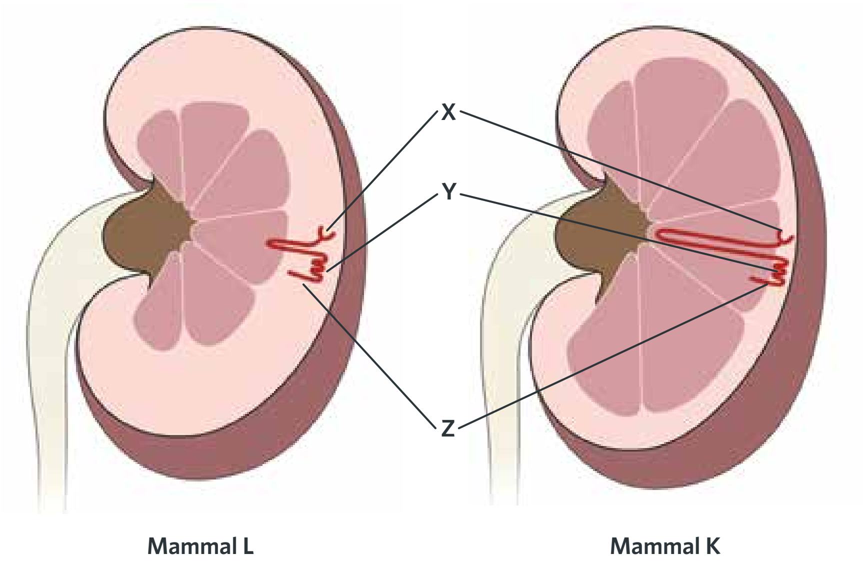


Image: Aldona Griskeviciene/Shutterstock.com

Question 19 (1 MARK)

The Bowman's capsule is represented by

A Structure X.

B Structure Y.

C Structure Z.

D Structures X, Y, and Z.

Question 20 (1 MARK)

The desert-dwelling mammal is likely to be

A Mammal K, because it has a long loop of Henle to remove minerals.

B Mammal K, because it has a long loop of Henle to reabsorb lots of water.

C Mammal L, because it has a short loop of Henle to reabsorb lots of water.

D Mammal L, because it has a large Bowman's capsule to filter a large blood volume.

Question 21 (1 MARK)

Which of the following statements is correct in regards to both mammals?

A Blood is delivered to the glomerulus by the afferent capillary.

B The Bowman's capsule is responsible for creating urine from filtrate.

C The distal convoluted tubule always reabsorbs large amounts of water.

D The proximal convoluted tubule removes glucose, amino acids, and water from the blood.

Question 22 (5 MARKS)

The kidneys form a part of the body's excretory system. Blood arrives at the kidneys via the renal artery and leaves via renal veins. Nephrons are the functional unit of the kidney and the site of urine production.

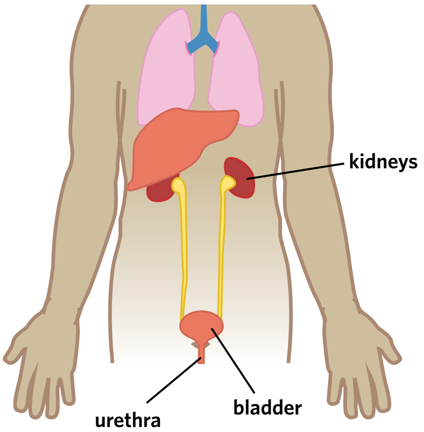
a Describe the process that occurs within the nephrons of the kidneys to produce urine from blood arriving from the renal artery. (3 MARKS)

b Outline how urine leaves the body after being produced in the kidneys. (2 MARKS)

Multiple lessons

Question 23 (1 MARK)

The excretory system includes the kidneys, bladder, and urethra.



In these particular organs

A food is digested and faeces are produced before being excreted.

B hormones are sent between organs to dictate the level of digestion.

C unwanted materials are removed from the blood and excreted as urine.

D urine is produced and excreted containing a large amount of amino acids.

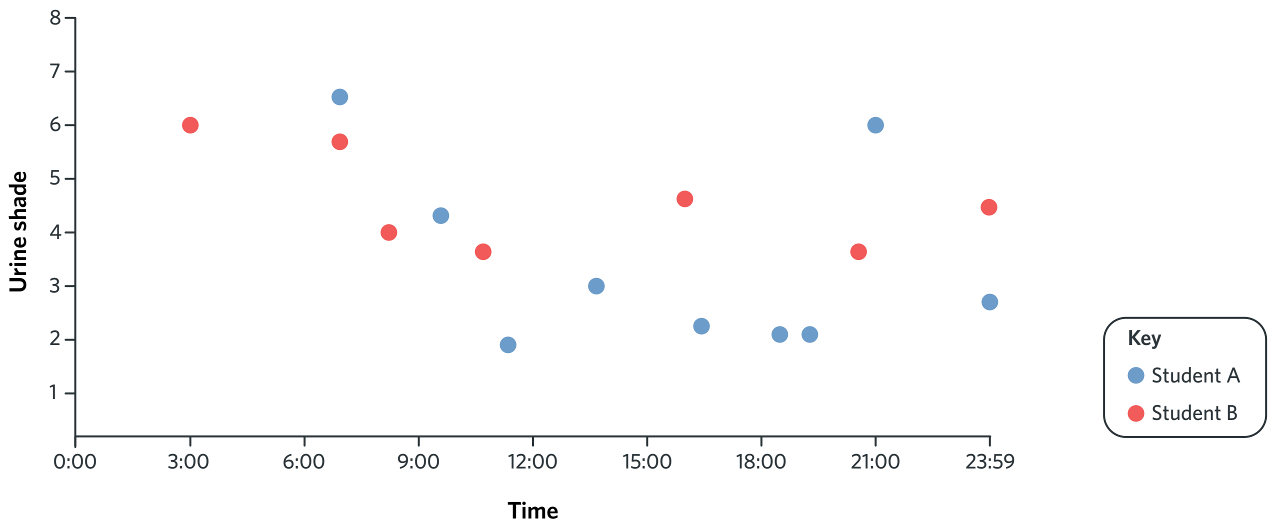
Adapted from VCAA 2017 Section A Q23

Key science skills and ethical understanding

Question 24 (9 MARKS)

Two students were investigating the effects of water consumption on the composition of their urine. They wanted to see if the shade of their urine changed throughout the day as they consumed more water and underwent different activities. Changes in urine shade would indicate changes in the water levels of the urine. The students agreed to monitor the shade of urine over a 24-hour period, using a guide of urine shades.

The guide ranged from one to eight, with one being a lighter shade indicating lower solute content, and eight the darkest shade indicating a very high solute content. After the experiment, the students produced the following graph.



a Describe the trends of both students' results seen on the graph. (2 MARKS)

b Which student on average had a lower solute concentration in their urine? (1 MARK)

c Which student do you think went to the gym after they ate dinner? Justify your response. (2 MARKS)

d Identify a potential flaw in the students' experimental design and explain how it affects the outcome of the experiment. (2 MARKS)

e After looking at the results, Student A suggested they redo the experiment. This time, Student A wanted both students to avoid drinking water for one day, drink normally the next day, then drink 15 litres over the course of the third day. Student A said this would provide more meaningful results, as they would better understand the levels of hydration required to achieve particular urine shades. Student B was hesitant to participate in the new trial.

Identify one ethical concept and explain how it may be undermined during the new experiment. (2 MARKS)

5E THE ENDOCRINE SYSTEM

As the great Marshall Bruce Mathers III (Eminem) once said;

'His palms are sweaty, knees weak, arms are heavy
There's vomit on his sweater already, mom's spaghetti
He's nervous, but on the surface he looks calm and ready
To drop bombs, but he keeps on forgetting'...

Indeed, but have you ever found yourself wondering about the underlying biology behind this killer verse? Why does his body experience all these traits when he is nervous?

Image: Kathy Hutchins/Shutterstock.com

Lesson 5E

In this lesson you will learn that the endocrine system is responsible for producing and secreting hormones which have a range of effects on the body.

◀ Prerequisite knowledge

Years 7–10
Remember how cells make up tissues, and tissues make up organs? In the endocrine system, cells of endocrine tissues and organs produce and release hormones.

Lessons 5C
The digestive system is influenced by the endocrine system.

Future applications ▶

Chapter 6
The endocrine system contributes to the maintenance of homeostasis in the body.

Study design dot point

- specialisation and organisation of animal cells into tissues, organs, and systems with specific functions: digestive, endocrine, and excretory

Key knowledge unit

Specialisation of the endocrine system	1.2.2.8

Specialisation of the endocrine system 1.2.2.8

OVERVIEW

In multicellular eukaryotes, distant cells must communicate with one another. To do so, cells use chemicals called signalling molecules. The body's endocrine system is responsible for producing hormones, a major group of signalling molecules, that have a variety of effects throughout the body.

THEORY DETAILS

Chemicals and cells of the endocrine system

Cells need to be able to communicate with each other in order to perform many synchronous functions within the body. If one cell detects a change in the environment, communication allows other cells to respond. To communicate, cells send and receive special chemicals called **signalling molecules**. Signalling molecules can instruct cells to do a variety of things such as alter gene expression, open and close protein channels, release other signalling molecules, or even die.

One of the most important groups of signalling molecules is **hormones**. Hormones influence growth, metabolism, and the maintenance of a stable internal environment. Hormones also play a crucial role in sexual development and maturity.

signalling molecule a molecule which can interact with and initiate a response in a target cell

hormone a signalling molecule released from endocrine glands that regulates the growth or activity of target cells

Hormone molecules function by binding to specific **receptors** on **target cells** that are complementary to the hormones, eliciting a response in the target cell. Because of this, we say hormonal communication is specific. Hormones only influence cells with specific receptors (Figure 1).

receptor a structure (usually a protein) that detects a signal or external change

target cell a cell that will receive and respond to a specific signalling molecule

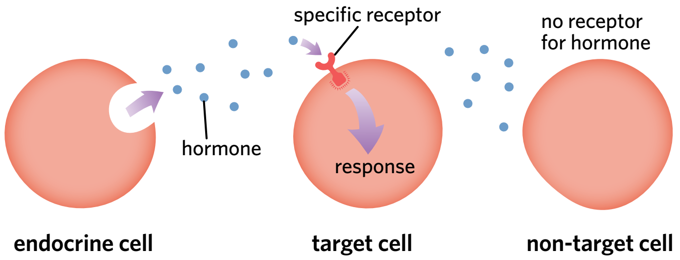


Figure 1 Hormones bind to receptors on specific cells and cause a response.

Tissues and organs of the endocrine system

So how does the body produce such a wide range of hormones? The **endocrine system** is the collection of **glands** in an organism responsible for producing hormones. After being produced by glands of the endocrine system, hormones are transported to where they are needed in the body via the bloodstream in the **blood circulatory system**.

The major components of the endocrine system are seen in Figure 2. Each organ is responsible for producing the hormones needed to keep the body running. Table 1 contains a brief description of each endocrine organ.

endocrine system the collection of glands in animals responsible for producing hormones that can be transported in the bloodstream to regulate distant organs/cells

gland a group of cells that secretes chemical substances to regions of the body or discharges them into the surroundings

blood circulatory system the network consisting of blood vessels and the heart that pumps blood around the body

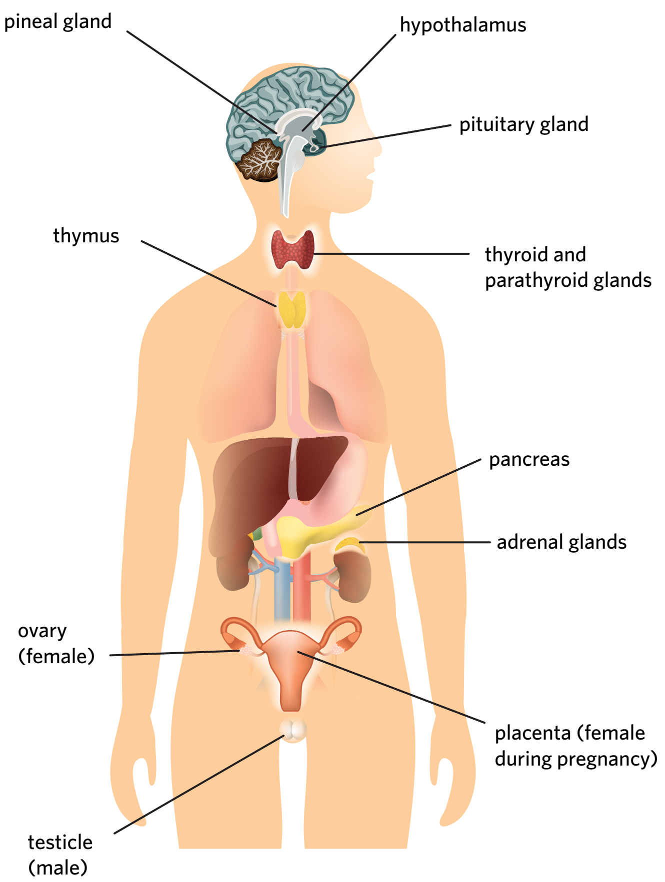


Image: Designua/Shutterstock.com

Figure 2 The endocrine system in humans

Table 1 Organs of the endocrine system

Organ	Description
Hypothalamus	A small region in the brain that helps maintain body temperature and often influences the function of the pituitary gland
Pituitary gland	A pea-sized area in the brain that is often called the 'master gland' as it regulates many other glands, including the thyroid glands, adrenal glands, and ovaries or testes
Pineal gland	Located in the brain, the pineal gland is involved in sleep regulation. Studies suggest that it also may be involved in influencing the pituitary gland and the regulation of bone metabolism
Thyroid and parathyroid glands	Several small glands located in the base of the neck that are involved in controlling the growth rate, metabolic rate, and development of the body
Thymus	Located between the lungs, produces the hormone thymosin which stimulates the development of cells of the immune system. The thymus is only active in the body until puberty
Pancreas	An organ that sits across the back of the abdomen that is involved in the functioning of the digestive system and maintenance of blood glucose levels by releasing insulin and glucagon
Adrenal glands	Found above the kidneys, the adrenal glands are involved in the body's stress response, metabolic regulation, blood pressure, and immune system
Placenta (in pregnant females)	The placenta is located in the uterus. It maintains a healthy pregnancy and stimulates mammary growth
Ovaries (females) and testes (male)	Play a major role in developing and regulating the body's reproductive system

Some specific examples of hormones produced by the endocrine glands of the body and their functions are seen in Table 2. It's important to note, however, that endocrine glands often produce many different types of hormones – for example, ovaries produce testosterone as well as oestrogen. Also, the hormones produced by the endocrine glands typically affect many different organs, tissues, and cells throughout the body, as long as they have the specific receptor.

Table 2 Examples of hormones produced in the endocrine glands of the body

Endocrine gland	Hormone	Target organs/cells	Response
Pituitary gland	Growth hormone	Bone and muscle	Promotion of protein synthesis and growth
Thyroid glands	Thyroxine	Many cells	Regulation of the rate of cellular metabolism
Adrenal glands	Adrenaline (epinephrine)	Many cells	Increased heart rate and blood pressure, increased respiratory rate, increased muscle contractions
Pancreas	Insulin	Many cells	Regulation of blood glucose levels
Ovaries	Oestrogen (estrogen)	Female reproductive tissues	Sexual development, breast development, regulation of the menstrual cycle
Testes	Testosterone	Male reproductive tissues	Sexual development, increased muscle, body hair growth

hypothalamus a section of the brain in mammals that controls much of the body's internal environment via hormone secretion

pituitary gland a gland in the brain that plays a large role in maintaining bodily functions by controlling the activity of several other endocrine glands

pineal gland a small gland in the brain which helps regulate sleep patterns

thyroid gland a butterfly-shaped gland in the neck that produces hormones that influence metabolic rate

parathyroid glands four small glands in the neck that control the levels of calcium in the body

thymus a gland found between the lungs that plays a role in the body's endocrine and immune systems

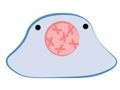
pancreas an organ of the digestive and endocrine system that releases both digestive juices and hormones to regulate blood glucose

adrenal glands collection of endocrine cells located above the kidneys that produce a variety of hormones involved in the stress response, including cortisol, aldosterone, and adrenaline

placenta an organ that develops during pregnancy and provides oxygen and nutrients to a foetus

ovaries female reproductive organ in which both egg cells and hormones such as oestrogen are produced

testes male reproductive organ in which both sperm cells and hormones such as testosterone are produced



Theory in context

CELLS AND TISSUES OF THE PANCREAS

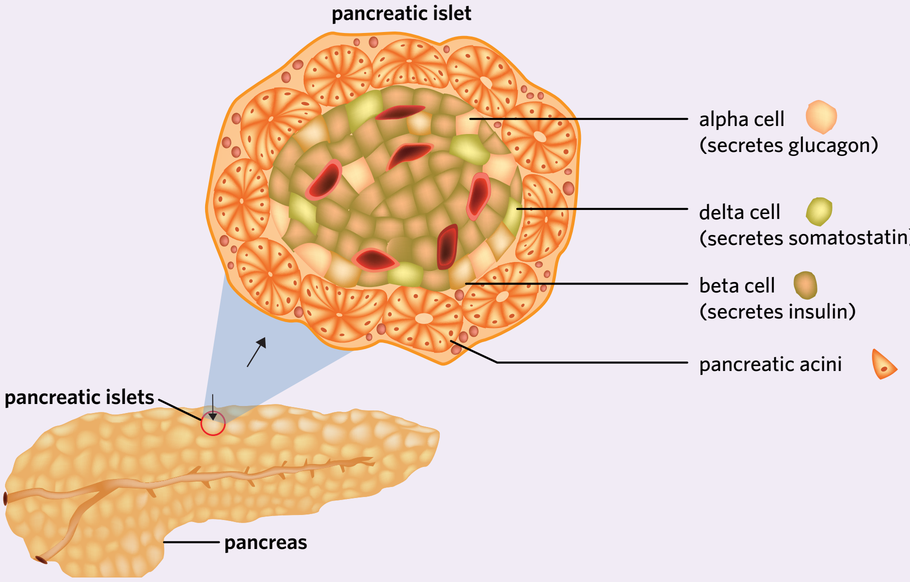


Image: Sakurra/Shutterstock.com

Figure 3 Alpha, beta, and delta cells make up pancreatic islet tissue of the pancreas.

The pancreas is an organ that releases the hormone insulin into the endocrine system of the body. There are two major types of tissue within the pancreas: exocrine acini tissue and pancreatic islets. The exocrine acini tissue is responsible for producing and secreting pancreatic enzymes for digestion directly to the target site in the first section of the small intestine – the duodenum, rather than into the bloodstream like in the case with hormones.

Conversely, the pancreatic islets are made up of different endocrine cells that produce and secrete hormones. Figure 3 shows the structure of a pancreatic islet and some of the major cells found in the tissue. Alpha cells produce the hormone glucagon which signals the liver to convert stored glycogen into glucose and release it into the bloodstream, raising blood glucose levels. Beta cells produce insulin which encourages cells to take in glucose, lowering blood glucose levels. Delta cells produce somatostatin, which has a number of effects on target cells such as inhibition of hormone secretion and influencing the activity of the gastrointestinal tract.

Theory summary

The endocrine system is the collection of organs and glands in the body that are responsible for producing hormones. Hormones are produced and released by the endocrine system and can be transported all over the body via the bloodstream. Hormones are integral for life as they allow cells of the body to communicate and instruct a wide range of processes. The next chapter will look at these different endocrine organs in detail and how they each maintain homeostasis in the body.

The rapper is so nervous about his one shot to prove himself that his body has activated its fight-or-flight response in order to ensure he doesn't blow it.

When stressed, adrenocorticotropic hormone (ACTH) is secreted by the pituitary gland which stimulates the adrenal gland. In turn, the adrenal gland secretes the stress hormones adrenaline and cortisol. These two stress hormones are released into the bloodstream and cause several changes to target cells in the body such as: the expansion of the air passages of the lungs, alter the body's metabolism to increase blood glucose levels, and increase or decrease blood pressure (which can result in weak knees and heavy arms).

Adrenaline and cortisol also can cause enlarged pupils, and an increase in heart rate – increasing the body's temperature. This increase in temperature leads to sweating (such as on the palms). Finally, non-essential systems like the digestive system shut down to allow more energy to be used for emergency functions (which can result in spaghetti-related mishaps).

Image: Yummypic/Shutterstock.com

5E QUESTIONS

Theory review questions

Question 1

The endocrine system

A is a collection of glands responsible for breaking down waste.

B is responsible for the production of hormones in mammals.

Question 2

Which of the following are organs of the endocrine system? (*Select all that apply*)

I pancreas

II adrenal glands

III kidneys

IV spinal cord

V thyroid gland

VI uterus

Question 3

Label the parts of the endocrine system from the list of terms.

- pituitary gland
- parathyroid glands
- adrenal glands
- testes (male)

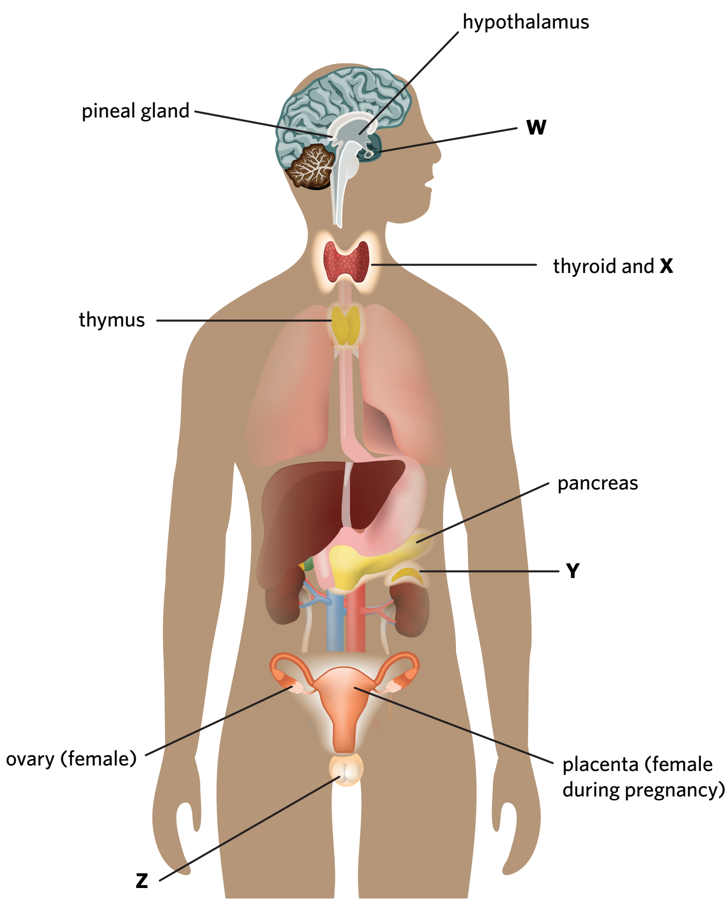


Image: Designua/Shutterstock.com

Question 4

Fill in the blanks in the following sentences.

The __________ is an organ involved in both the body's endocrine system and digestive system, and releases enzymes for digestion as well as hormones such as insulin for blood glucose regulation. The __________ is an area of the brain responsible for hormone secretion, the maintenance of body temperature, and often influences the pituitary gland.

Question 5

Hormones are

A signalling molecules produced by endocrine cells that influence target cells when released.

B produced by all cells of the body before being transported to the endocrine system.

Question 6

The hypothalamus

A is a region in the neck involved in hormone production and secretion.

B plays a major role in maintaining an organism's stable internal body temperature.

Question 7

Order the steps in the process of hormone secretion and reception.

I The hormone binds to a receptor on the target cell.

II An endocrine cell produces and secretes a hormone.

III The hormone leaves the bloodstream and arrives at a target cell.

IV The target cell undergoes a response.

V The hormone travels from the endocrine cell into the bloodstream.

SAC skills questions

Case study analysis

Use the following information to answer Questions 8–13.

Worldwide, over two million women develop breast cancer each year. Despite several treatment options, more than 600 000 die from the disease annually (Bray et al., 2019). A common misconception is that breast cancer is a single disease, rather it is a grouping of diseases. Because of this, each different tumour type responds to treatment differently.

Approximately 70% of breast cancers are dependent on the presence of oestrogen for their growth and survival (Duss et al., 2019). Currently, endocrine therapy (also known as hormonal therapy) is the most effective treatment against oestrogen-dependent tumours. Doctors are able to predict a patient's response to the endocrine therapy treatment using techniques involving the use of oestrogen receptors within tumours as biomarkers. However, some oestrogen-dependent tumours can develop resistance to therapy drugs such as tamoxifen, leaving the predictions inapplicable.

It is believed that approximately 40-50% of breast cancer patients do not respond to endocrine therapy, and instead relapse (Ma et al., 2009). Non-responders do not benefit from endocrine therapy methods and can potentially suffer from treatment-associated harmful effects.

At present, there is uncertainty as to whether methods can accurately predict which oestrogen-dependent tumours will gain resistance to endocrine therapy drugs.

Question 8

The hormone in this scenario is

A oestrogen.

B tamoxifen.

Question 9

The treatment is called endocrine therapy because

A the therapy removes all endocrine functioning from the body.

B it involves altering the effects of a hormone which influences cancer growth.

Question 10

If 645 women with breast cancer underwent endocrine therapy, what is the likely number of women that would not respond to hormonal therapy and instead relapse?

A 292

B 228

C 360

Question 11

The function of endocrine therapy drugs is to

A stimulate oestrogen receptors on tumour cells in the same way oestrogen does.

B block oestrogen receptors on tumour cells so oestrogen cannot stimulate them.

Question 12

Being able to accurately predict a patient's response to endocrine therapy is important as

A it will allow all sufferers worldwide to be able to respond to endocrine therapy drugs.

B it will save patients whose tumour cells do not respond from suffering side-effects of the treatment for nothing.

Question 13

An elderly woman continues to take endocrine therapy drugs despite her tumour cells not responding. The patient is unaware that she is a non-responder, as her doctor has not informed her. The reason the doctor has not told the patient is that they have seen a drastic improvement in the patient's mood since taking the drugs. Being a doctor requires the consideration of a number of bioethical approaches. Which of the following options best reflects a duty/rule-based approach to bioethics?

A The doctor should continue to withhold information and not inform the patient as it results in the patient being happy and healthy and makes the doctor's job easier, maximising positive outcomes.

B The doctor should inform the patient immediately that the drugs she is taking are not combating her cancer, even if it means her morale drops.

C Rather than try to tell the patient, the doctor should ask the patient's family if she should know the truth and wait for a reply. Then, follow their wishes.

Exam-style questions

Within lesson

Question 14 (1 MARK)

The pituitary gland is a part of the body's endocrine system.

Which of the following is a correct statement about the pituitary gland?

A The pituitary gland influences the functioning of many different endocrine glands.

B Another name for the pituitary gland is the pineal gland.

C All hormones are first produced in the pituitary gland.

D The pituitary gland is located just above the kidneys.

Adapted from VCAA 2018 Northern Hemisphere Section A Q5

Question 15 (1 MARK)

Which one of the following glands are located in the neck in humans?

A adrenal glands

B hypothalamus

C pancreas

D thyroid

Adapted from VCAA 2019 Section A Q2

Question 16 (1 MARK)

Certain hormones can cause drastic responses in some cells, yet other cells remain unaffected.

The reason that some cells do not respond to a hormone is they

A do not contain the receptor specific to the hormone.

B require multiple hormones to bind with them at one time.

C are too large for the hormone to have any sort of impact.

D are not part of the endocrine system and so cannot respond.

Question 17 (1 MARK)

Endocrine glands

A circulate hormones around the body.

B all produce the same type of hormone.

C are found only within the chest cavity in humans.

D are responsible for the production of the array of hormones in the body.

Multiple lessons

Use the following information to answer Questions 18–21.

The table shows the function of three major systems in the human body and some examples of the major tissues and organs involved in them.

System	**Digestive system**	**Excretory system**	**Endocrine system**
Purpose	The breakdown of food into small molecules which are absorbed along the digestive tract	**W**	The production and secretion of hormones which have a variety of functions in the body
Major components	• Stomach • Pancreas • **X** • Small intestine • Large intestine • Mouth	• Kidneys • **Y** • Ureter • Urethra	• Hypothalamus • Adrenal glands • **Z** • Ovaries • Testes

Question 18 (1 MARK)

What belongs in box W?

A The removal of excess and unwanted substances from the body to maintain a stable internal environment.

B The removal of toxins and other unwanted materials by transporting lymph around the body.

C The circulation and transportation of nutrients and blood to cells to provide nourishment.

D The control of the body and communication between its parts via neurons.

Question 19 (1 MARK)

Which of the following could be listed at X?

A adrenal glands

B thyroid gland

C lungs

D liver

Question 20 (1 MARK)

Which of the following could be listed at Y?

A ovaries

B bladder

C pancreas

D gallbladder

Question 21 (1 MARK)

Which of the following could be listed at Z?

A liver

B spleen

C bladder

D pancreas

Question 22 (7 MARKS)

To avoid dehydration or overhydration, proper water balance must be maintained in the body. One way that the water concentration of the body is monitored is by osmoreceptors in the hypothalamus which detect the concentrations of ions in the extracellular fluid. When a change in the concentration of ions in the blood is detected, such as during exercise, the body must respond. To do so, the hypothalamus produces antidiuretic hormone (ADH), also known as vasopressin. ADH is then transported to and released from the pituitary gland, where it travels to several areas of the body including the kidneys. ADH functions to stimulate the insertion of 'water channels' called aquaporins into the membranes of the kidney tubules, allowing for greater water reabsorption.

a When the hypothalamus detects the change caused by exercise, an increase in the production of ADH occurs. Using your knowledge of hormones, describe how ADH is transported to the kidneys, and how it stimulates cells of the kidney tubules. (2 MARKS)

b ADH acts on the kidneys, where it regulates the amount of water excreted in the urine. Briefly outline how the kidneys produce and secrete urine. In your response, refer to the specific areas of the nephron. (3 MARKS)

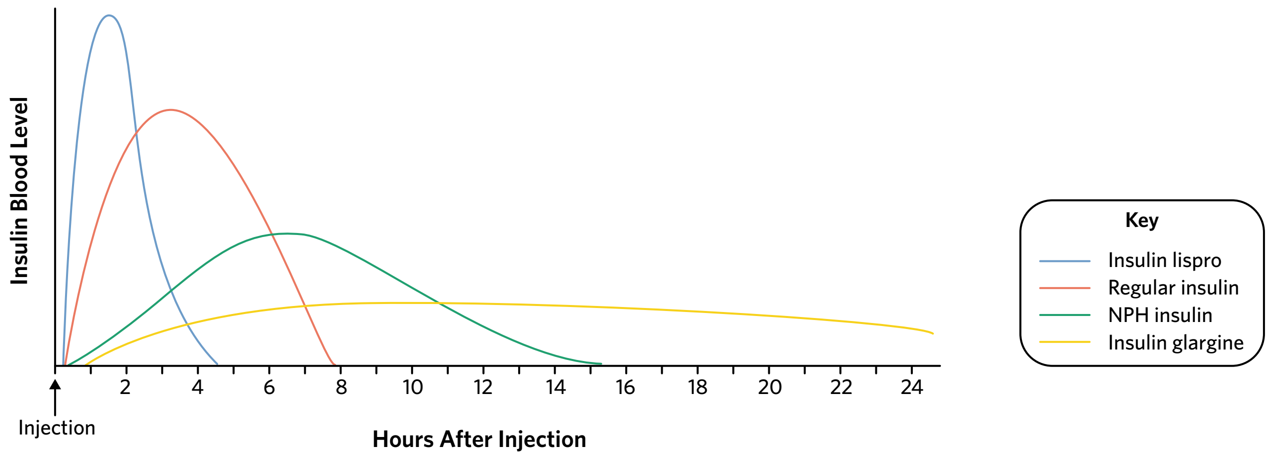
c If a person were to experience over hydration, what would happen to the levels of ADH secreted from the pituitary gland and the permeability of water in the kidney tubule? (2 MARKS)

Key science skills and ethical understanding

Question 23 (5 MARKS)

Insulin is a hormone made by the pancreas that promotes the breakdown and storage of glucose in the blood, lowering your blood glucose levels. Following a meal, insulin is released by the pancreas when a rise in blood glucose is detected. Upon release, insulin travels to cells of the body and instructs them to open glucose channels, allowing for the glucose to enter the cells of the body and be converted into energy.

Type 2 diabetes is a disease that often causes high blood-sugar levels. To combat this, diabetics can take insulin injections that stimulate cells to break down large sugars into glucose, allowing it to be absorbed by cells. There are many different forms of insulin that can be injected, including insulin lispro, NPH insulin, insulin glargine, and regular insulin. The duration of effect of some of these are shown in the graph.



a Which form of insulin is the slowest acting? (1 MARK)

b Which form of insulin has the shortest duration? (1 MARK)

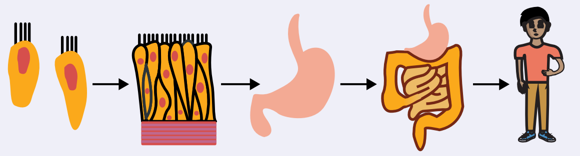
c Briefly describe the role of the pancreas in the body. (2 MARKS)

d Insulin lispro and insulin glargine are far more expensive to buy compared to regular and NPH insulin. Using the bioethical concept of justice, state one concern with the differences in prices of insulin options. (1 MARK)

CHAPTER 5 SUMMARY

Cells, tissues, organs, and systems

Cells are organised into increasing levels of complexity – tissues, organs, and systems – to carry out functions vital for survival that can't be performed by single cells.



Organisation of plants

Xylem and phloem tissues

Xylem cells are responsible for the transport of water and minerals throughout the plant, while phloem cells are responsible for the transport of sugars and other nutrients.

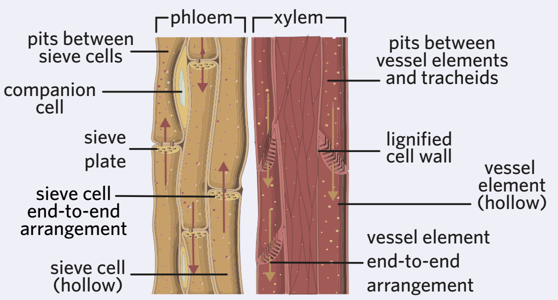
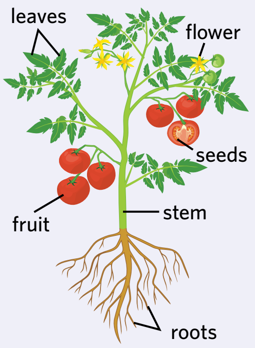
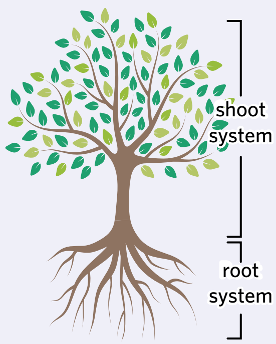


Image: Aldona Griskeviciene/Shutterstock.com

Plant organs



Vascular plant systems



Images: Kazakova Maryia, Alazur/Shutterstock.com

Pathways of water and nutrient absorption

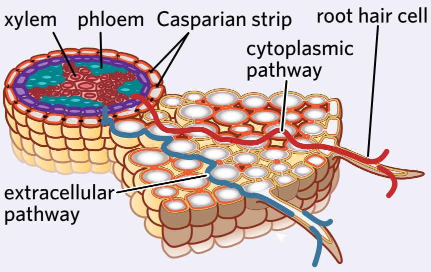


Image: Emre Terim/Shutterstock.com

Leaf anatomy

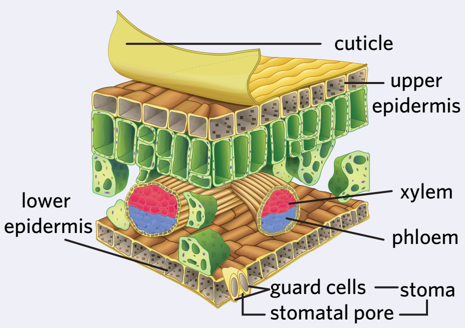


Image: BlueRingMedia/Shutterstock.com

Organisation of animals

Animal cell examples

- Skin cells
- Nerve cells
- Muscle cells
- Red blood cells

Animal tissue examples

- Muscle tissue – allows contraction and movement.
- Nervous tissue – detects stimuli and transmits electrical signals.
- Epithelial tissue – covers the internal and external surfaces of the body.
- Connective tissue – connects and supports other tissues and organs in the body.

Animal organ examples

- Liver
- Brain
- Heart
- Lungs
- Bladder
- Kidneys
- Stomach
- Pancreas

The digestive system

The digestive system is responsible for breaking down and processing food for the body to use, as well as eliminating food waste that is not absorbed.

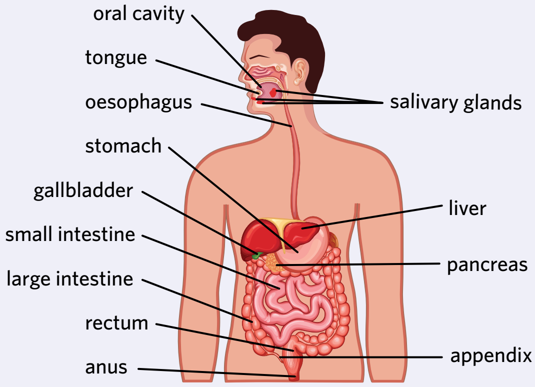
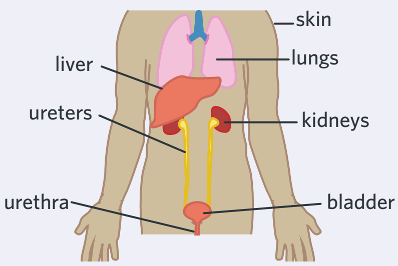


Image: Vecton/Shutterstock.com

The excretory system

The excretory system is responsible for removing waste substances from the blood via excretion and assisting in the control of water balance in the body.



The endocrine system

The endocrine system is responsible for producing hormones that can be transported in the bloodstream to regulate distant organs/cells.

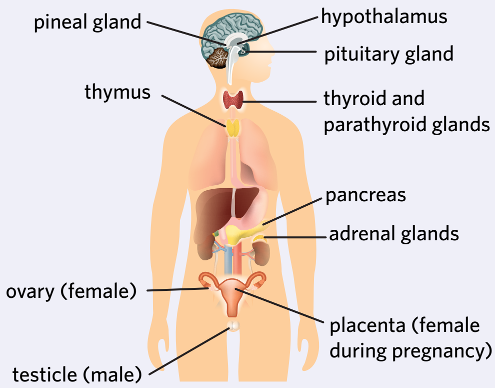


Image: Designua/Shutterstock.com

CHAPTER 5 SAC PRACTICE

SAC skills covered in this section:

✓ Case study analysis ✓ Data analysis ✓ Bioethical deep dive

BILL'S BODILY BLUES (23 MARKS)

The case

It was a beautiful sunny day as 40 something-year-old Bill Billson strolled down the street in his small hometown. His kids were at after-school care, his wife was in a session at the gym, and Bill was making his way to the pub. The pub is small and old, and it likely would have gone out of business years ago if it weren't for Bill's close-to-daily visits. As Bill took his final steps towards the door, he felt a deep pain high in his back under his ribs. He thought to himself, 'Oh well, nothing a beer can't fix', and wandered in.

The following day, Bill was lounging on the couch at home as he made his way through a jumbo meal deal from his local takeaway shop. The pain from yesterday returned but it had become worse. Bill's daughter Britney entered the room to find her father in pain, exclaiming that it felt like he was being stabbed under the ribs. Britney told her father that she had learned about the organs of the body in Biology class. She believed that Bill was experiencing pain in his kidneys. When Bill's wife Bonnie returned home from the gym, she took Bill to the hospital.

1 What is the function of kidneys within the body? (1 MARK)

2 Kidneys make up part of the body's excretory system. List the major structures that are a part of the excretory system. (2 MARKS)

At the hospital, doctors were quick to note Bill's symptoms of kidney pain and were concerned about the levels of uric acid circulating in his blood. They thought that Bill may be suffering from hyperuricemia, a state of abnormally high blood uric acid levels. They decided to run a few tests, but Bill was afraid of needles and only after his wife Bonnie completed the test first, did he take the test.

Blood uric acid level ranges (mg/L)			Bonnie's result	Bill's result
Gender	Male	Female	0.033 g/L	0.124 g/L
Regular range	34–70	24–60		
Hyperuricemia	Above 86	Above 71		

The test results are shown. Unfortunately for Bill and Bonnie, the small town hospital used very old equipment that gave results in grams per litre.

3 What are Bonnie and Bill's blood uric acid levels in milligrams per litre? (1 MARK)

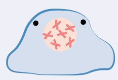
4 Do Bonnie and Bill's readings fall within the regular range, or would they be diagnosed with hyperuricemia? (2 MARKS)

The doctor began to hand Bill several pamphlets of ways to reduce the levels of uric acid in his blood. One was titled 'Eat good, feel good'. Bill asked why his diet affects his uric acid levels. The doctors explained that uric acid, and other waste products such as urea, are produced in the body from the food we eat, with most of it being excreted in the urine. Consuming foods that are high in certain nitrogen-containing compounds can lead to increased uric acid levels. These foods include some meats such as bacon, organs, seafood, caffeine, and alcoholic beverages. When the levels of uric acid in the blood significantly increase, the kidneys cannot expel the excess uric acid. This can lead to severe problems such as kidney stones, digestive issues, and cardiovascular disease.

5 When food enters the body, how is it digested? Describe the process by referring to the function of each organ. (4 MARKS)

6 How does Bill's diet, largely consisting of fast food, alcohol, and coffee, affect the levels of uric acid in his blood? (1 MARK)

7 A third major system of tissues and organs within the body is the endocrine system. The endocrine system is involved in the regulation of uric acid levels as many hormones influence the concentration of urine. Describe the process of how a given hormone, hormone X, could be produced in the parathyroid glands and still influence cells of the kidney. (2 MARKS)



The experimental drug

Bonnie asked how long Bill would have to eat healthy like this and the doctors explained that it could take weeks or months before the kidney pain would disappear. 'Months?! I don't have months. I want this pain gone now. Surely there is some drug that can help me? Give me something that will help my pain go away more quickly!' cried Bill.

In the dirt-poor hospital, there were no short-term solutions to Bill's hyperuricemia. As doctors tried to calm Bill down, an ominous figure wandered past in the hallway. The strange man poked his head in the door and explained that he runs a pharmaceutical company which is testing pre-market drugs. He claimed to have a solution to Bill's problem. Bill was ecstatic, but Bonnie was sceptical.

A visit to the pharmaceutical company did not quell Bonnie's scepticism. The strange man showed Bill and Bonnie around his laboratory, giving them a first-hand look at his company's newly developed drug Allobillinol, which promised to lower uric acid levels in just five days. Bill was also introduced to a group of scientists that wanted to monitor his experience on the new drug. Bonnie was concerned about Bill taking the drug. She asked if the drug had any side effects and queried what it was made from. The scientists explained that the drug was 99% plant-based. A species of cress flowering plant known as *Lepidium billium* was used as it had medicinal properties that reduce pain.

8 Flowering plants have two major organ systems that allow them to grow and metabolise. Describe the organ systems that would be found within the *L. billium* plant. (2 MARKS)

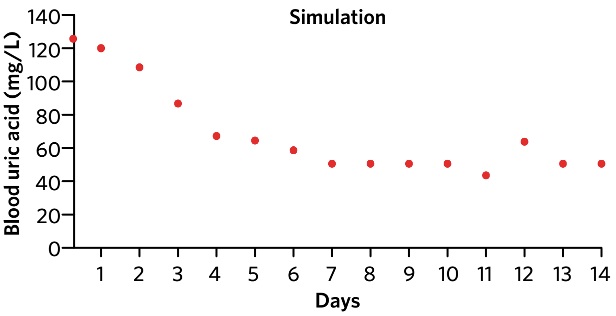
9 As part of the manufacturing process, *L. billium* plants are placed in a chemical solution. Identify the vascular tissue type in vascular plants that is responsible for the transportation of water up a plant. How does it differ from the other major type of vascular tissue in plants? (2 MARKS)

10 Trialling new drugs that have never been tested on human subjects raises a number of bioethical issues. Discuss the relevance of the bioethical principle of beneficence to Bill's situation. (2 MARKS)

The drug itself is claimed to target specific cells of the kidneys, known as kidney glomerulus podocytes. Kidney glomerulus podocytes make up the epithelial lining of the part of the nephrons of the kidneys known as the Bowman's capsule.

11 Explain why cells in multicellular organisms are organised into tissues, organs, and systems. (1 MARK)

Bill hesitantly agreed to take the Allobillinol. The scientists hypothesised that Bill's blood uric acid levels would be lowered to normal levels five days after the administration of Allobillinol. The scientists ran a simulation for what they believed would be the results of the experiment. They produced a projected graph of Bill's blood uric acid levels.

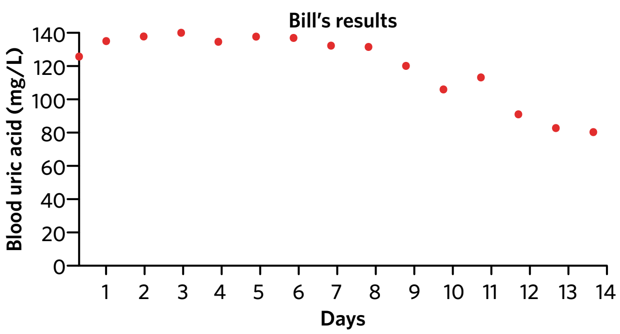


12 What day is Bill projected to return to regular blood uric acid levels? (1 MARK)

13 Justify whether Bill's projected blood uric acid levels support the hypothesis. (1 MARK)

Bill took the Allobillinol drug for 14 straight days. His blood uric acid levels were monitored. The results of the experiment are shown in the graph.

14 Using data from the graph, describe the general trend. (1 MARK)



CHAPTER 5 EXAM PRACTICE

30 min

Section A (6 MARKS)

Question 1 (1 MARK)

Which of the following tissue types is found in animals?

A xylem
B dermal
C vascular
D connective

Question 2 (1 MARK)

What is the name of the animal organ system responsible for removing carbon dioxide from the body and delivering oxygen to the blood?

A reproductive system
B respiratory system
C circulatory system
D nervous system

Question 3 (1 MARK)

The small intestine is

A part of both the digestive and respiratory systems.
B specialised to increase absorption by having a small surface area.
C responsible for the majority of the fat breakdown in the digestive tract.
D responsible for producing hormones that travel to all parts of the body.

Question 4 (1 MARK)

Which of the following environmental conditions would produce the greatest rate of transpiration?

A low humidity and low light exposure
B high humidity and low light exposure
C low humidity and high light exposure
D high humidity and high light exposure

Question 5 (1 MARK)

Which of the following organs is responsible for producing hormones?

A gallbladder
B pancreas
C kidneys
D bladder

Question 6 (1 MARK)

The first area of the nephron where the reabsorption of nutrients and water occurs is the

A loop of Henle.
B Bowman's capsule.
C distal convoluted tubule.
D proximal convoluted tubule.

Section B (14 MARKS)

Question 7 (5 MARKS)

In vascular plants, the root system is responsible for absorbing water from the soil and providing support to the plant. There are two different pathways of water and nutrient absorption in roots: the extracellular pathway and the cytoplasmic pathway.

a How is the root system specialised to aid the absorption of water? (1 MARK)

b Briefly describe the extracellular pathway of water and nutrient absorption in roots. (2 MARKS)

c Briefly describe the cytoplasmic pathway of water and nutrient absorption in roots. (2 MARKS)

Question 8 (5 MARKS)

Digestion is the breakdown of food molecules into smaller molecules that can be taken in by cells of the body. Digestive processes can be classified as either physical or chemical.

a Explain the difference between physical and chemical digestion. (2 MARKS)

b Briefly describe the physical and chemical digestion that occurs in the stomach. (2 MARKS)

c Outline the importance of a high surface area to volume ratio in the small intestine for digestion. (1 MARK)

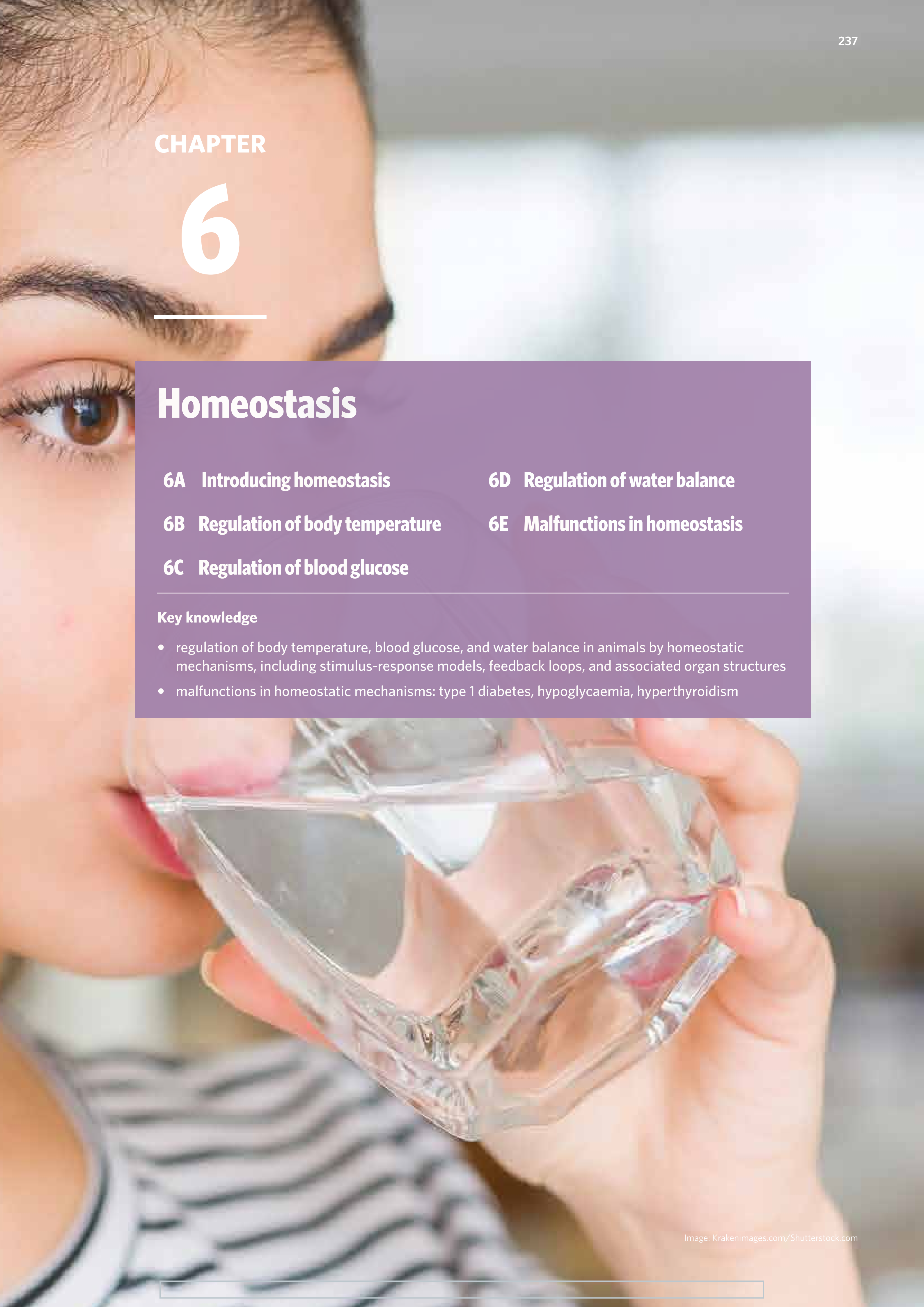
Question 9 (4 MARKS)

The endocrine system is responsible for producing hormones. The signalling molecules elicit a range of responses in the body.

a Why do some cells respond to a certain hormone, but others do not? (1 MARK)

b State the name of the system responsible for transporting hormones around the body. (1 MARK)

c Briefly describe the role of the pancreas in both the digestive and endocrine systems. (2 MARKS)



CHAPTER

6

Homeostasis

Key knowledge

- regulation of body temperature, blood glucose, and water balance in animals by homeostatic mechanisms, including stimulus-response models, feedback loops, and associated organ structures
- malfunctions in homeostatic mechanisms: type 1 diabetes, hypoglycaemia, hyperthyroidism

Image: Krakenimages.com/Shutterstock.com

6A INTRODUCING HOMEOSTASIS

It's a forty-degree summer day, and you decide to go down to the beach with your friends. 'Don't forget to eat something down there. And drink water. And keep cool!' your mum tells you as you walk out the door. Naturally, you don't do any of these, but you still make it home alive at the end of the day (albeit feeling a bit burnt and hungry). Was your mum wrong about the importance of these things? Or was something else ensuring your body continued to function normally during your time on the beach?

Of course, you take your laptop with you so you can Edrolo & chill by the waves!

Image: Song_about_summer/Shutterstock.com

Lesson 6A

In this lesson you will learn about homeostasis and its role in maintaining a constant internal environment in the body.

◀ Prerequisite knowledge

Years 7–10
Multicellular organisms rely on homeostatic mechanisms to respond to changes in their environment.

Years 7–10
An animal's response to a change in the environment is coordinated by its central nervous system.

Future applications ▶

Chapter 6
Homeostatic mechanisms can be used to combat a number of different environmental changes in humans.

Chapter 10
Further adaptations have been made by species living in extreme conditions to help them maintain homeostasis.

Study design dot point

- regulation of body temperature, blood glucose, and water balance in animals by homeostatic mechanisms, including stimulus-response models, feedback loops, and associated organ structures

Key knowledge units

What is homeostasis?	1.2.4.1
Homeostatic mechanisms	1.2.4.2

What is homeostasis? 1.2.4.1

OVERVIEW

Homeostasis is a complex process that maintains the internal environment of an organism within set limits so that cells and systems can function properly.

THEORY DETAILS

It's a fact of life that all living things are fussy. Plants are fussy – too much or too little light and they will die. Fish are fussy too – if the water is too hot or too cold they will die, and if it's too salty or not salty enough they will die too. Humans are the most fussy – we get upset if it's too cold or too hot, if we're too full or too hungry, if the internet is too slow, and even if we're having a bad hair day.

Cells are exactly the same. As you learned in lesson 2A, living organisms are composed of cells. These cells are alive, which means they're fussy. They're a bit like Goldilocks – they like things in their environment to be just right. Unfortunately for us, if their demands aren't met then our cells don't behave properly.

Cells inhabit the internal environment of our bodies. Within this environment, cells like to exist within a set range of parameters.

If these parameters are not met, then cells can't function normally and may potentially become damaged or die. Parameters that affect the functioning of cells include:

- temperature (your optimal internal body temperature is around 36.5 – 37.5 °C)
- pH (acidity level) (the optimal pH of the blood is 7.35 – 7.45)
- blood sugar levels (blood sugar levels are maintained between 4.0 – 7.8 mmol/L)
- sodium and potassium concentration (normal levels are 135 – 145 mmol/L for sodium and 3.5 – 5.0 mmol/L for potassium)
- fluid balance.

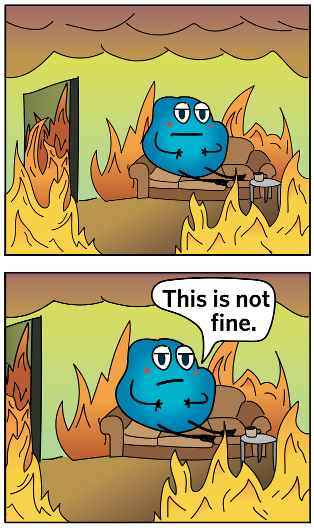


Figure 1 Cells are fussy, and if their environment isn't within their desired ranges they cease to function properly.

The external environment, that is, the world outside our bodies, influences our internal environment. When you stand outside in a blizzard, the freezing conditions cause your body temperature to drop. Conversely, when you stand outside in the heat your body temperature goes up, you start to sweat, and you lose fluid. All these things alter the internal environment of your body, making things unpleasant for our cells.

As you know, however, you can stand outside in the heat for a little while before you start to feel really uncomfortable. Your cells don't instantly die when the external environment of your body changes. Why is that? Because our bodies are constantly maintaining **homeostasis**.

Homeostasis is a complex group of regulated processes that occur throughout the body with the aim of maintaining an internal environment that is just right for our cells. We'll now take a general look at how homeostasis is maintained in the body.

homeostasis the maintenance of a relatively stable internal environment in the body despite changes in the external environment

Homeostatic mechanisms 1.2.4.2

OVERVIEW

Homeostatic processes can be explained using the stimulus-response model and feedback loops.

THEORY DETAILS

As described earlier, there are a large number of conditions that need to be controlled for cells to function properly. Because of this, our bodies have developed a number of different systems to combat changes in the external environment and maintain a constant internal environment. All of these homeostatic systems can be described using a **stimulus-response model** and **positive** and **negative feedback systems**. We'll look at each of these now.

The stimulus-response model

The stimulus-response model (Figure 2) outlines how changes in the external and internal environment can influence an organism's function.

The stimulus-response model can be simplified into five components:

1. **Stimulus** – a change in the external or internal environment of an organism.
2. **Receptor** – the stimulus is detected by a receptor in the body which then transfers this stimulus into a chemical or electrical signal for transmission to the modulator. There are many types of receptors. Cell receptors, for example, often come in the form of proteins embedded in the membrane or in the cytosol which detect a change in the environment. In many cases, a whole cell can act as a receptor.
3. **Modulator/s** – information from the receptors is sent to the modulator. In some homeostatic mechanisms, the modulator is a part of the brain, in others, it is a specific type of cell. The modulator compares the information received from the receptors with an ideal condition the body aims to maintain (for example, the set point for temperature in the body is 37 °C). Depending on the result of this, the modulator releases molecules that go on to alter the functioning of an effector. The modulator may also be called the processing centre.
4. **Effector** – the effector is a molecule (usually a **hormone**), cell, or organ that responds to a signal from the modulator and produces a response.
5. **Response** – the effector initiates the response to the stimulus. The response is any change in the function of a target cell, organ, or organism after stimulation from an initial signal.

stimulus-response model a model that describes how a system responds to a stimulus

positive feedback system a stimulus–response process in which the response increases the stimulus

negative feedback system a stimulus–response process in which the response counters the stimulus

stimulus (pl. stimuli) an event or molecule that can initiate a response

receptor a structure that detects a signal or external change, usually a protein

modulator location where information from receptors is sent to and compared to a set point, and where molecules altering the functioning of an effector are released. Also known as the **processing centre**

effector a molecule, cell, or organ that responds to a signal and produces a response

hormone a signalling molecule released from endocrine glands that regulates the growth or activity of target cells

response the action of a cell, organ, or organism caused by a stimulus

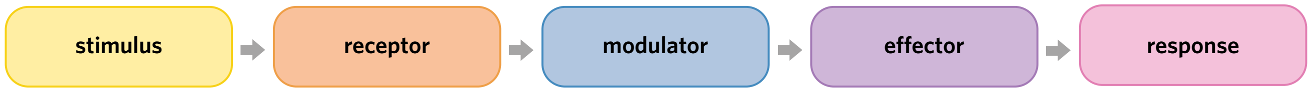
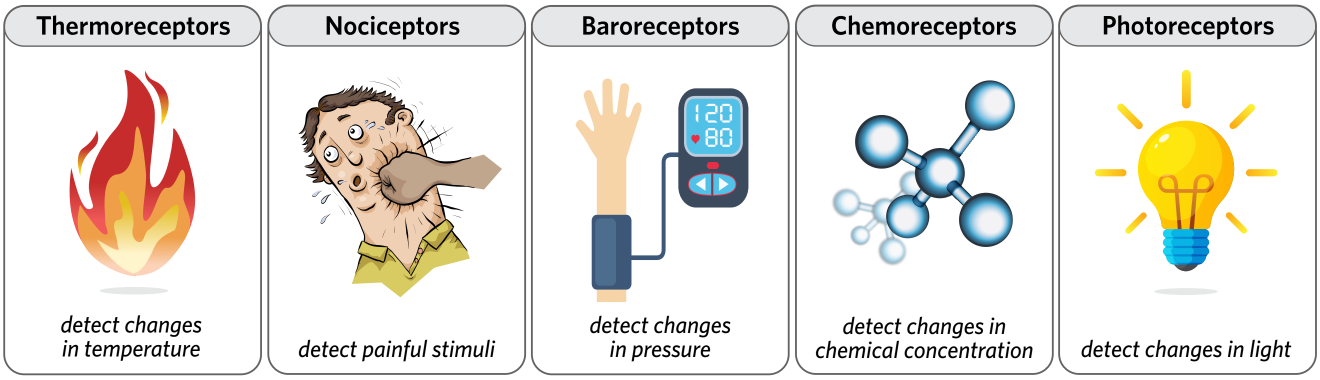


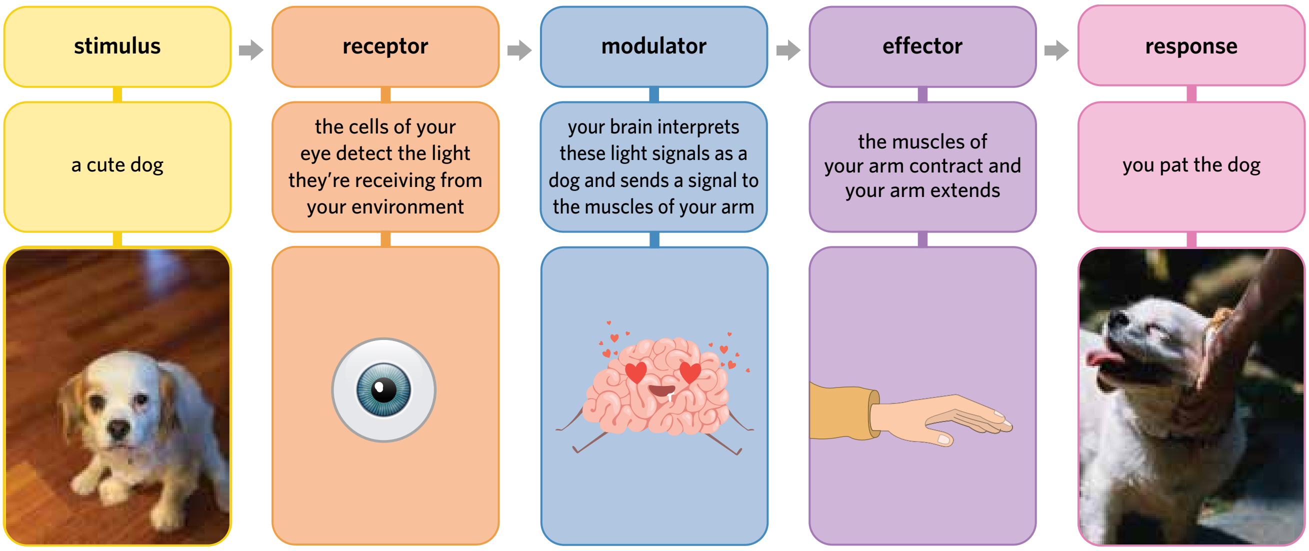
Figure 2 The stimulus-response model



Images (left to right): Blamb ca, Photoroyalty, DamienVectors & Mochipet/Shutterstock.com

Figure 3 Types of receptors in the body

The stimulus-response model can be used to explain a number of physiological processes that aren't related to homeostasis. For example, imagine you're walking along the street and you see a dog. The stimulus-response model can explain your reaction of bending down to pat it (Figure 4).



Images (left to right): Taylen Furness; extradryrain, ONYXprj & grmarc/Shutterstock.com

Figure 4 A stimulus-response model explaining your reaction when you see a dog

Positive feedback system

Positive feedback systems occur when the response increases the initial stimulus. Positive feedback systems are rare in the body, and don't form part of homeostasis.

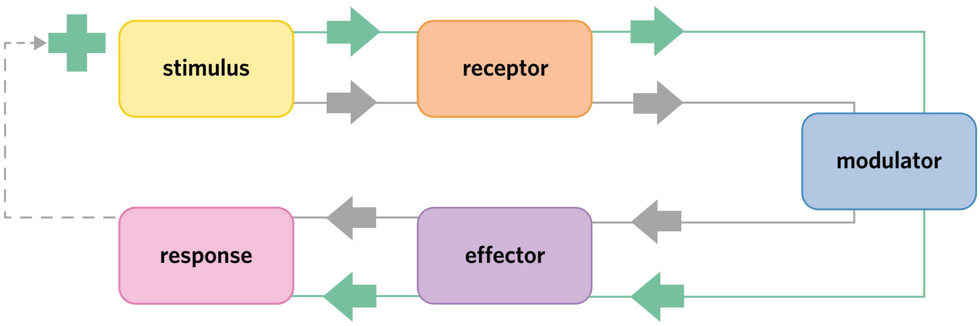


Figure 5 A positive feedback system. Note that the response (dotted line) increases the initial stimulus (grey), which in turn increases the stimulus-response cascade to create an even larger response (green).

Theory in context

One example of a positive feedback system occurring in the body is during childbirth. As the uterus contracts, it sends electrical signals to the pituitary gland in the brain, which then releases oxytocin. Oxytocin then travels to the uterus, causing the uterus to contract more and the generation of more electrical signals. This continues in a cycle until the baby is delivered.

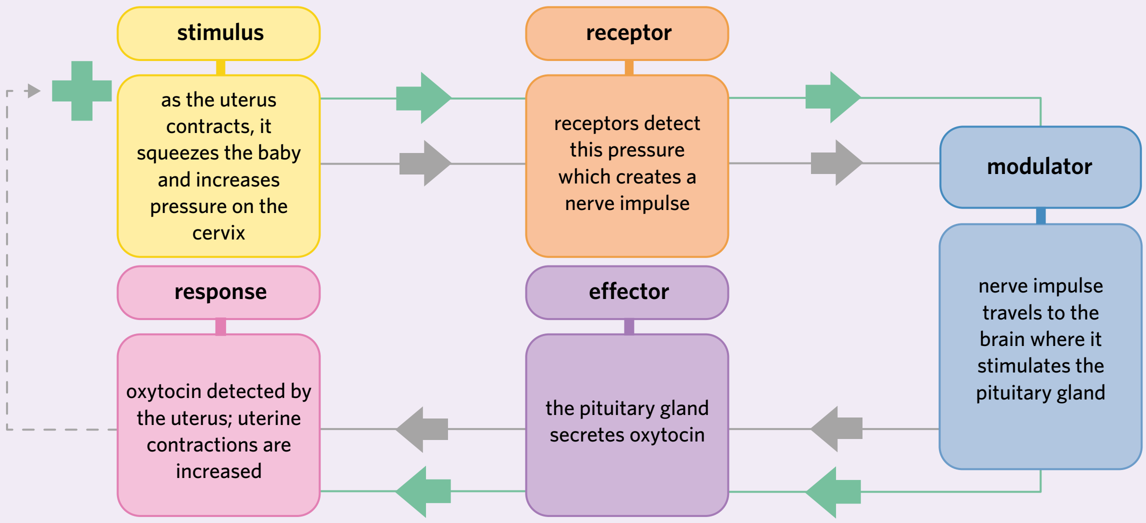


Figure 6 Childbirth is an example of a positive feedback system.

Negative feedback system

Negative feedback systems occur when the response counters the stimulus – that is, the response attempts to revert the system back to the state it was in before the stimulus occurred. This point is known as the set point, and is the value the body aims to maintain a given variable at (for example, the set point for temperature in the body is 37 °C). Homeostasis typically involves negative feedback loops – for example, the stimulus detected could be an increase in the external temperature, and the response initiated could be sweating (sweating causes the evaporation of water and the removal of heat from the body, which lowers the body temperature). You'll learn about three specific negative feedback loops involved in maintaining homeostasis in the next three lessons – 6B, 6C, and 6D.

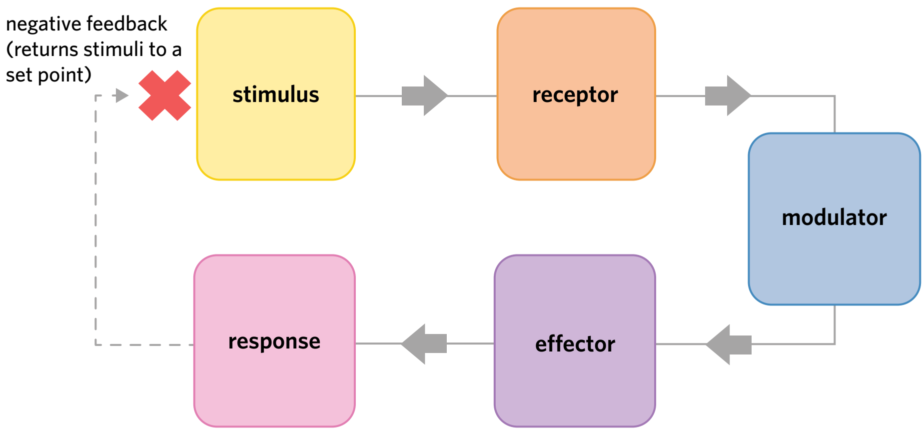


Figure 7 A negative feedback loop. Note that the response (dotted line) counteracts the initial stimulus, which in turn prevents the stimulus-response cascade from occurring again.

Negative feedback loops often overcompensate to respond to the stimulus. That means when something is too high, the negative feedback loop works to reduce it and ends up making it too low. Therefore, another negative feedback loop is made to then increase it again.

Cellular signalling

Sometimes, when discussing the stimulus-response model at a cellular level it is presented as a three-step process involving reception, transduction, and response. The same processes occur as in the five–step process, although they're grouped together a little differently:

1 Reception – the detection of a stimulus and the transmitting of this stimulus into a mechanical, electrical, or chemical signal

2 **Transduction** – 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. Transduction can involve sending a signal between organisms, across the body, to a neighbouring cell, or back to the original receptor cell

3 Response – the change in the function of a target cell, organ, or organism.

These three steps are summarised in Figure 8.

transduction the series of events that occur after the reception of a signal which results in the generation of a response

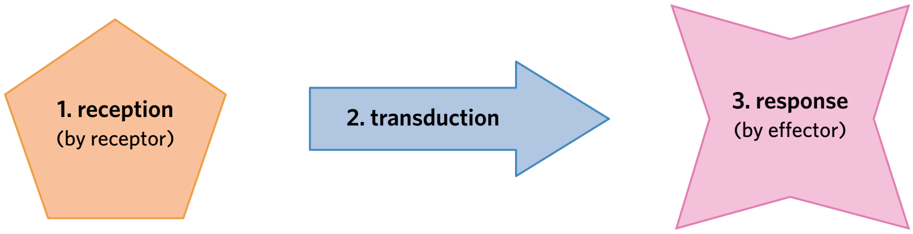


Figure 8 The three–step stimulus-response model

Theory in action

Check out scientific investigations 6.1 & 6.2 to put this into action!

Theory summary

Homeostasis maintains a constant internal environment in the body so cells can continue to function despite changes to the external environment. Homeostasis can be explained by using the stimulus-response model and the concept of feedback loops.

Mum wasn't wrong – you DO need to eat, drink, and keep cool when you're down at the beach. Fortunately, even if you don't do these things, your body works hard to maintain homeostasis so that your cells can continue to function normally despite the heat you experience, and the lack of water and glucose in your body.

Unfortunately, homeostasis can't stop you getting sunburnt so always make sure you slip, slop, slap, slide, and seek shade!

Image: Suzanne Tucker/Shutterstock.com

6A QUESTIONS

Theory review questions

Question 1

Homeostasis is a process that

A maintains the internal environment of an organism.

B counters alterations in the internal environment of an organism.

Question 2

Which of the following statements about homeostasis is true?

A Homeostasis only occurs in extreme external conditions.

B Homeostasis allows an organism to survive in response to a variety of changes to its environment.

Question 3

What is the function of the receptor in the stimulus-response model?

A produce a response
B process incoming information
C send information to the effector
D detect an environmental change

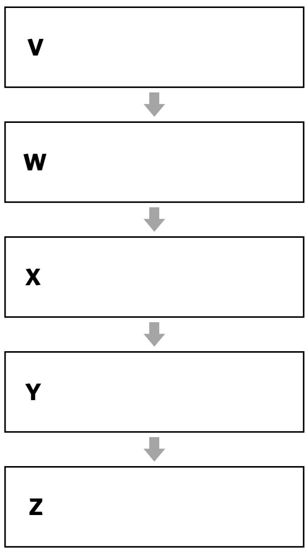
Question 4

In a homeostatic negative feedback loop the

A response counters the change in the environment that serves as the stimulus.
B effector counters the change in the environment that serves as the stimulus.

Question 5

Label the parts of the stimulus-response model.



Question 6

Match the components of the stimulus-response model to their corresponding real-world example.

Real-world example

- the brain
- a glass of water
- retinal cells in an individual's eye
- picking up the glass of water to drink it
- extending the muscles of the arm and hand to pick up the glass of water

Model component

I __________ stimulus
II __________ receptor
III __________ modulator
IV __________ effector
V __________ response

Question 7

Fill in the blanks with the following terms.

- negative
- response
- internal
- stimulus-response model
- stimulus

Homeostatic processes can be described using the __________ and mainly occur via __________ feedback loops. This involves the __________ counteracting the __________. In doing so, homeostasis maintains a constant __________ environment of an organism.

SAC skills questions

Case study analysis

Use the following information to answer Questions 8–14.

Human beings have evolved a number of homeostatic processes that help them to live in a variety of places on Earth. One place the human body has never had to adapt to, however, is space. The bodies of astronauts experience a number of physiological challenges whilst in space, and many of these are to do with homeostasis. One problem concerns the homeostatic process of fluid and blood pressure regulation.

On Earth, gravity draws blood and other fluids towards the lower body. In space, however, when gravity is no longer present this fluid tends to collect in the upper body. The redistribution of fluid in the body causes an increase in blood pressure in the head, which can damage the brain. Homeostatic measures counter this by causing a reduction in plasma volume and red blood cell production, leading to a 10% decrease in total blood volume. Due to this reduction, upon returning to Earth many astronauts suffer from a condition called orthostatic hypotension, in which their blood pressure drops by a significant amount when they stand up. This can cause them to feel lightheaded, and even pass out due to reduced blood flow to their brain.

Question 8

One example of a homeostatic mechanism that occurs in astronauts in space is

A an increase in blood pressure.

B a reduction in the production of red blood cells.

Question 9

The orthostatic hypotension experienced by the astronauts upon their return to Earth is caused by

A increased gravity in space.

B a reduction in blood volume.

C an increase in blood pressure in the brain.

Question 10

The redistribution of blood volume in the body in space is caused by

A a reduction in gravity.

B orthostatic hypotension.

C a loss of fluid from the body.

D the increase of red blood cell production.

Question 11

The example of reduced blood volume countering the redistribution of fluid in the body of astronauts is an example of

A a positive feedback loop.

B a negative feedback loop.

Question 12

In this example of homeostasis, the stimulus is

A the decrease in blood volume.

B an increase in brain blood pressure.

C the redistribution of blood in low gravity.

Question 13

One potential treatment for orthostatic hypotension in astronauts who return from space could be

A getting astronauts to donate blood to reduce their blood volume.

B giving astronauts medication to decrease their blood pressure.

C giving astronauts fluids to increase their blood volume.

D keeping them in chambers with increased gravity.

Question 14

Commercial space travel is a growing industry, and soon people from the general population will be able to experience space, including the potential negative effects of space travel. Which of the following ethical principles would need to be adhered to by companies offering space travel to reduce the risks of participation for their customers?

A beneficence

B integrity

C respect

D justice

Exam-style questions

Within lesson

Use the following information to answer Questions 15 and 16.

The stimulus-response model can be used to explain homeostatic processes that occur throughout the body. It is comprised of a number of components, including a stimulus, receptor, modulator, effector, and response.

Question 15 (1 MARK)

When considering the stimulus-response model, all receptors are

A proteins.

B changes in the external environment.

C cells that detect a change in the external temperature of an organism.

D structures that detect changes in either the internal or external environment.

Question 16 (1 MARK)

When considering the stimulus-response model and homeostasis, responses typically

A attempt to counter the stimulus.

B attempt to increase the stimulus.

C prevent the receptor from functioning correctly.

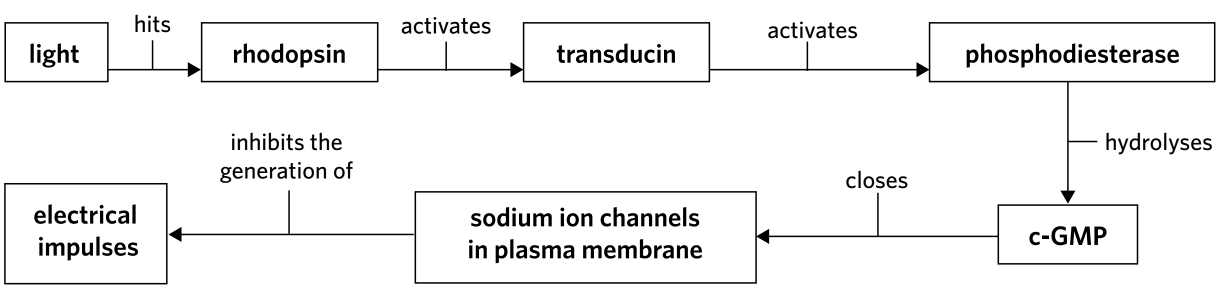
D change the external environment of the organism.

Question 17 (5 MARKS)

One essential feature for the survival of an organism is the maintenance of a relatively stable internal environment.

a What term is used for the process that maintains an internal environment within a set range of limits? (1 MARK)

b The flow chart summarises a sequence of events occurring inside a rod cell in the retina of the human eye. The electrical impulses produced cause the pupil to dilate, allowing increased amounts of light into the eye.



i Explain why light is regarded as the stimulus in this system. (1 MARK)

ii In a game of basketball, one of Jordan's teammates passed her the ball. Light was reflected off the ball and intercepted by Jordan's retina. Following this, Jordan's arm moved to catch the ball. What is the response in this stimulus-response system? (1 MARK)

iii Many human regulatory systems are based on negative feedback. Explain what a negative feedback system is, and the actions of the eye in response to too much light. (2 MARKS)

Adapted from VCAA 2012 Exam 1 Section B Q6

Multiple lessons

Question 18 (1 MARK)

An example of homeostasis is when

A water is absorbed by the root hairs of plants.

B plants close their stomata to reduce water loss.

C a positive feedback loop occurs during labour in humans.

D the body surface colour of an octopus changes to match the colour of its environment.

Adapted from VCAA 2011 Exam 1 Section A Q21

Question 19 (1 MARK)

The kidneys play a key role in maintaining homeostasis. Which of the following is a mechanism through which the kidneys contribute to homeostasis?

A reduction in blood flow to the kidneys to increase the amount of filtrate produced

B increased reabsorption of water when fluid levels are low in the body

C increased reabsorption of water in the bladder

D increased production of water by the kidneys

Adapted from VCAA 2017 Northern Hemisphere Exam Section A Q12

Key science skills and ethical understanding

Question 20 (7 MARKS)

The cheetah (*Acinonyx jubatus*) is a highly endangered animal, and breeding programs in zoos have low success rates due to captive cheetahs reproducing poorly and having a high prevalence of unusual diseases.

A group of scientists hypothesised that the stress of captivity might be affecting this species' ability to reproduce. They sought to explore this by measuring chronic stress levels in cheetahs by comparing blood concentrations of glucocorticoids (a type of hormone released when a cheetah is stressed) between captive and free-ranging cheetahs. They also sought to quantify the concentrations of estradiol and testosterone (sex hormones) in the cheetahs' blood to determine if increased glucocorticoid concentration impacted upon the concentration of sex hormones in cheetahs.

In their study, the scientists captured 23 free-ranging and 4 captive cheetahs and took blood samples from them. They found that concentrations of baseline faecal glucocorticoids were significantly higher in captive cheetahs than free-ranging cheetahs, and that testosterone concentrations were lower in captive male cheetahs than free-ranging males. Estradiol production was normal in captive females.

They proposed the following stimulus-response model to explain their findings.

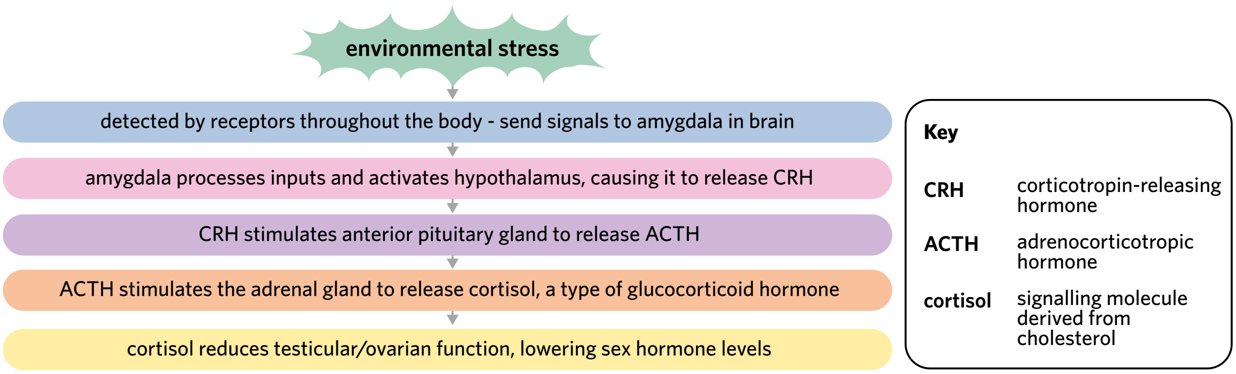


Image: Adapted from Terio et al. (2004)

a What is the effector in the stimulus-response model that accounts for lower reproductive success among captive cheetahs? (1 MARK)

b State the independent and dependent variables in the experiment. (2 MARKS)

c Identify a limitation with the experimental design used by the scientists and state how it could be rectified in a future experiment. (2 MARKS)

d Name an ethical concept that is relevant to this experimental design and explain what the scientists need to consider in relation to it to make their experiment more ethical. (2 MARKS)

6B REGULATION OF BODY TEMPERATURE

You've just come home from the gym. You're hot, you're sweaty. The first thing you do is jump in the shower and turn the cold water on full, right? Wrong. In fact, you should have a warm shower to cool down more. Wait, what? How does that work?

Image: Dmitry Tkachev/Shutterstock.com

Lesson 6B

In this lesson you will learn how organisms maintain a constant internal temperature via homeostasis.

◀ *Prerequisite knowledge*

Years 7–10
Homeostasis can be used to respond to changes in a multicellular organism's environment.

Lesson 6A
Thermoregulation is a homeostatic process, and can be explained by the stimulus-response and negative feedback models.

Future applications ▶

Chapter 10
Different species have a number of different adaptations that help them regulate body temperature in a variety of ways.

Year 12
Maintaining a constant internal temperature prevents enzymes from freezing or denaturing.

Study design dot point

- regulation of body temperature, blood glucose, and water balance in animals by homeostatic mechanisms, including stimulus-response models, feedback loops, and associated organ structures

Key knowledge units

Heat in the body	1.2.4.3
Regulating body temperature	1.2.4.4

Heat in the body 1.2.4.3

OVERVIEW

Heat transfer in the body occurs via four methods: conduction, convection, evaporation, and radiation.

THEORY DETAILS

If you make a cup of tea and leave it on the bench for an hour, when you come back it will no longer be hot. Why is that?

Objects can either gain heat from, or lose heat to, their environment. The same is true of the human body – it can gain heat from the environment, and it can lose heat to it as well. It is important to note that heat will always travel from a region of higher temperature into a region of lower temperature and that there are four main ways this heat transfer can occur. These are summarised in Table 1.

Table 1 Methods of heat transfer

Type of heat transfer	Explanation	Example
Conduction	The transfer of heat through physical contact with another object	When you touch something hot, heat from that object is transferred to your fingers via conduction
Convection	The transfer of heat via the movement of a liquid or a gas between areas of a different temperature	The temperature is warmer in the second storey of your house because hot air rises, taking heat energy with it
Evaporation	The loss of heat via the conversion of water from liquid to gas form	When you sweat, the water on your skin evaporates. Turning a liquid into a gas requires a lot of energy, and when sweat evaporates it takes away heat energy from your skin making you cool down
Radiation	The transfer of heat via electromagnetic waves such as light (i.e. doesn't require physical contact with another object)	The sun warms you via radiation. Conversely, when you stand in a cold room and you aren't wearing much clothing, you lose heat to your environment via radiation

conduction the transfer of heat through physical contact with another object

convection the transfer of heat via the movement of a liquid or gas between areas of different temperature

evaporation the loss of heat via the conversion of water from liquid to gas

radiation the transfer of heat via electromagnetic waves

These processes are illustrated in Figure 1. In the next section, we'll learn about some ways your body uses, and in some cases counters, these methods of heat transfer to maintain a constant internal body temperature.

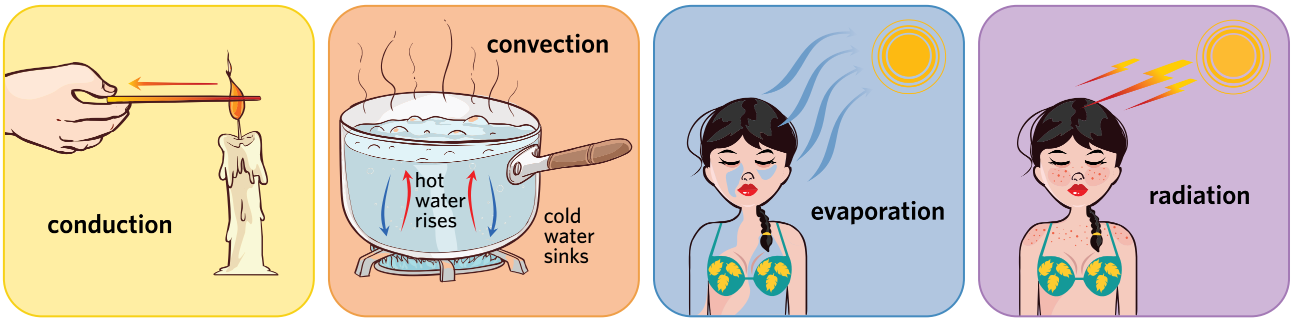


Image: corbac40/Shutterstock.com

Figure 1 The four main methods of heat transfer

Regulating body temperature 1.2.4.4

OVERVIEW

Thermoregulation occurs via a negative feedback stimulus-response system. Different responses are produced depending on whether the internal or external temperature becomes warmer or cooler.

THEORY DETAILS

As you learned in lesson 6A, the body temperature of organisms needs to be tightly controlled so that their cells can function properly. The overall body temperature of an organism is a balance of the heat being put into the system, the heat generated within a system, and the heat lost by the system. This can be explained by the equation:

total heat change = heat in + **metabolic** heat – heat out

In the previous section, you learned about how heat is transferred into and out of a system. In terms of **thermoregulation**, species can be divided into two different groups based on where the majority of their heat energy is gained – **endotherms** and **ectotherms**.

Endotherms (also known as warm-blooded animals) are able to generate the majority of their heat energy internally using metabolic processes. Ectotherms (also known as cold-blooded animals), on the other hand, produce very little metabolic energy, and instead rely on environmental sources of heat to warm themselves.

Humans are endotherms but we also gain energy from our environment – for example, the sun can warm us, as can standing in front of a heater. But as you've also experienced when you get out of the shower on a freezing morning, our bodies also lose heat to the external environment.

metabolism the set of chemical reactions within cells that help maintain the body's normal functioning including converting food and drink to energy

thermoregulation the homeostatic process of maintaining a constant internal body temperature

endotherm an animal that produces the majority of its own heat via metabolic processes

ectotherm an animal that obtains heat primarily from the environment, rather than its own metabolic heat

As you can see then, our environment plays a large role in thermoregulation. This is where the process of homeostasis comes into play. As explained in lesson 6A, homeostasis maintains a constant internal environment by using the stimulus-response model and negative feedback loop to counter changes in the external environment of an organism.

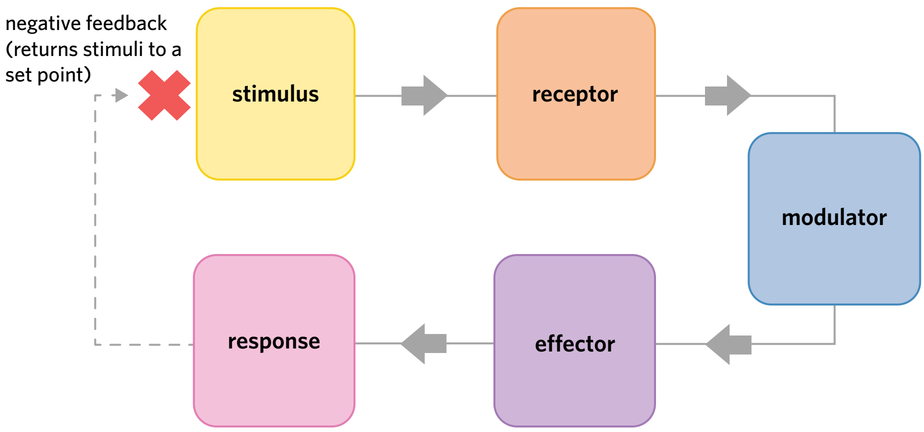


Figure 2 A stimulus-response model with negative feedback

Figure 2 is the negative feedback loop you learned in lesson 6A. We can use this model to explore thermoregulation in humans:

- The stimulus is a change in core body temperature or the environmental temperature
- The receptor component is fulfilled by either thermoreceptors near the brain or thermoreceptors in the skin. Such receptors detect temperature changes and send messages to the modulator
- In the case of thermoregulation, the modulator is a part of the brain called the **hypothalamus**
- The hypothalamus then sends messages to a variety of effector cells and tissues throughout the body
- These signals create a response that causes a change in heat transfer, helping to maintain a core body temperature of 37 °C.

hypothalamus a section of the brain in mammals that controls the maintenance of the body's internal environment

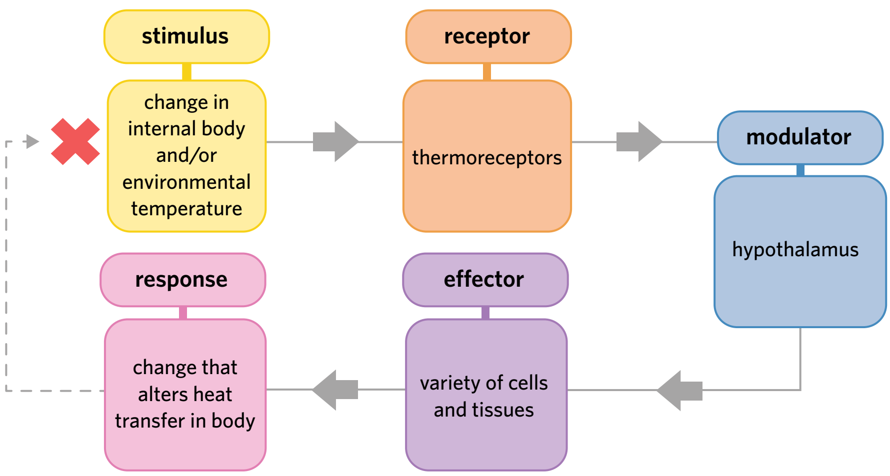


Figure 3 General stimulus-response model of thermoregulation

It is at the effector and response levels that the body's response to temperature change differs. We'll now take a look separately at exactly what happens in the body when the environmental temperature becomes warmer, and what happens when it becomes colder.

What happens if it's too hot?

When your body detects a rise in environmental or internal temperature, for example on a hot day, the hypothalamus sends signals to a number of different effectors, which then go on to produce a variety of different responses. All of these responses are aimed at increasing the amount of heat lost to the environment and decreasing the amount of heat produced by the body. These are summarised in Figure 4.

Some examples of these effectors and responses include:

- Sweat glands produce sweat which evaporates from the skin, taking heat energy with it
- Small blood vessels in the skin **vasodilate**, increasing surface blood flow. Blood is warm, so by increasing the amount of blood at the surface of the body the heat lost to the environment via convection and conduction is increased
- The **cerebral cortex** causes changes in behaviour, such as seeking shade
- **Arrector pili muscles** in the skin relax, which flattens body hair against the skin. Doing this increases the free flow of air against the skin, which increases the amount of heat lost due to convection
- At a cellular level, signals are sent by the hypothalamus to slow metabolic processes which reduces the amount of heat made by the body.

vasodilation the widening of blood vessels

cerebral cortex the outer layer of the brain that plays a key role in a number of processes including memory, attention, and perception

arrector pili muscles small muscles attached to hair follicles

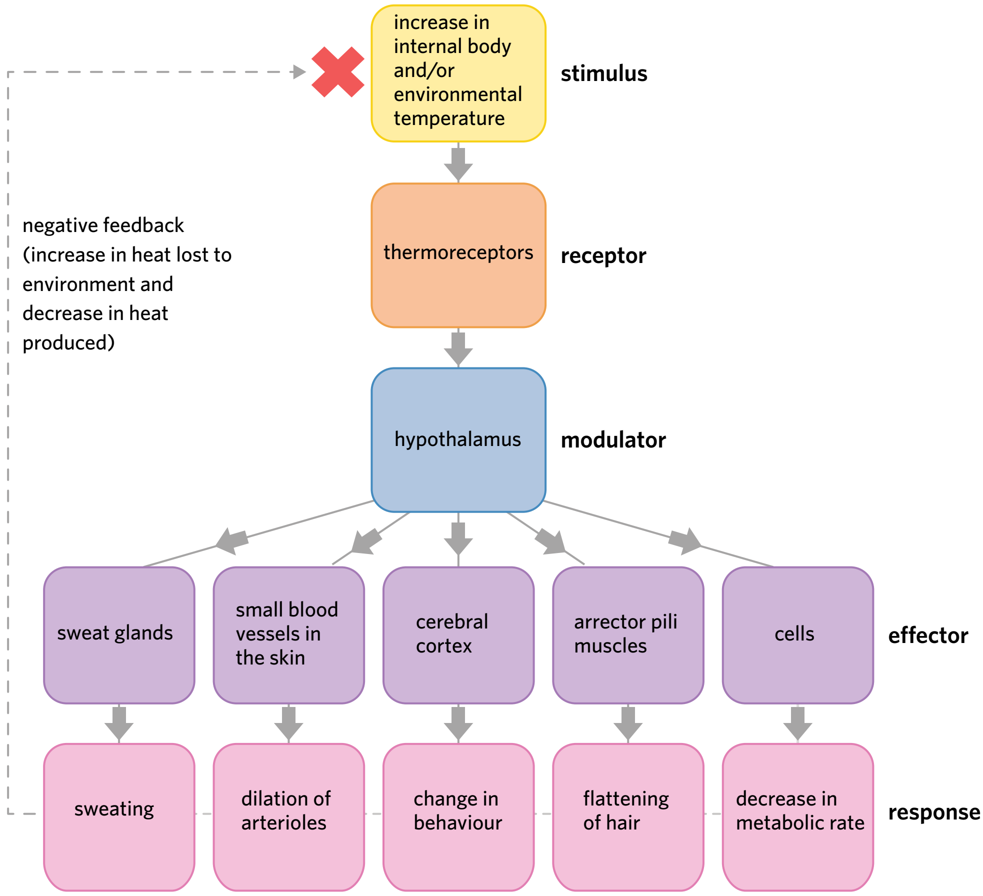


Figure 4 Methods used by the body to remain cool

What happens if it's too cold?

Similarly, when the internal or external environment gets colder, thermoreceptors located throughout the body detect the change and signal the hypothalamus which, in turn, stimulates a number of effectors. When the change detected is a decrease in temperature, the responses initiated by the effectors aim at decreasing the amount of heat lost to the environment, and increasing the amount of heat produced by the body. These are summarised in Figure 5.

Some examples of these effectors and responses include:

- **Skeletal muscles** are stimulated to cause shivering, a process in which muscle cells are stimulated to move quickly which increases their metabolism and creates more heat energy
- Small blood vessels in the skin constrict through a process known as **vasoconstriction**, decreasing surface blood flow. This means that less body heat is lost to the environment
- The cerebral cortex causes changes in behaviour, such as putting on more clothing

skeletal muscle a type of muscle that is voluntarily controlled and that is usually attached to bones

vasoconstriction the narrowing of blood vessels

- Arrector pili muscles in the skin contract, lifting hair follicles up, causing goosebumps, and trapping a layer of air. This layer of air serves as an insulating layer against the surrounding cold environment
- At a cellular level, signals are sent to increase metabolic processes such as cellular respiration which in turn results in more heat energy being produced
- **Brown fat** cells are stimulated to produce heat via the burning of triglycerides.

brown fat a type of body fat that is activated when the human body experiences low temperatures

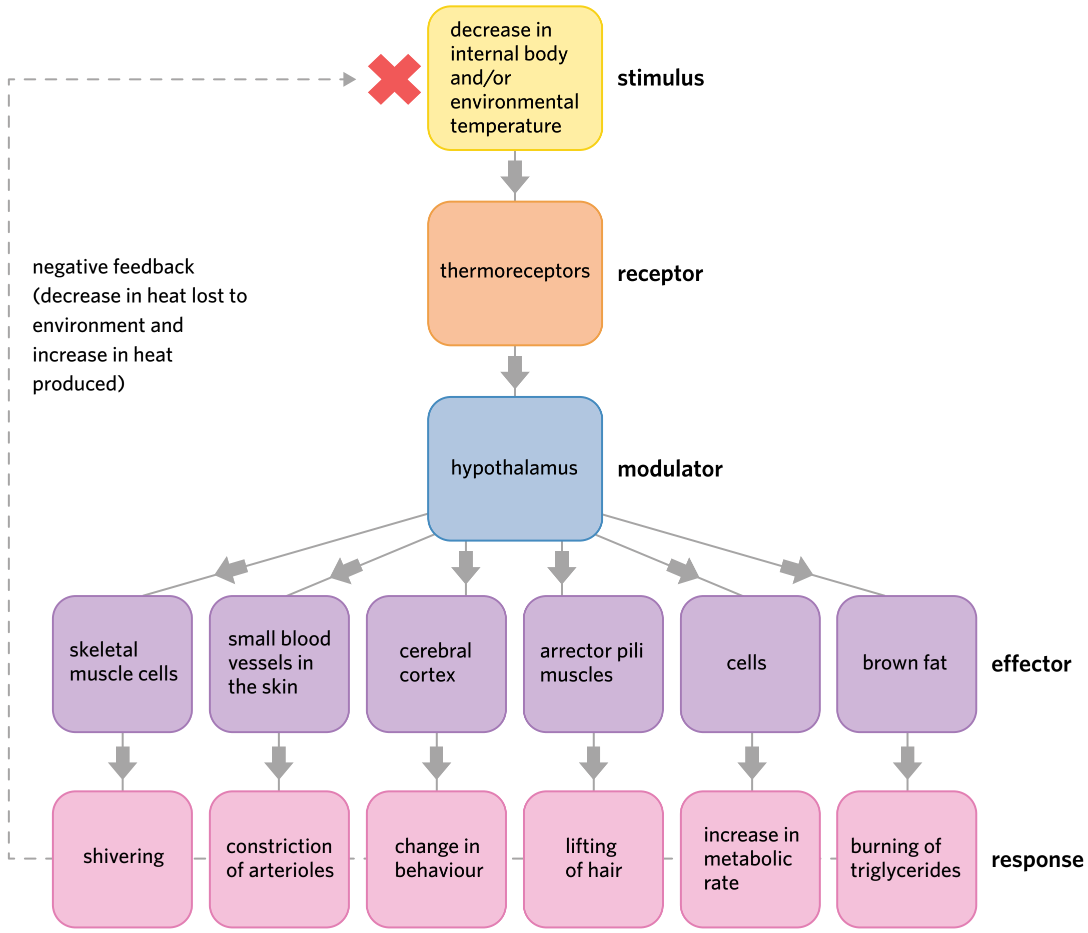


Figure 5 Methods used by the body to remain warm

It's important to note that the mechanisms of thermoregulation in this lesson have focused on humans. Later, in chapter 10, you'll learn about how different species have adapted different ways to deal with changes in their external environment.

Theory summary

Thermoregulation in humans occurs via negative feedback stimulus-response systems. A number of different factors help to counter changes in environmental temperature, however, all of them aim to either increase or decrease the heat generated/lost via the heat transfer principles of conduction, convection, evaporation, and radiation.

So why don't you have a cold shower after the gym? As you now know, part of the thermoregulatory response to a cold environment is to constrict arteriolar blood flow to the skin. This means that when you have a cold shower, your body directs less warm blood to your skin, which actually prevents you from cooling down. Instead, if you have a warm shower (around 33 °C), the blood flow to your skin isn't altered and the warm water can cool more of your blood, which in turn decreases your body temperature.

If this is you cramming Edrolo videos the night before your Biology exam in Year 12, then you know you're in trouble.

Image: Kopytin Georgy/Shutterstock.com

6B QUESTIONS

Theory review questions

Question 1

Thermoregulation involves the regulation of

A body temperature.

B homeostasis.

Question 2

Thermoregulation is a homeostatic process that occurs via

A positive feedback.

B negative feedback.

Question 3

Thermoregulation

A counters the temperature change in the environment of an organism.

B changes the temperature in the environment of an organism.

Question 4

Label the type of heat exchange occurring in each of the diagrams.

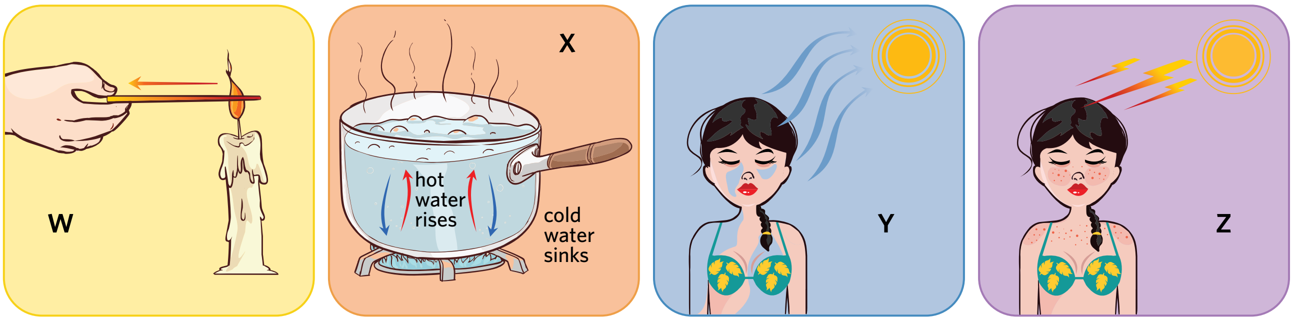


Image: corbac40/Shutterstock.com

Question 5

Match the response to the effector that is stimulated when the external environment of the body becomes cold.

Response

- shivering
- behavioural changes
- raising of hair follicles
- burning of triglycerides
- reduction in surface blood flow

Effector

I __________ skin arterioles

II __________ brown fat cells

III __________ cerebral cortex

IV __________ skeletal muscle

V __________ arrector pili muscles

Question 6

Match the effector to the response that occurs when the external environment of the body becomes hot.

Effector

- cells
- sweat glands
- skin arterioles
- cerebral cortex
- arrector pili muscles

Response

I __________ increase in heat loss due to convection and conduction

II __________ increase in heat loss due to evaporation

III __________ slowing of metabolic processes

IV __________ flattening of hair follicles

V __________ seeking shade

Question 7

Fill in the blanks in the following sentences.

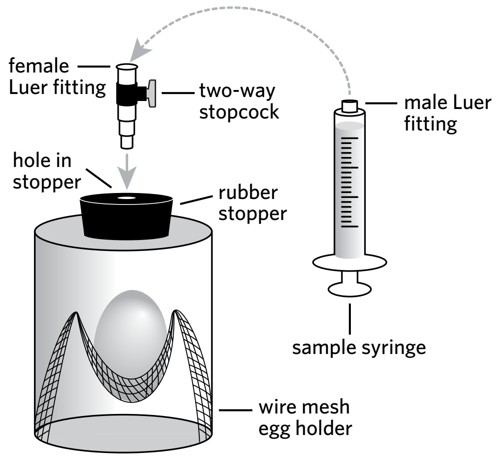
When __________ detect an increase in environmental temperature, signals are sent to the __________. From here, a number of different processes are activated, including the __________ in the skin which relax, flattening body hair against the skin. Doing so increases the amount of heat loss via __________.

SAC skills questions

Data analysis

Use the following information to answer Questions 8–14.

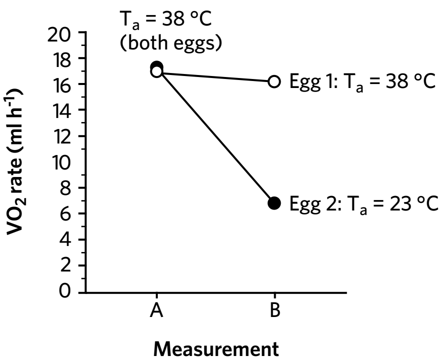
Two students with a passion for Biology and possibly too much time on their hands wanted to find out whether chicken embryos were endothermic or ectothermic. Their experimental design was as follows:



1. Place a fertilised egg (Egg 1) in a wire mesh egg holder in a jar. Place a rubber stopper on top of the jar with a hole in it, and fit a female Luer fitting in this stopper. The diagram provided illustrates what this set up should look like.
2. Repeat the exact same setup with another fertilised egg (Egg 2).
3. Place both jars in an incubator set at 38 °C.
4. Use the sample syringe shown to extract a 20 mL sample of air from both jars (Sample A).
5. Inject the air sample into an oxygen analyser and record the percentage of oxygen in the air sample recorded.
6. Immediately place the Egg 2 setup into an incubator set at 23 °C.
7. After 90 minutes, repeat steps 4–5 for each egg. These samples of air are Sample B.

The students intended to use their oxygen recordings to calculate the rate of oxygen consumption (VO_2) by the embryos per hour at the time each sample was taken, and from this, estimate the metabolic rate of the embryos. Embryos with higher VO_2 rates have higher levels of metabolism.

The students placed their findings in a graph.



Question 8

The first egg was initially placed in an incubator set at

A 23 °C.

B 38 °C.

Question 9

Which of the following measurements can be used as an estimate for metabolic rate?

A the amount of oxygen in the syringe sample

B the volume of oxygen consumed per hour

Question 10

Endotherms

A produce the majority of their body heat internally.

B receive the majority of their body heat from the environment.

Question 11

Which type of heat loss will be affecting the embryos most in this experiment?

A radiation

B conduction

C evaporation

Question 12

Which egg had a higher VO_2 rate after 90 minutes?

A Egg 1

B Egg 2

C neither – they were roughly the same

Question 13

Using the information provided, which embryo had the higher metabolic rate?

A Egg 1

B Egg 2

Question 14

The information obtained by the students suggests that chicken embryos are

A endotherms.

B ectotherms.

C neither.

Exam-style questions

Within lesson

Question 15 (1 MARK)

Which one of the following statements about thermoregulation is correct?

A Thermoregulation refers to the changing of bodily processes in response to a changing temperature in the internal or external environment.

B According to the stimulus-response model, the response would most likely be the change in the environmental temperature.

C Thermoregulation is an example of a positive feedback system.

D Thermoregulation is not part of homeostasis.

Adapted from VCAA 2019 Section A Q18

Question 16 (1 MARK)

Which one of the following is a thermoregulatory process?

A the flattening of body hairs to increase insulation

B the dilation of surface arterioles to increase heat absorption

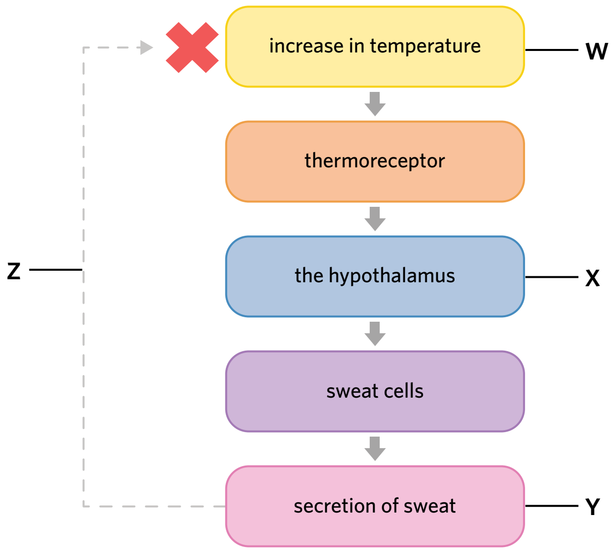
C the secretion of sweat from sweat glands to increase heat energy

D the generation of shivering in skeletal muscles to increase heat energy

Adapted from VCAA 2016 Exam 1 Section A Q16

Use the following information to answer Questions 17 and 18.

The diagram represents a thermoregulatory mechanism.



Question 17 (1 MARK)

The modulator in this model is shown by

A W.

B X.

C Y.

D Z.

Question 18 (1 MARK)

A feature of thermoregulation that can be seen in the diagram is that

A it only occurs in endotherms.

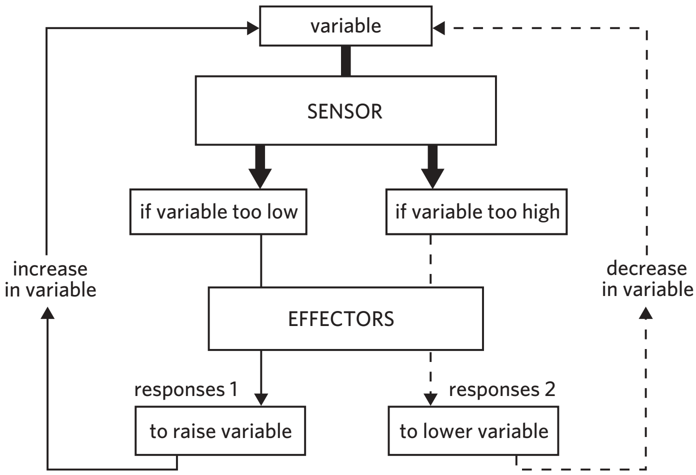
B it operates via positive feedback.

C the response counters the stimulus.

D it requires the effector cells to stimulate the modulator.

Question 19 (5 MARKS)

One way in which the general principle of homeostasis can be outlined is given in the following diagram.



Adapted from VCAA 2005 Section A Q13–15

a What is the role of the sensor in this model? (1 MARK)

b State two effectors that are stimulated in the human body in response to a low external temperature, and describe their respective response. (2 MARKS)

c Describe how sweating can help reduce the internal temperature of the body. (2 MARKS)

Multiple lessons

Question 20 (1 MARK)

Which of the following statements about water loss in the human body is correct?

A Water lost due to radiation of sweat can be replaced by increased reabsorption of water in the loop of Henle.

B Water lost due to radiation of sweat can be replaced by increased reabsorption of water in the collecting duct of the nephron.

C Water lost due to evaporation of sweat can be replaced by increased reabsorption of water in the glomerulus of the nephron.

D Water lost due to evaporation of sweat can be replaced by increased reabsorption of water in the collecting duct of the nephron.

Question 21 (4 MARKS)

Thermoregulation is essential for the survival of endothermic organisms.

a One way the human body can generate heat is by increasing metabolic processes in cells. Identify the organelle that would be targeted by this method of heat generation, and explain your response. (2 MARKS)

b State the type of feedback used in thermoregulation and explain how this feedback maintains homeostasis. (2 MARKS)

Key science skills and ethical understanding

Question 22 (6 MARKS)

A group of students wanted to test whether preventing a person from sweating during exercise would affect their body temperature. Before starting their experiment, they did some research and found that the average human body temperature is 37 °C, and healthy human body temperatures generally range from 36.1 °C – 37.5 °C.

To test their hypothesis, they came up with the following experimental design:

1. Use an analog thermometer to record the initial body temperature of the subject.
2. Cover the subject's arms and legs in cling wrap.
3. Re-measure their body temperature after five minutes.
4. Have the subject run around the school oval for five minutes.
5. Record their temperature after running.

They repeated their experiment on five different classmates.

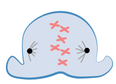
a State whether a control was used in the experiment and identify what the control is/should be. (2 MARKS)

b Give an example of an ethical principle that isn't adhered to in the student's experimental design. Explain your response. (2 MARKS)

c When they were analysing the data, the students found that their average resting body temperature measurement was 42 °C. One of the students said that this meant a systematic error had occurred.

i What evidence supports this student's suggestion? (1 MARK)

ii How could the students avoid this type of error if they were to conduct their experiment again? (1 MARK)



6C REGULATION OF BLOOD GLUCOSE

Step aside Atkins diet. Move along Paleo diet. Introducing the Phelps diet. Nearly every day during his career, American swimmer Michael Phelps ate a huge amount of food, including 0.5 kg of pasta and two ham and cheese sandwiches for lunch, and another 0.5 kg of pasta and a whole pizza for dinner. Was there a reason behind him eating so much pasta and bread before a big swim? Did they help him win his staggering 28 Olympic medals? Or did he just love food?

Michael Phelps after finishing his second bowl of pasta for the day

Image: CP DC Press/Shutterstock.com

Lesson 6C

In this lesson you will learn about the regulation of blood glucose in the human body via homeostasis.

◀ *Prerequisite knowledge* | *Future applications* ▶

Years 7–10
Homeostasis can be used to respond to changes in a multicellular organism's environment.

Lesson 6A
The regulation of blood glucose is a homeostatic process, and can be explained by the stimulus-response and negative feedback models.

Lesson 6E
Type 1 and type 2 diabetes result in the inability to homeostatically regulate blood glucose levels.

Year 12
Glucose plays a key role in the processes of photosynthesis and cellular respiration.

Study design dot point

- regulation of body temperature, blood glucose, and water balance in animals by homeostatic mechanisms, including stimulus-response models, feedback loops, and associated organ structures

Key knowledge units

Glucose in the body	1.2.4.5
Regulating blood glucose	1.2.4.6

Glucose in the body 1.2.4.5

OVERVIEW

Glucose plays a number of key roles in the human body and must be maintained within a narrow range in order for the body to function correctly.

THEORY DETAILS

Cars require petrol to work. When the little yellow light on the dashboard pops up saying 'low fuel', we have to quickly find the nearest petrol station to fill up or else we'll be making a call to a tow truck.

Our bodies are the same. They require a fuel called **glucose** to work. When our little yellow 'low fuel' light comes on, usually in the form of a grumbling stomach, and all our back up fuel reserves are depleted, we have to quickly make a pit stop at the nearest fridge to fill up on some food or else we'll be making a call to a human tow truck (also known as an ambulance) to pick us up because we've passed out (Figure 1)!

glucose a six-carbon carbohydrate that comes from the food we eat

Images (left to right): Richy99, CHAjAMP, Syda Productions, Africa Studio, New Africa, William Perugini/Shutterstock.com

Figure 1 Our bodies are just like well oiled (and hopefully well-fed) machines.

Glucose from food

Glucose is the main source of energy for all the cells in our body. We get it from the food we eat in the form of **carbohydrates**. When we eat carbohydrates, the digestive system breaks them down using a variety of enzymes into monosaccharides, including glucose. Glucose is then absorbed by the small intestine and released into the bloodstream via **glucose transporters**. From here, glucose can travel around the body where it gets taken up into cells. Once in cells, the process of respiration breaks glucose up into smaller parcels of energy called ATP that are used to power cell function (Figure 2).

carbohydrate a class of biomacromolecules made from monosaccharide monomers consisting of carbon, hydrogen, and oxygen. Also known as **saccharides** or **sugars**

glucose transporter a group of membrane proteins that transport glucose across the plasma membrane

glycogen a polysaccharide of glucose that stores energy. Serves as the main storage of glucose in the body

glycogenesis the process of creating glycogen from glucose

glycogenolysis the process of breaking down glycogen into glucose

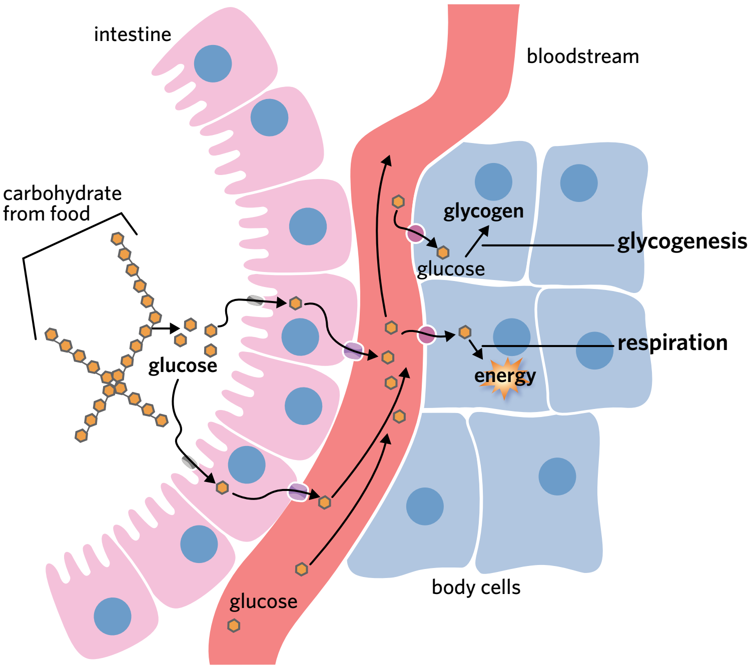


Image: udaix/Shutterstock.com

Figure 2 The breakdown and absorption of glucose into the bloodstream and cells

Glucose from body stores

Another source of glucose is **glycogen**. Glycogen is produced by the process known as **glycogenesis** that joins glucose absorbed by skeletal muscle and liver cells together into glycogen. Glycogen is essentially a long series of glucose molecules joined together, and in this form, glucose can be stored for prolonged periods of time in cells. When you don't eat for a long period of time, or you exercise strenuously and use up all your available blood glucose, this glycogen is broken down via a process called **glycogenolysis** back into glucose. This glucose then re-enters the bloodstream, where it can go on to power cells throughout the body (Figure 3).

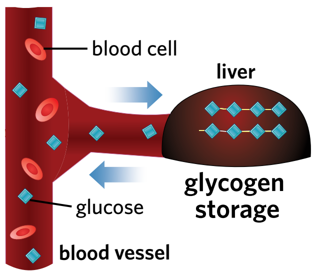


Image: grayjay/Shutterstock.com

Figure 3 Glucose gets stored as glycogen in the liver and skeletal muscle cells. When blood glucose levels fall, glycogen gets broken down back into glucose and re-enters the bloodstream.

Glucose transport around the body

Glucose is transported in **blood plasma** around the body. When we talk about the concentration of glucose in the body at any one time, we refer to this as the **blood glucose level**. The normal blood glucose level in a human is roughly between 4.0 mmol/L and 7.8 mmol/L (this equates to approximately four grams of glucose in the body of a 70 kg person, or one teaspoon of glucose). Our bodies need to maintain our blood glucose level within this narrow range – if it goes too high and a person becomes **hyperglycaemic**, glucose can actually harm the body in a number of ways (explored more in lesson 6E); if it goes too low and a person become **hypoglycaemic**, they may not be able to provide their cells with enough energy to function properly.

blood plasma the liquid component of blood that supports blood cells

blood glucose level a measure of the amount of glucose present in the blood. Normal homeostatic mechanisms keep blood glucose levels between 4.0 – 7.8 mmol/L

hyperglycaemia the state of having blood glucose levels above the normal range (>7.8 mmol/L)

hypoglycaemia the state of having blood glucose levels below the normal range (<4.0 mmol/L)

So how does our body maintain a steady level of glucose in the blood? How can we go hours, sometimes even days or weeks, without eating and yet maintain normal blood glucose levels? The answer, it shouldn't surprise you, is… **homeostasis**!

Regulating blood glucose 1.2.4.6

OVERVIEW

Homeostasis maintains constant blood glucose levels by releasing insulin to lower blood glucose levels and glucagon to increase blood glucose levels. The process occurs via negative feedback according to the stimulus-response model.

THEORY DETAILS

The stimulus-response model can be used to explain how blood glucose levels are regulated in humans via negative feedback loops:

- The stimulus is a change in blood glucose levels to above or below approximately 5 mmol/L
- The receptor in the model is the **pancreas**, specifically, clusters of specialised cells called the **islets of Langerhans**. These islets are comprised of two types of cells – **alpha cells** and **beta cells** – and it is these cells that detect blood glucose levels (Figure 4)
- The modulator in the regulation of glucose is also the islets of Langerhans. **Insulin** or **glucagon** is released depending on whether glucose levels are high or low
- Insulin and glucagon travel through the bloodstream to alter effectors throughout the body
- The response is an increase/decrease in blood glucose levels to within normal limits.

This is summarised in Figure 5.

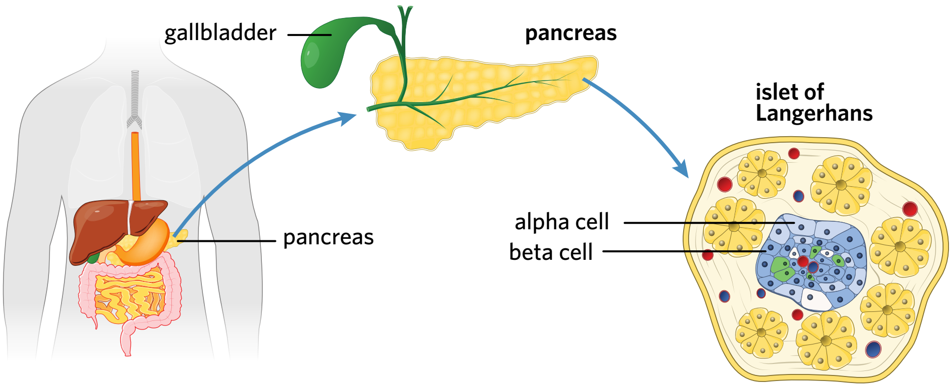


Image: Designua/Shutterstock.com

Figure 4 Islets of Langerhans located in the pancreas consist of glucagon-secreting alpha cells and insulin-secreting beta cells.

Similar to how we approached thermoregulation in the previous lesson, let's now look at what happens in the body when blood glucose levels are too high, and what happens when they become too low.

What happens when blood glucose levels increase?

When an islet of Langerhans detects a blood glucose level above around 5 mmol/L, beta cells release insulin. Insulin goes on to stimulate two different effectors via two different pathways:

1. Skeletal muscle and fat cells absorb more glucose from the blood. When insulin binds to these cells, glucose transporters are inserted into the cells' membrane, thus increasing the amount of glucose that can be absorbed by the cell via facilitated diffusion (Figure 6). Glucose transporters are necessary because glucose is hydrophilic and does not readily pass through lipid cell membranes. Once in the cell, this extra glucose can be used by mitochondria to create energy. Additionally, in skeletal muscle cells, some of the absorbed glucose gets turned into glycogen for storage. In fat cells, this extra glucose is converted into fatty acids for long term storage.
2. Liver cells are stimulated to convert more glucose into glycogen. The liver already has a high uptake of glucose and this is unaffected by insulin. However, insulin activates a number of different enzymes responsible for glycogenesis.

homeostasis the maintenance of a relatively stable internal environment in the body despite changes in the external environment

pancreas an organ of the digestive and endocrine system that releases both digestive juices and hormones

islets of Langerhans regions of the pancreas that contain cells that secrete hormones

alpha cells cells that occupy the islets of Langerhans and secrete glucagon

beta cells cells that occupy the islets of Langerhans and secrete insulin

insulin a hormone secreted by beta cells of the pancreas when blood glucose levels are elevated

glucagon a hormone secreted by alpha cells of the pancreas when blood glucose levels are low

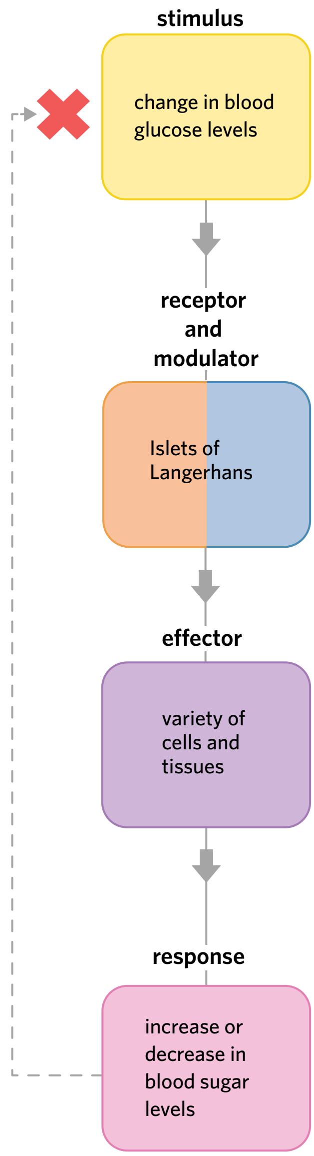


Figure 5 General stimulus-response model of blood glucose regulation

When cells absorb glucose, glucose levels in the blood are lowered. Once levels are around 5 mmol/L, insulin will stop being released by beta cells and these two effectors will no longer be stimulated. Each pathway is summarised in Figure 7.

> ***Lesson link***
>
> The insertion of glucose transporters into the cell membrane is an example of exocytosis, whilst uptake of glucose via glucose transporters is an example of facilitated diffusion.
> If your knowledge of these has passively diffused out of your brain, head on back to ***lesson 3B*** to revise the process of diffusion, and reread ***lesson 3C*** to catch up on exocytosis!

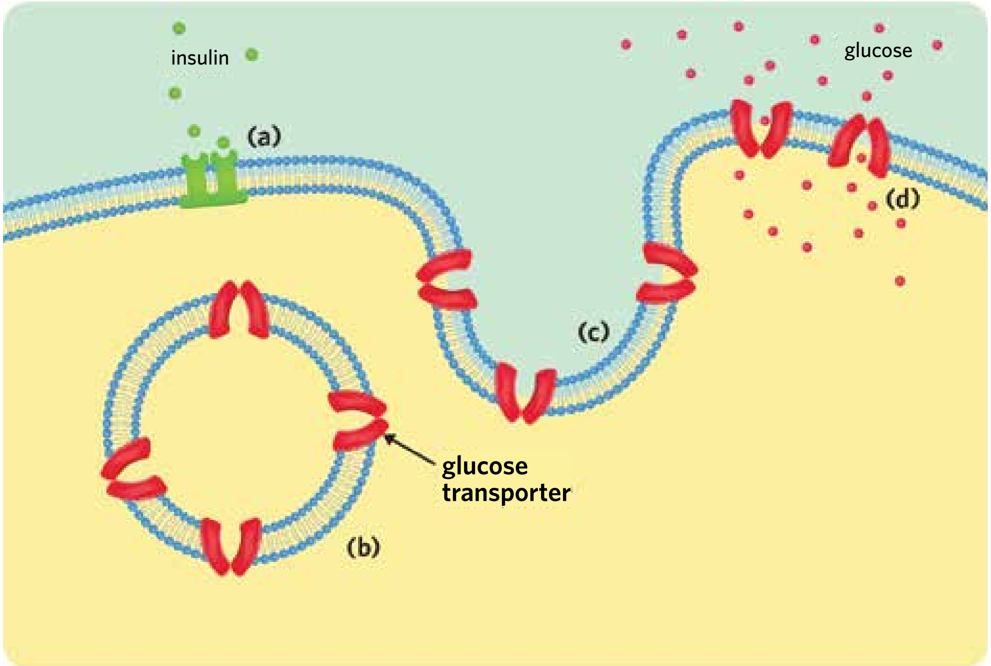


Image: extender_01/Shutterstock.com

Figure 6 **(a)** Insulin binds with receptors on skeletal muscle cells, causing **(b)** vesicles embedded with glucose transporters to **(c)** fuse with the cell membrane, **(d)** allowing more glucose into the cell.

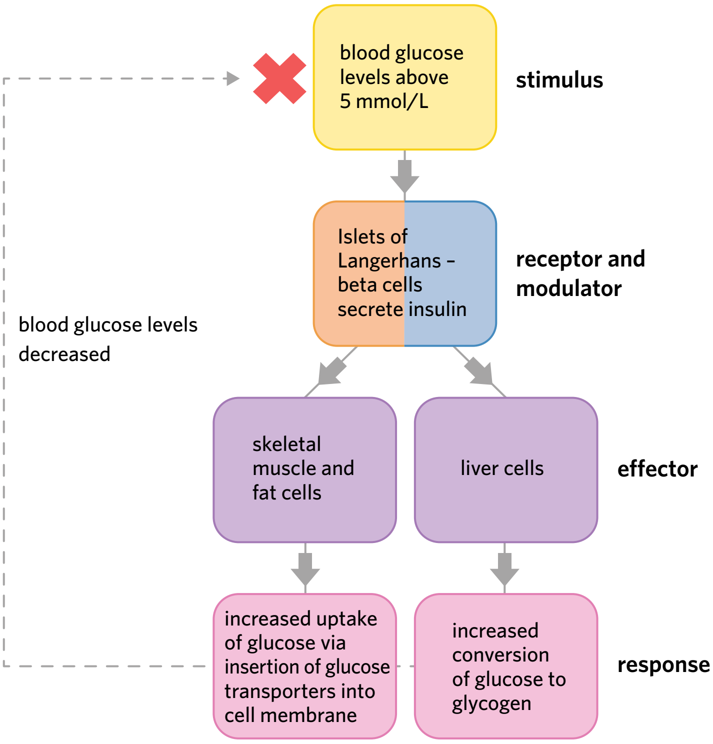


Figure 7 The two pathways used by the body to reduce elevated blood glucose levels

What happens when blood glucose levels decrease?

When an islet of Langerhans detects a fall in blood glucose levels below about 5 mmol/L, alpha cells secrete glucagon. Glucagon stimulates liver cells to break down glycogen into glucose and release it into the bloodstream via glycogenolysis.

Once glucose levels are close to 5 mmol/L again, alpha cells stop secreting glucagon. This means the effector, liver cells, stop breaking down glycogen and glucose is no longer released into the blood. This pathway is summarised in Figure 8.

> ***Memory device***
>
> Glycogen is the stored form of glucose, lysis means breaking down. Glycogenolysis is the breakdown of glycogen into glucose.

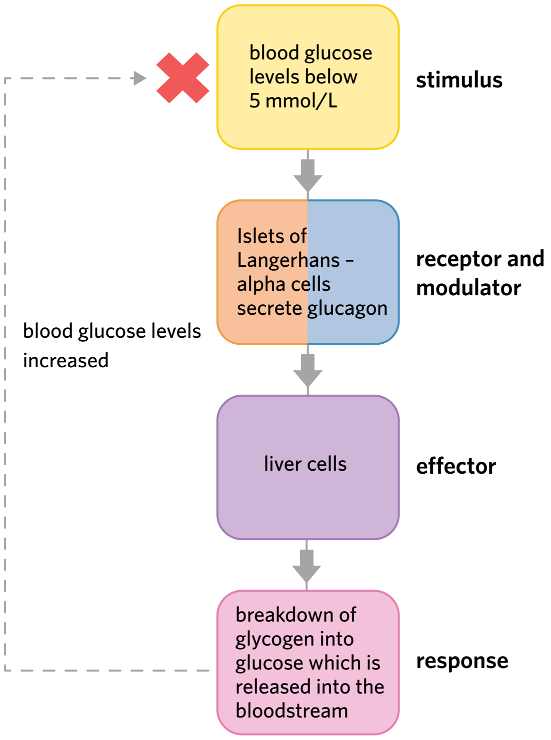


Figure 8 The pathway used by the body to increase low blood glucose levels

Memory device

Insulin gets glucose **in**to the cell, gluca**gon** makes glycogen be **gon**e!

Theory summary

Blood glucose levels are maintained within narrow limits due to a negative feedback stimulus-response system. When blood glucose levels are elevated, beta cells in the pancreas release insulin that increases the uptake of glucose into skeletal muscle and fat cells, and upregulates the conversion of glucose into glycogen in the liver and skeletal muscle cells. When blood glucose levels are low, alpha cells in the pancreas release glucagon which stimulates liver cells to break glycogen down into glucose and release it into the bloodstream.

Table 1 Summary of blood glucose regulation

Blood glucose level	Cell stimulated	Hormone released	Effector	Response
Elevated (>5 mmol/L)	Beta cells	Insulin	Liver cells and skeletal muscle cells	Increased production of glycogen
			Skeletal muscle and fat cells	Increased uptake of glucose
Decreased (<5 mmol/L)	Alpha cells	Glucagon	Liver cells and skeletal muscle cells	Breakdown of glycogen into glucose and release into bloodstream

The reason why elite athletes like Michael Phelps eat so much bread and pasta is because these foods are rich in carbohydrates. Called 'carbohydrate loading', athletes eat high amounts of carbohydrates before training and/or a competition to provide their cells with glucose and increase their stores of glycogen to ensure they have enough energy to power their bodies. Some research suggests that athletes should eat up to 12 grams of carbohydrate per kilogram of body weight per day to achieve the best results. How much pasta does that mean you would have to eat if you were cycling the Tour de France tomorrow?

Elite marathon runners carb loading for an upcoming race

Image: pz71/Shutterstock.com

6C QUESTIONS

Theory review questions

Question 1

Glucose is important in the body because it

A provides cells with energy.

B is converted to glucagon.

Question 2

The regulation of blood glucose

A maintains blood glucose levels within a narrow range.

B alters the absorption of glucose in the digestive system.

Question 3

Which of the following best describes the molecule glycogen?

A It is a hormone released by the beta cells of the pancreas.

B It is a multi-branched polysaccharide used to store glucose in skeletal muscle and liver cells.

Question 4

Fill in the blanks with the following terms.

- homeostatic
- hypoglycaemia
- hyperglycaemia
- blood glucose levels

Unhealthy people may suffer from abnormal __________. High glucose in the blood may cause __________, and low glucose in the blood could cause __________. Either of these conditions are caused by malfunctioning __________ mechanisms.

Question 5

Fill in the blanks with the following terms.

- insulin
- glycogen
- glucagon
- beta cells
- alpha cells

When __________ in the pancreas detect an increase in blood glucose levels, they release __________. Alternatively, if __________ detect a decrease in blood glucose levels then they release __________. Both of these hormones alter the amount of __________ present in the liver.

Question 6

Categorise the following responses as a result of **insulin secretion** or **glucagon secretion**.

I increased blood glucose levels __________

II decreased blood glucose levels __________

III increased production of glycogen __________

IV breakdown of glycogen into glucose __________

V insertion of glucose transporters into cell membranes __________

SAC skills questions

Data analysis

Use the following information to answer Questions 7–14.

The glycaemic index (GI) of a food is a measure of how quickly its carbohydrates are broken down and absorbed into the bloodstream. Foods with a low glycaemic index (<55) take longer to be broken down into glucose. Therefore, these foods cause a person's blood sugar to rise more gradually after being eaten. Foods with a high glycaemic index (>70) are very quickly converted into glucose and absorbed. A person's blood sugar levels will rise extremely quickly, or 'spike', shortly after consuming such foods.

A group of students wanted to test the glycaemic index of five different foods – white bread, brown rice, mung bean noodles, taro (a root vegetable), and sweet potatoes. The students consumed 50 grams of each food and tested their plasma insulin levels 0, 15, 30, 45, 60, 90, and 120 minutes after consumption. The students averaged their results and produced the following graphs.

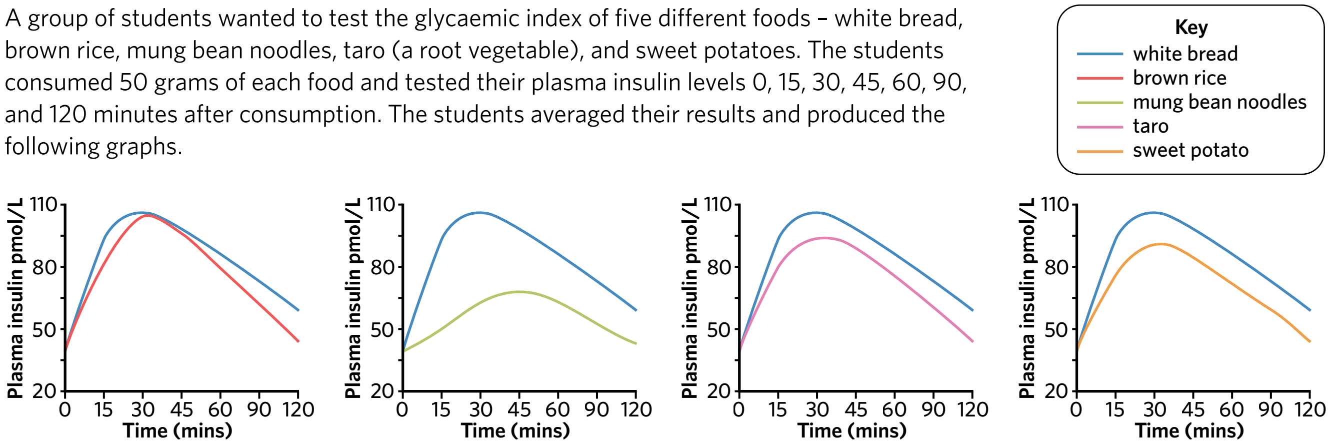


Image: adapted from Lin et al. 2010

Question 7

A food with a glycaemic index of 73 would be considered

A high GI.

B low GI.

Question 8

Foods that have low glycaemic indexes

A increase blood glucose levels quickly after consumption.

B increase blood glucose levels slowly after consumption.

Question 9

Which food caused the highest plasma insulin level after 120 minutes?

A white bread

B brown rice

C taro

Question 10

After eating the carbohydrate-containing food, a student's pancreas will

A secrete insulin to increase absorption of blood glucose.

B secrete glucagon to increase absorption of blood glucose.

C secrete insulin to increase the conversion of glycogen to glucose.

D secrete glucagon to increase the conversion of glucose to glycogen.

Question 11

Based on the information provided in the graph for brown rice, the glucose level in a person eating brown rice would have peaked

A before 30 minutes after eating the rice.

B after 30 minutes after eating the rice.

Question 12

The food with the lowest glycaemic index is

A mung bean noodles.
B sweet potato.
C white bread.
D brown rice.

Question 13

Which food should a student eat if they wanted to increase their blood glucose levels as much as possible in 30 minutes?

A mung bean noodles
B sweet potato
C white bread
D taro

Question 14

In this experiment, the consumption of white bread sample served as

A a control.
B a reference food.

Exam-style questions

Within lesson

Question 15 (1 MARK)

Cats that have not been fed for two to three days are able to maintain a constant blood glucose concentration. After 24 hours without food, the molecule broken down by the liver into glucose is

A gluten.
B insulin.
C glycogen.
D glucagon.

Adapted from VCAA 2004 Exam 1 Section A Q20

Use the following information to answer Questions 16 and 17.

A hormone involved in the control of plasma glucose concentration is insulin.

Question 16 (1 MARK)

Insulin is secreted by

A alpha cells in the pancreas.
B beta cells in the pancreas.
C skeletal muscles cells.
D liver cells.

Adapted from VCAA 2003 Exam 1 Section B Q5di

Question 17 (1 MARK)

High levels of insulin would

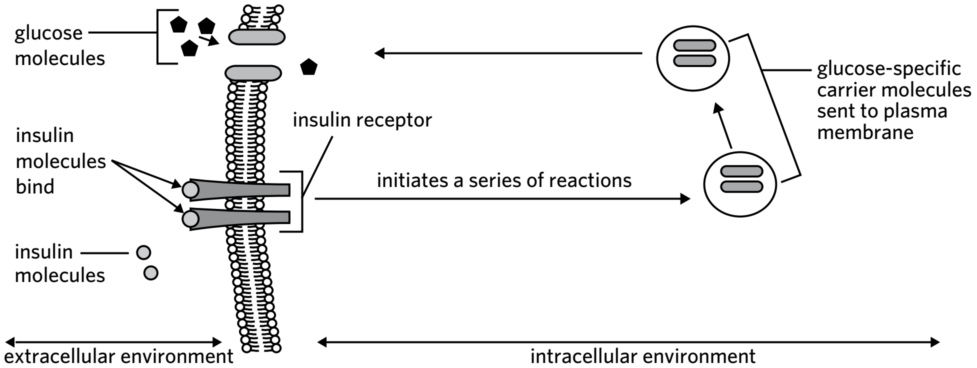
A increase plasma glucose levels.
B decrease plasma glucose levels.
C increase plasma glycogen levels.
D decrease plasma glycogen levels.

Adapted from VCAA 2003 Exam 1 Section B Q5dii

Multiple lessons

Use the following information to answer Questions 18 and 19.

The diagram shows a summary of the steps in an insulin signalling pathway that results in increased glucose uptake.



Question 18 (1 MARK)

The mechanism through which glucose-specific carrier molecules increase intracellular glucose concentration is

A facilitated diffusion.

B active transport.

C bulk transport.

D osmosis.

Question 19 (1 MARK)

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

A Increasing the concentration of glucose inside the cell will reduce the number of glucose-specific carrier molecules transported to the membrane.

B Glucose will continue moving down its concentration gradient until its intracellular and extracellular concentrations are equal.

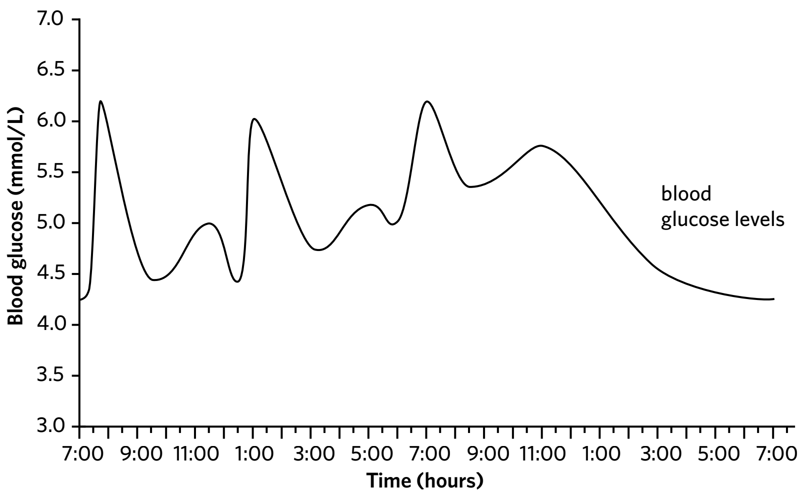
C ATP will be used to pump glucose against its concentration gradient into the cell.

D Glucose will simply diffuse across the membrane.

Adapted from VCAA 2017 Section A Q17

Question 20 (6 MARKS)

A student measured their blood glucose levels over 24 hours. The graph shows the results they obtained.



a Explain the large rises in blood glucose that occurred three times throughout the day. (1 MARK)

b Suggest why blood glucose levels rise at around 10:00 AM. (1 MARK)

Adapted from VCAA 2010 Exam 1 Section B Q1bii

c To prevent the concentration of glucose in the blood rising above the normal range the pancreas releases insulin. Insulin travels in the bloodstream and triggers specific responses after attaching to specific receptors on cells throughout the body.

- **i** Based on the information provided, state the type of molecule insulin represents. (1 MARK)
- **ii** What are the target cells for insulin? (1 MARK)
- **iii** How does insulin cause a decrease in blood glucose concentration? (2 MARKS)

Adapted from VCAA 2005 Exam 1 Section B Q7d

Key science skills and ethical understanding

Question 21 (6 MARKS)

The table shows the mean levels of glucose and insulin in two groups of people sampled one hour after the ingestion of 75 g of glucose. One of the experimental groups consisted of people with a disease that affected their ability to produce insulin; the other acted as a control.

	group X		**group Y**	
time after glucose ingestion	0 min	60 min	0 min	60 min
plasma glucose (mmol/L)	5.3	13.0	5.3	7.8

a Which group consists of people with the disease? Justify your response using data from the table. (2 MARKS)

b Explain the importance of having a control group in this experiment. (1 MARK)

c Another hormone involved in the control of plasma glucose concentration is glucagon. Explain how glucagon increases blood glucose concentration. (1 MARK)

d Identify an ethical concept pertaining to the individuals with impaired insulin production that needs to be considered by the scientists conducting this experiment, and explain how it could be addressed by them. (2 MARKS)

Adapted from VCAA 2003 Exam 1 Section B Q5

6D REGULATION OF WATER BALANCE

Booze. Juice. Bevvies. The sauce. Vino. Liquid courage. The hard stuff. A rosé by any other name would smell as sweet, and a drink of alcohol by any other name will still hurt a person's head as much the next morning. But what is it about alcohol that creates the unpleasantness of a hangover? And can we stop it from happening?

The calm before the storm...

Image: Rawpixel.com/Shutterstock.com

Lesson 6D

In this lesson you will learn about the regulation of water balance in the human body via homeostasis.

◀ Prerequisite knowledge — *Future applications ▶*

Lesson 3B
Water travels across the plasma membranes of cells via osmosis.

Lesson 5D
The excretory system plays a key role in the regulation of water in the body.

Lesson 6E
Diseases such as diabetes can influence the amount of water in the body.

Lesson 10A
Animals and plants that have adapted to live in hot environments have evolved a number of strategies to limit water loss and maintain homeostasis.

Study design dot point

- regulation of body temperature, blood glucose, and water balance in animals by homeostatic mechanisms, including stimulus-response models, feedback loops, and associated organ structures

Key knowledge units

Water in the body	1.2.4.7
Regulating water balance	1.2.4.8

Water in the body 1.2.4.7

OVERVIEW

Water plays a key role in the human body and it is regulated via the process of osmoregulation.

THEORY DETAILS

It's an often repeated fact that the average human body is between 55–60% water. So we know there's plenty of H_2O around, but what is H_2O? The answer – lots of different things!

Osmolality and our cells

All the cells in your body sit within **extracellular fluid**. The composition of this fluid has to be 'just right' for cells because, as we learned in lesson 6A, if their environment isn't optimal they'll cease to function properly. Water plays a key role in regulating this extracellular fluid to make it 'just right' for cells.

extracellular fluid the fluid outside of cells

There is a lot of water inside cells in the form of **intracellular fluid**, and it's important this fluid stays inside cells – it forms the cytosol in which all the organelles are suspended. If the extracellular fluid around a cell has a high **solute** concentration then water will rush out of the cell via **osmosis** – when this happens a cell is said to be **crenate**, and can't function normally. Conversely, if the extracellular fluid has a low solute concentration, then water will rush into the cell, causing it to swell and potentially even burst (Figure 1).

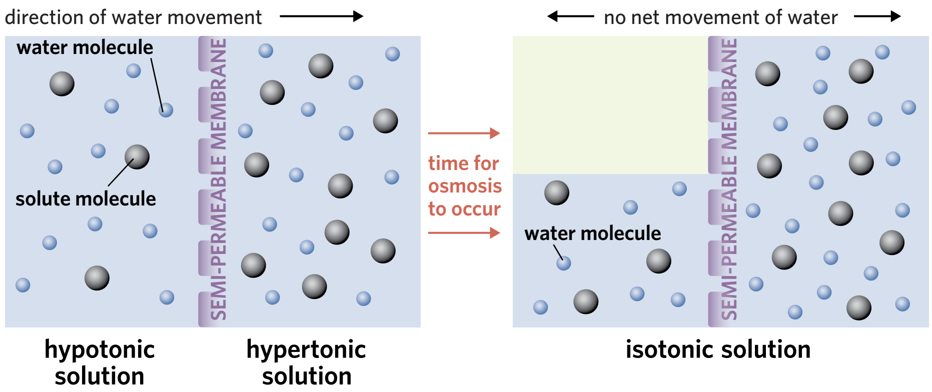


Figure 1 Water diffusing across a membrane via osmosis

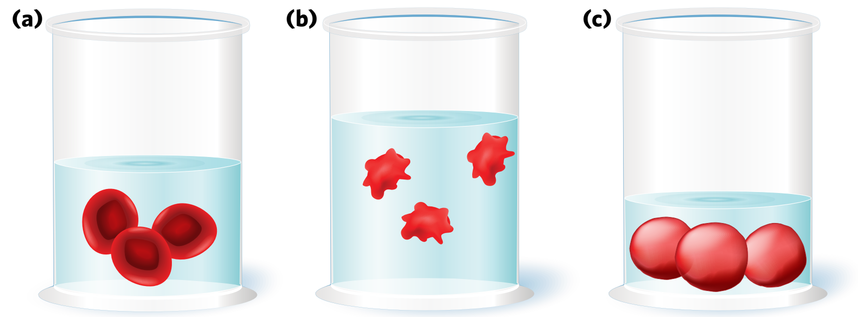


Image: Designua/Shutterstock.com

Figure 2 Osmosis can cause **(a)** normal cells to **(b)** lose water and crenate, or **(c)** gain water and swell.

Regulating water balance in the body can help prevent either of these things from happening by regulating the **osmolality** of the extracellular fluid. It's much easier for the body to alter the amount of water in extracellular fluids than it is to change the amount of solutes. Therefore, to keep osmolality within the optimal range, the amount of water present is regulated.

If more water is added to the extracellular fluid, its osmolality will decrease as the overall concentration of solutes will be lower. In other words, the extracellular fluid is being diluted. If water is removed from the extracellular fluid, its osmolality will increase as the overall concentration of solutes will be higher (Figure 3). By systematically increasing or decreasing the amount of water in extracellular fluid, the body can make sure that the extracellular fluid and intracellular fluid are **isotonic**, so that there is no net gain or loss of water from cells and the cells can function normally. The regulation of water balance for this purpose is called **osmoregulation**.

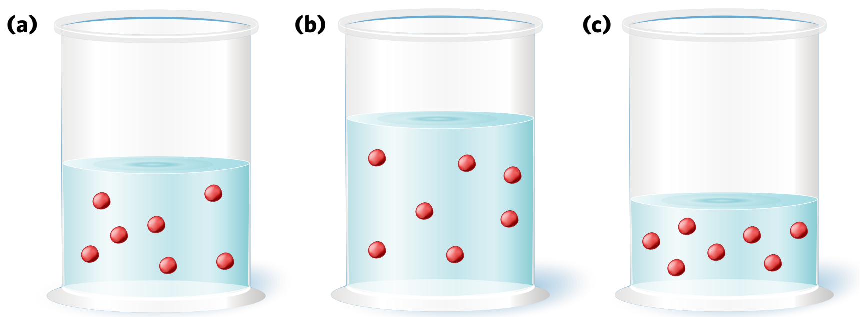


Image: Designua/Shutterstock.com

Figure 3 When water levels of **(a)** a solution are **(b)** increased, the concentration of that solution decreases, and when water levels are **(c)** decreased, the concentration of that solution increases.

intracellular fluid the fluid inside cells

solute a substance dissolved in the solvent

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

crenate the distorted shape taken by cells when exposed to a hypertonic environment

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

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

Lesson link

If the process of osmosis has diffused out of your memory, flick back to ***lesson 3B*** to reabsorb everything you need to know about it.

osmolality the total concentration of solute in a given weight of water

osmoregulation the homeostatic regulation of osmolality in the body via the alteration of water and solute balance

isotonic describes a solution with an equal solute concentration when compared to another solution

Other functions of water

Water isn't just useful for maintaining osmolality during osmoregulation, it also plays key roles in many other fundamental processes of the body. Some of these include:

- the production of urine – you'll recall from lesson 5D that water is a large component of urine
- the removal of waste heat via the evaporation of sweat – you should remember that in lesson 6B we discussed how evaporation is a key thermoregulatory mechanism (Figure 4)
- the maintenance of blood volume within the circulatory system – blood plasma is 92% water
- the protection of the brain and central nervous system – cerebrospinal fluid is a liquid that surrounds your brain and central nervous system, protecting it from harm when you fall over or bang your head along to your favourite song (Figure 5).

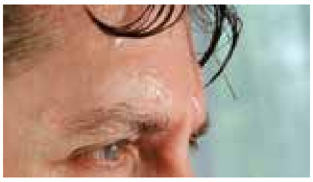


Image: Cliplab/Shutterstock.com

Figure 4 Can you see the fear in this man's eyes? He is nervous about losing too much water from sweating and the effect this will have on his extracellular fluid. Ironically, this is making him sweat even more.

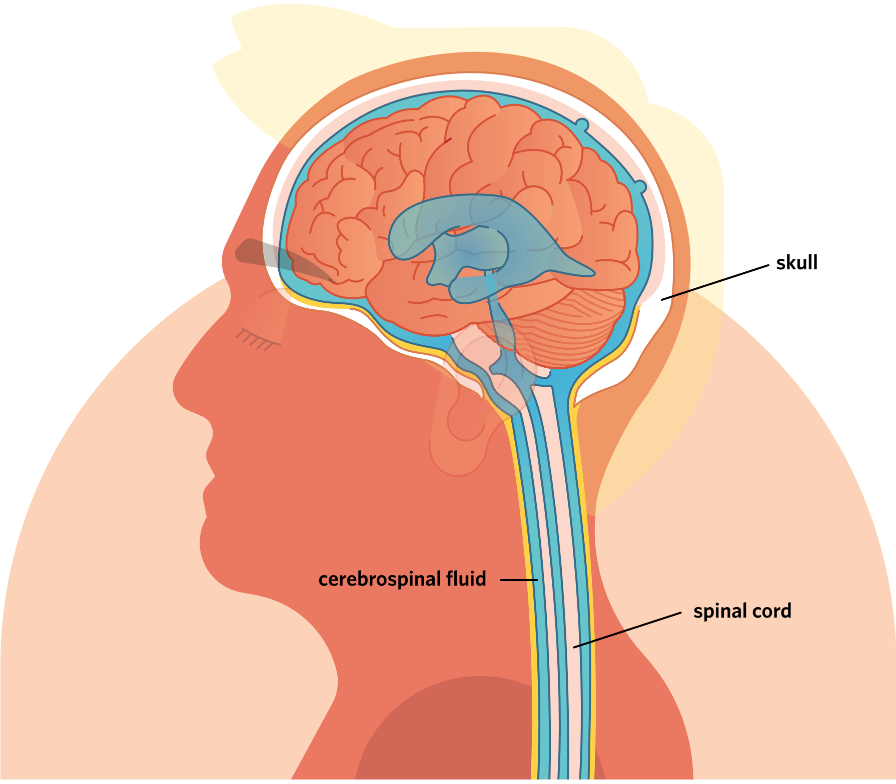


Image: VectorMine/Shutterstock.com

Figure 5 The brain and spinal cord are surrounded by cerebrospinal fluid, which is largely composed of water.

Regulating water balance 1.2.4.8

OVERVIEW

When too much or little water is present in the body, the normal amount of water will be restored via the stimulus-response models.

THEORY DETAILS

The total amount of water in a body is a balance of the water being put in, the metabolic water being produced, and the water that is lost.

total water change = water in + metabolic water – water out

Ideally the 'water in' plus the 'metabolic water' terms should be equal to the 'water out' term, meaning that there is no net gain or loss of water and by extension no overall change in osmolality. However, if you consume a large amount of salt (for example, if you eat an entire bag of chips) you will need more water to maintain a constant osmolality.

In order to maintain this balance of water and osmolality, the amount of water in the body is homeostatically controlled. Like all homeostatic mechanisms, the regulation of water in the body can be explained using a stimulus-response model (Figure 6).

- The stimulus is a change in the osmolality of blood or a change in blood volume and pressure, caused by a change in the volume of water in the body
- The receptors are **osmoreceptors** in the hypothalamus and **baroreceptors** in the aortic arch, the carotid artery in the neck, and in the kidneys. For the osmoreceptor pathway, there are two main modulators – the **hypothalamus** and the **pituitary gland**. For the baroreceptor pathway, cells in the kidneys serve as the modulators. Baroreceptors also send signals to the hypothalamus, adding to the effects of the osmoreceptor pathway
- The primary effectors are the cells of the distal convoluted tubule and collecting duct in the nephrons of the kidneys, and the hypothalamus
- The responses from these organs return the amount of water in the body to the set point.

osmoreceptor a type of receptor found primarily in the hypothalamus that detects changes in osmolality

baroreceptor a type of receptor found throughout the body that detects changes in blood pressure

hypothalamus a section of the brain in mammals that controls the maintenance of the body's internal environment

pituitary gland a gland in the brain that plays a large role in maintaining bodily functions by controlling the activity of several other endocrine glands

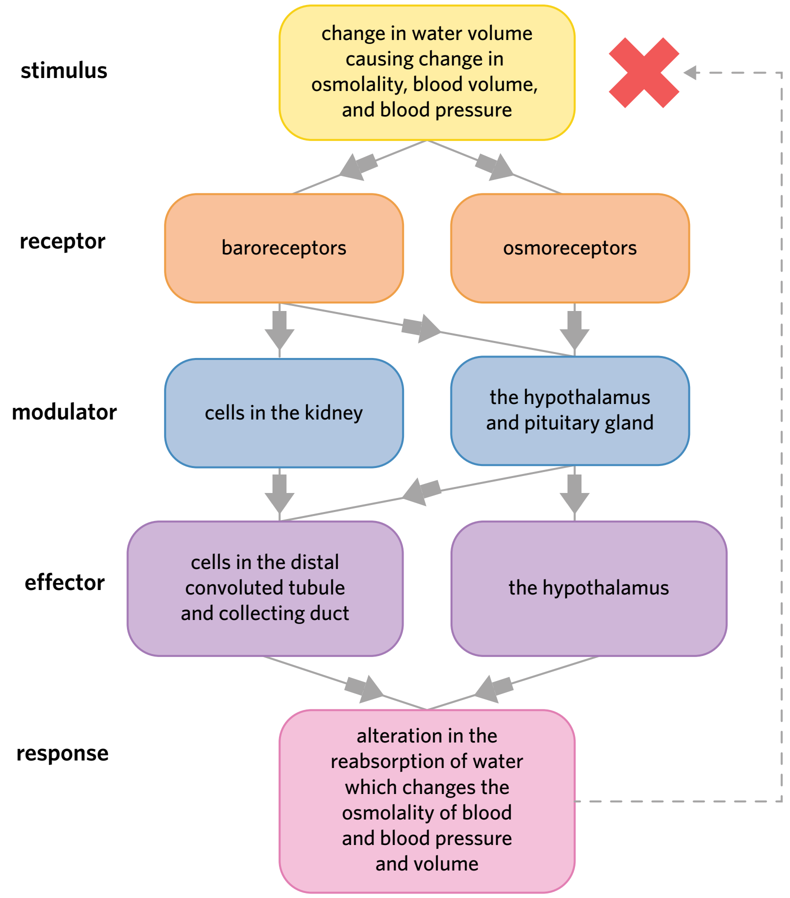


Figure 6 General stimulus-response model of water balance in the regulation of osmolality and blood pressure and volume

We'll now take a look at what happens when water levels in the body decrease and when water levels in the body increase separately.

What happens when water levels decrease?

When the amount of water in the body decreases, it causes both an increase in the osmolality of blood, and a decrease in blood pressure and volume. The increase in osmolality is detected by osmoreceptors in the hypothalamus, initiating a pathway involving the release of **antidiuretic hormone (ADH)**. The decrease in blood pressure and volume are detected by baroreceptors in the atria of the heart, the carotid artery in the neck, and in the kidneys, which stimulate the release of **renin**.

Antidiuretic hormone (ADH) pathway

Following increases in osmolality and detection by osmoreceptors, signals are sent to the posterior pituitary gland which causes the release of ADH. ADH has two primary effects. First – ADH increases water reabsorption in the nephrons of the kidney by increasing the number of **aquaporins** inserted into the cells of the distal convoluted tubule and collecting duct (Figure 7). As this water is reabsorbed back into the body, urine output is reduced and it becomes much more concentrated. Therefore, as the body retains more water, the osmolality of blood decreases.

antidiuretic hormone (ADH) a molecule secreted by the posterior pituitary gland in response to high solute concentrations in the blood. ADH increases the amount of water reabsorbed by the distal convoluted tubule and collecting duct and hence the amount of water conserved by the body. Also known as **vasopressin**

renin an enzyme secreted by the kidneys in response to low blood pressure and volume. Renin initiates a process which increases the reabsorption of water and sodium, and increases the excretion of potassium in the distal convoluted tubule and collecting duct

aquaporin a family of transmembrane proteins facilitating the transport of water into and out of a cell

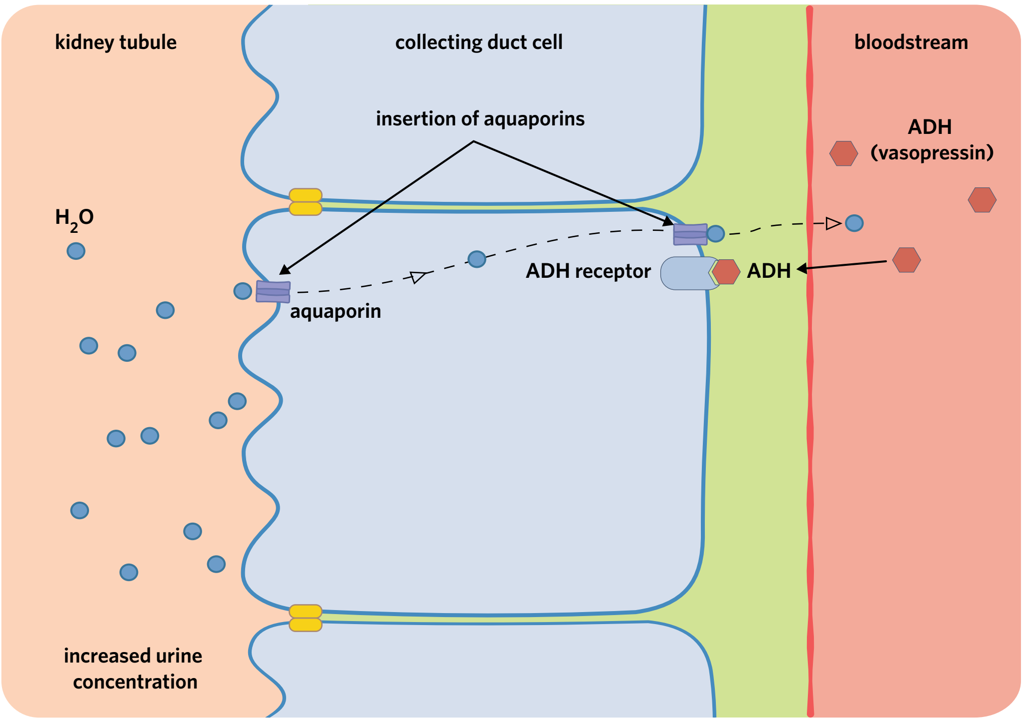


Image: ellepigrafica/Shutterstock.com

Figure 7 ADH increases the amount of water reabsorbed from the kidney filtrate in the distal convoluted tubule and collecting duct.

Second – ADH travels to the thirst centre in the hypothalamus. The thirst centre then generates the feeling of thirst, leading the person to drink something to increase the water volume in their body.

Secretion of renin

Decreases in blood pressure and volume are detected by baroreceptors, which cause two primary effects. First – baroreceptors send signals to the hypothalamus which contribute to the release of ADH from the posterior pituitary gland. Second – baroreceptors trigger the release of renin from the kidneys. Through a series of complicated reactions, renin causes the release of **aldosterone** from the adrenal glands. Aldosterone activates sodium-potassium pumps in the cells lining the distal convoluted tubule and collecting duct, increasing the amount of sodium absorbed in these areas and increasing the amount of potassium excreted in urine. Due to osmosis, water follows the movement of sodium from urine back into the bloodstream, increasing blood pressure and volume (Figure 8).

aldosterone a steroid hormone secreted by the adrenal gland following the release of renin. Aldosterone increases the reabsorption of water from kidney filtrate by increasing the reabsorption of sodium

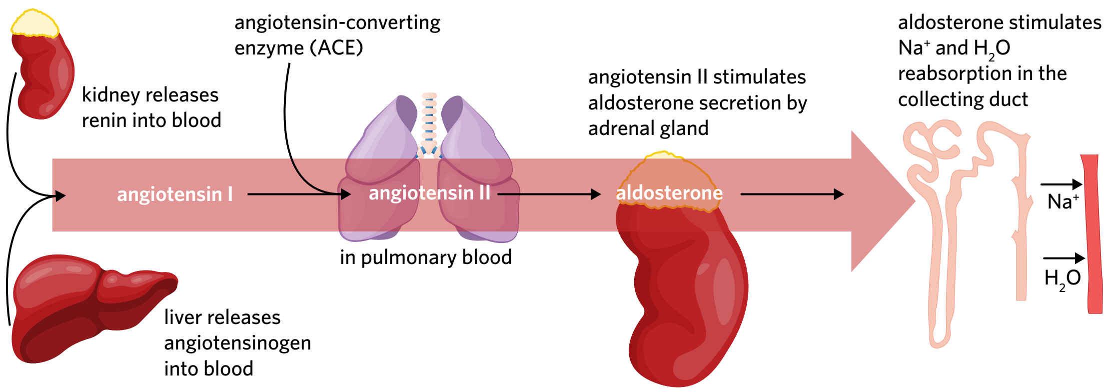


Image: VectorsBang/Shutterstock.com

Figure 8 The complex mechanism through which renin increases water reabsorption in the kidneys. You will note that there are terms present in this diagram such as 'angiotensinogen' that have not been presented in the theory of this lesson – they've been left here, however, just to illustrate that the conversion of renin to aldosterone is complicated and involves many different components.

The ADH pathway and renin systems are summarised in Figure 9.

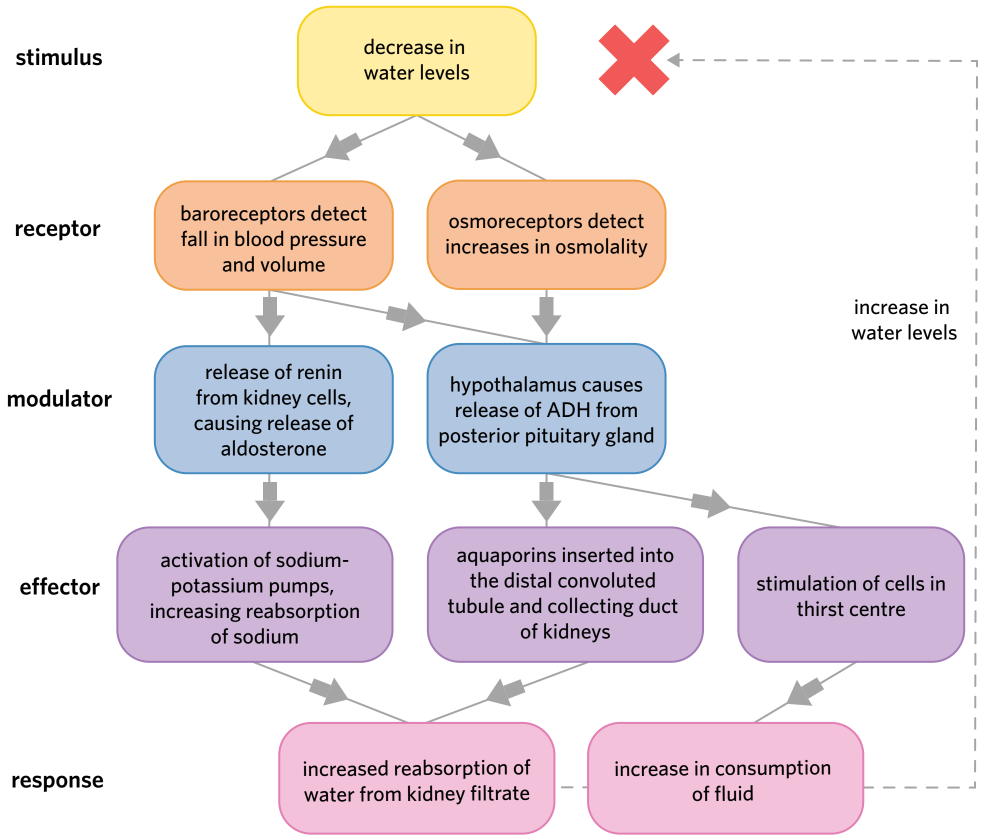


Figure 9 Methods used by the body to increase water levels

Memory device

ADH is secreted when you **A**re **D**e**H**ydrated, and ren**IN** is secreted when you want more water **in** your body!

What happens when water levels increase?

When the amount of water in the body increases, it causes both a decrease in the osmolality of blood, and an increase in blood pressure and volume. Decreases in osmolality are detected by osmoreceptors, and increases in blood pressure and volume are detected by the baroreceptors. In the case of too much water, these receptors signal the hypothalamus to decrease the release of ADH from the posterior pituitary gland. This means that fewer aquaporins will be inserted into the distal convoluted tubule and collecting duct, and solute concentrations in the tissue surrounding the nephrons will not increase. As a result of these changes, more water will be excreted in urine, lowering the total volume of water in the body (Figure 10).

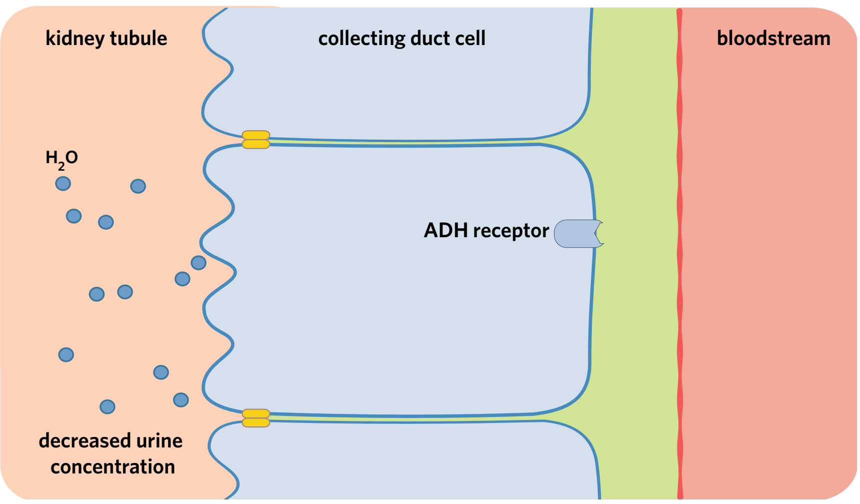


Image: ellepigrafica/Shutterstock.com

Figure 10 In the absence of ADH, kidney filtrate remains dilute and light-coloured urine is produced.

Additionally, the thirst centre in the hypothalamus is suppressed, and someone with too much water in their system will be less likely to consume liquid.

These processes are summarised in Figure 11.

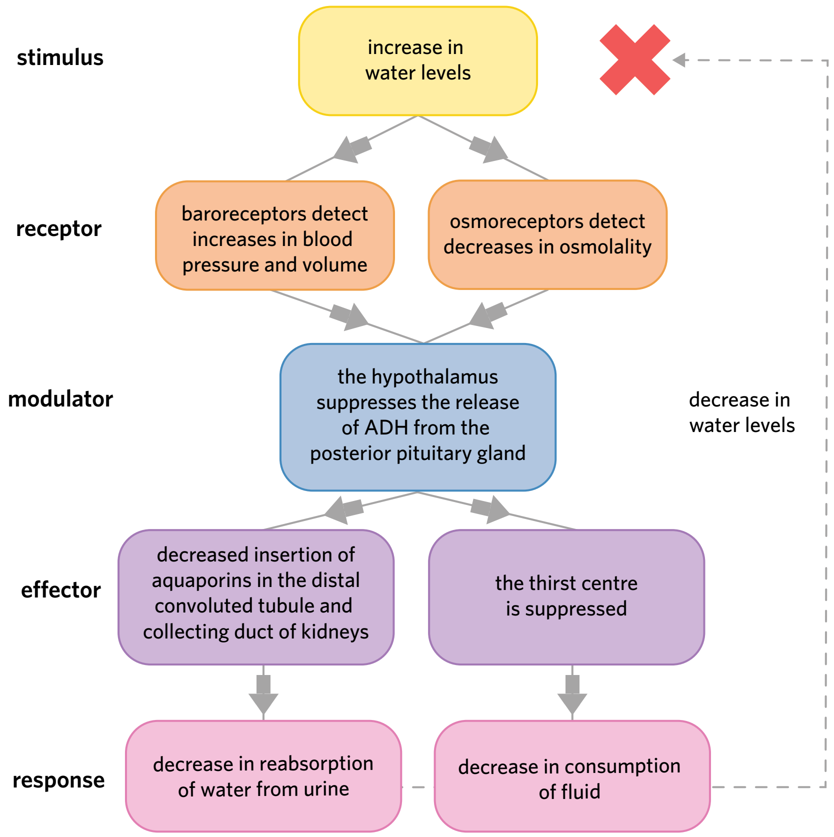


Figure 11 Methods used by the body to decrease water levels

Theory summary

Water balance is homeostatically controlled in the body. When water levels are too low, ADH and renin increase the reabsorption of water from kidney filtrate back into the bloodstream. When water levels are too high, the secretion of ADH is suppressed, increasing the amount of water excreted by the kidneys in urine.

Currently, we don't know exactly what causes a hangover, although one big contributing factor to feeling horrible the day after heavy drinking is dehydration. Ethanol, the fancy chemistry name for the alcohol present in alcoholic beverages, reduces the secretion of ADH. With less ADH present the kidneys reabsorb less water from their urine, meaning that a person who has drunk alcohol loses much more water.

Everyone swears by a different method of curing hangovers. Some people think drinking raw egg yolks helps. Some other people swear by a greasy bacon sandwich. Cutting edge science suggests two methods to reduce the severity of a hangover. People can 1) drink plenty of water when drinking alcohol to prevent dehydration or 2) drink less alcohol, or avoid it completely.

The only form of double-parking backed by science.

Image: Pixelspieler/Shutterstock.com

6D QUESTIONS

Theory review questions

Question 1

Osmoregulation is a method of water balance in which

A receptors detect the concentration of solutes in the blood.

B receptors detect the concentration of water in the body.

Question 2

Which of the following is true of a cell surrounded by hypertonic fluid?

A water will diffuse out of the cell, causing it to crenate

B water will diffuse into the cell, causing it to swell

Question 3

Which of the following are effectors in the water regulation system? (*Select all that apply*)

I water

II aquaporins

III osmoreceptors

IV the hypothalamus

V cells in the thirst centre

Question 4

Fill in the blanks with the following terms.

- distal convoluted tubule and collecting duct
- thirst centre
- osmoreceptors
- aquaporins
- antidiuretic hormone

When __________ detect an increase in osmolality, increased amounts of __________ are released from the posterior pituitary gland. This causes __________ to be inserted into the __________, increasing the amount of water reabsorbed from kidney filtrate. It also travels to the __________ to stimulate the sensation of thirst.

Question 5

Order the steps to correctly describe the response to a decreased amount of water in the body.

I Aldosterone alters the reabsorption of sodium in the nephrons of the kidneys.

II Renin causes a number of cellular reactions to occur.

III Baroreceptors detect an increase in blood pressure.

IV Increased amounts of water are reabsorbed.

V Renin is secreted by cells in the kidneys.

Question 6

Fill in the blanks in the following sentences.

Increased amounts of water in the body causes a __________ in osmolality. This __________ the release of ADH, leading to a __________ in the number of aquaporins in the distal convoluted tubule and collecting duct. As a result of this, __________ water is reabsorbed by the kidneys.

SAC skills questions

Case study analysis

Use the following information to answer Questions 7–13.

Diuretics are a type of drug that increases the production of urine. There are many different types of diuretics, and their mechanisms of action vary dramatically. Many diuretics alter the homeostatic processes that regulate water balance in the body.

In some sports, athletes use diuretics to gain a competitive advantage. For example, in sports with weight categories such as boxing, athletes may use diuretics to lose a large amount of water. The goal is to reduce body weight and be placed in a lower body-weight category. Theoretically, the athletes gain an advantage as their true weight would be greater than others in this lower weight category.

Other athletes sometimes use diuretics to mask the presence of performance-enhancing drugs in their system. Many tests for performance-enhancing drugs detect traces of the drug in athletes' urine. By increasing the water content in their urine, the concentration of the metabolites of performance-enhancing drugs decreases, making their presence harder to detect.

Question 7

Diuretics cause

A increased amounts of urine to be produced.

B decreased amounts of urine to be produced.

Question 8

Diuretics are banned in some sports because they

A cause rapid weight gain, allowing an athlete to be placed in a higher weight category they would otherwise be too light for.

B cause rapid weight loss, allowing an athlete to be placed in a lower weight category they would otherwise be too heavy for.

Question 9

Athletes taking diuretics would produce

A dilute urine.

B concentrated urine.

Question 10

In athletes using diuretics, it's likely that their osmoreceptors would detect

A an increase in blood osmolality.

B a decrease in blood osmolality.

C no change in blood osmolality.

Question 11

Spironolactone is a diuretic that inhibits the action of aldosterone. As a result of this

A sodium will be excreted in higher concentration, however water reabsorption will not be affected.

B sodium will be reabsorbed more, increasing the amount of water reabsorbed.

C sodium will be reabsorbed less, increasing the amount of water excreted.

Question 12

Athletes using diuretics run the risk of becoming

A dehydrated as they are losing too much water in their urine.

B overhydrated as the concentration of water in their urine is reduced.

Question 13

A mechanism through which a diuretic may increase the volume of urine produced could be

A by decreasing the insertion of aquaporins in the collecting duct.

B by stimulating the ADH receptor in the kidney.

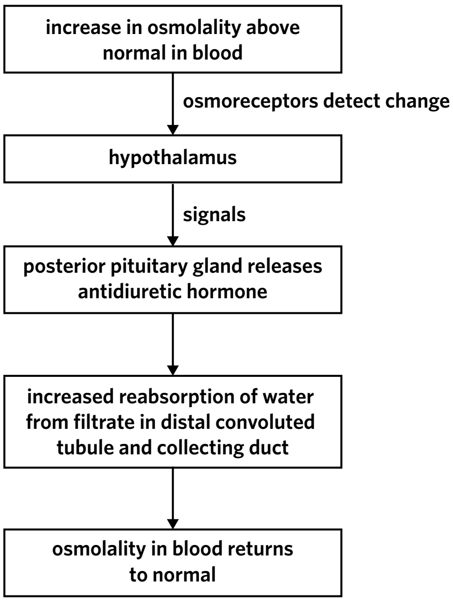
C by causing the release of renin.

Exam-style questions

Within lesson

Use the following information to answer Questions 14 and 15.

The diagram shows the regulation of water balance in the body.



Question 14 (1 MARK)

Based on the information provided, the modulator in the regulation of water would be the

A osmoreceptors.

B posterior pituitary gland.

C increase in osmolality above normal in blood.

D increased reabsorption of water from urine in the collecting duct.

Adapted from VCAA 2004 Exam 1 Section A Q21

Question 15 (1 MARK)

When the osmolality in blood returns to normal it would be reasonable to conclude that the

A posterior pituitary gland stops releasing all antidiuretic hormone.

B levels of antidiuretic hormone increase.

C kidneys stop reabsorbing water.

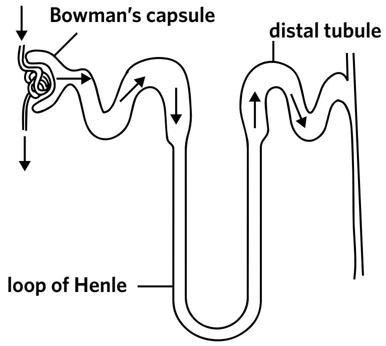
D number of aquaporins reduces.

Adapted from VCAA 2004 Exam 1 Section A Q22

Multiple lessons

Question 16 (1 MARK)

The kidneys play a vital role in homeostasis in mammals. The basic functional unit of a mammalian kidney is a nephron which is shown in the following diagram.



Normal functioning of a nephron relies on

A an increase in renin production as blood pressure rises.

B the secretion of antidiuretic hormone by the hypothalamus.

C a concentration gradient established within the distal tubule.

D an increase in water movement from distal tubules as antidiuretic hormone increases in the blood.

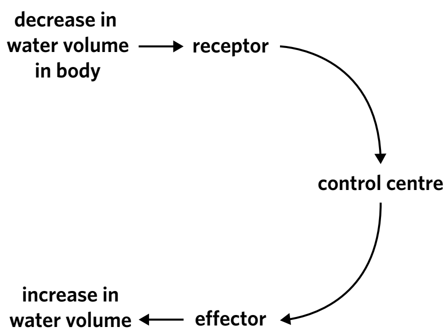
Adapted from VCAA 2004 Exam 1 Section A Q24

Question 17 (4 MARKS)

Homeostasis helps to maintain a constant internal environment in multicellular organisms.

a Explain the type of feedback utilised by homeostatic mechanisms. (2 MARKS)

b The diagram summarises the response to an increased blood plasma osmolality.



One example of an effector in this system is the activation of sodium pumps in the distal convoluted tubule and collecting duct in the nephrons.

i Describe how this effector brings about an increase in water volume in the body. (1 MARK)

Adapted from VCAA 2002 Exam 1 Section 2 Q4bi

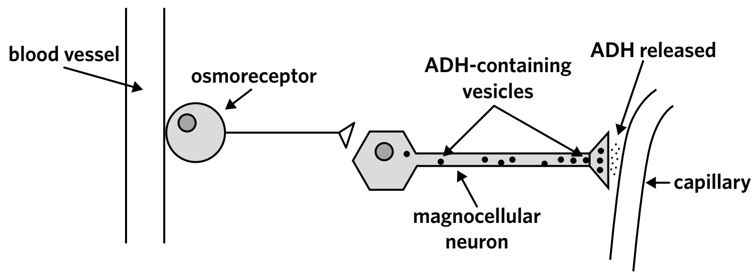
ii Apart from sodium pumps, state one other effector that would be involved in the increase in water volume in the body. (1 MARK)

Adapted from VCAA 2002 Exam 1 Section 2 Q4bii

Key science skills and ethical understanding

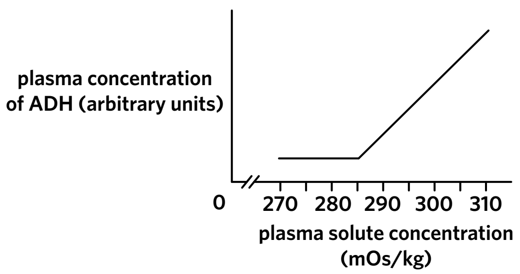
Question 18 (8 MARKS)

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. This process is shown in the diagram.



To find out more about the secretion of ADH, a group of scientists recruited 100 participants. Participants were not allowed to consume any food or liquid during the experiment. Over the experiment, as their water levels decreased their plasma solute concentration was measured, as was their plasma level of ADH.

The graph shows the average concentration of ADH in the blood of participants at different plasma solute concentrations.



Adapted from VCAA 2016 Exam 1 Section A Q14

a How does ADH help to regulate blood plasma solute concentration? (3 MARKS)

b Explain the trend seen in the graph, and describe the result this would have on the reabsorption of water from kidney filtrate in the participants. (2 MARKS)

c The scientists, as it turns out, didn't seek proper ethics approval to conduct their experiment. Based on the information provided, give an example of an ethical concept that may have been jeopardised by the experimental design, and identify a concern that the ethics committee may have had. (2 MARKS)

d Identify the dependent variable in this experiment. (1 MARK)

6E MALFUNCTIONS IN HOMEOSTASIS

The jelly bean. The most delicious yet overlooked member of the bean family. While all its brothers and sisters are busy packing fibre into their bodies and being overachieving 'superfoods', the humble jelly bean is just finding its own path in life. But what if I told you that for some people, jelly beans are a literal lifesaver? How many 'superfoods' can claim THAT?

A balanced diet should consist of eating foods of all different colours.
Image: Graeme J. Baty/Shutterstock

Lesson 6E
In this lesson you will learn about type 1 diabetes and hyperthyroidism, two diseases caused by malfunctions in homeostatic mechanisms

◀ *Prerequisite knowledge*

Lesson 5D
The functioning of the excretory system is altered in people with diabetes.

Chapter 6
Type 1 diabetes and hyperthyroidism are diseases that occur when homeostasis malfunctions.

Future applications ▶

Year 12
Malfunctions in homeostasis are often caused by the immune system losing its ability to distinguish between self and non-self cells, causing immune cells to attack vital cells, tissues, and organs.

Year 12
Bacteria can be genetically modified to produce human insulin, which can be used to treat hyperglycaemia caused by malfunctions in homeostasis.

Study design dot point

- malfunctions in homeostatic mechanisms: type 1 diabetes, hypoglycaemia, hyperthyroidism

Key knowledge units

Type 1 diabetes and hypoglycaemia	1.2.5.1
Hyperthyroidism	1.2.5.2

Type 1 diabetes and hypoglycaemia 1.2.5.1

OVERVIEW

Type 1 diabetes occurs when the body's immune system destroys insulin-secreting beta cells in the pancreas. This prevents the normal homeostatic processes that regulate blood glucose levels from occurring.

THEORY DETAILS

Homeostasis is a very delicate process. It relies on many different cells and organs working together to regulate multiple different body systems to keep the internal environment of the body stable. It should come as no surprise to you to learn that if any one part of the homeostatic pathway is damaged or malfunctions in any way, the whole regulatory pathway gets thrown out of whack and disease can occur. One of the most common diseases caused by a malfunction in homeostatic mechanisms is **type 1 diabetes**.

type 1 diabetes an autoimmune disease in which beta cells of the pancreas are destroyed, resulting in an inability to regulate blood glucose levels

What is type 1 diabetes and what causes it?

Type 1 diabetes is an **autoimmune disease** in which the body's immune system recognises **beta cells** in the pancreas as non-self and attacks them using **autoantibodies** (Figure 1). As a result of this, people with type 1 diabetes produce very little or no insulin, which means their blood glucose levels are left unregulated. Additionally, the neighbouring **alpha cells** are also impaired and can no longer function properly.

One of the leading theories is that a person may have an underlying genetic predisposition to developing type 1 diabetes, and that exposure to a viral infection of some kind could lead to the development of the condition.

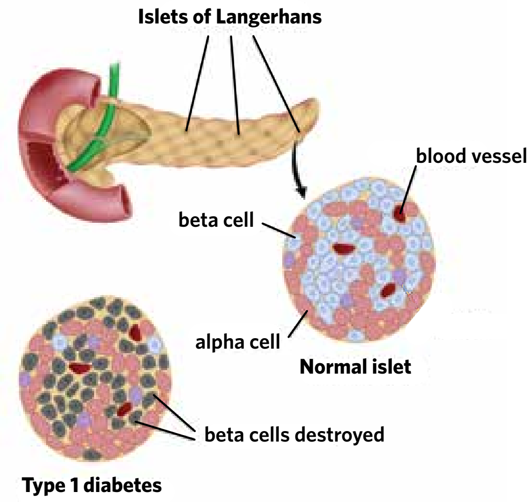


Image: Alila Medical Media/Shutterstock.com

Figure 1 In type 1 diabetes, beta cells in the pancreas are destroyed by autoantibodies.

autoimmune disease a disease in which an individual's immune system initiates an immune response against their own cells

beta cells cells that occupy the islets of Langerhans and secrete insulin

autoantibodies proteins created by the immune system that destroy an organism's own tissues

alpha cells cells that secrete the hormone glucagon

Lesson link

Beta cells are responsible for the production of insulin and the uptake of glucose. If your knowledge of glucose regulation has gluca-gone from your memory, it's probably best to revise ***lesson 6C*** before continuing or else things might get a little confusing.

Theory in context

TYPE 2 DIABETES

Another form of diabetes, called **type 2 diabetes**, also exists. Type 2 diabetes is caused by two factors:

- Firstly, the beta cells of people with type 2 diabetes don't produce enough insulin to meet the body's demands
- Secondly, the cells of type 2 diabetics are thought to be insulin-resistant – that is, the cells in their muscle, liver, and fat tissues don't respond normally to insulin, meaning they don't absorb glucose from the blood normally (Figure 2).

Whereas type 1 diabetes is an autoimmune disease, type 2 diabetes is currently thought to be caused by a combination of lifestyle and genetic factors. It typically occurs later in life, usually beginning around middle to older age. Fortunately, for people with type 2 diabetes, their condition can largely be controlled by altering their diet and exercise levels. If, however, their blood sugar levels remain uncontrolled some may require medication or insulin therapy.

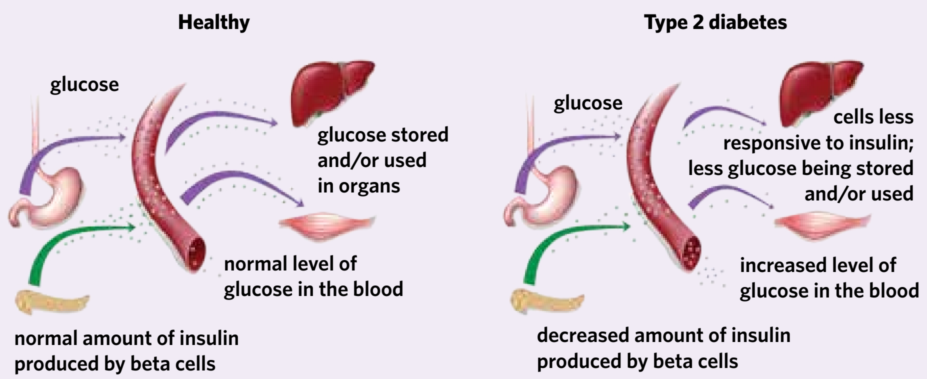


Image: Alila Medical Media/Shutterstock.com

Figure 2 In type 2 diabetes, cells become less sensitive to insulin and less insulin is produced by the pancreas. Note the build-up of glucose (hyperglycaemia) in the bloodstream of the type 2 diabetic.

type 2 diabetes a disease in which the body becomes resistant to the effects of insulin and/or doesn't produce enough insulin to maintain normal blood glucose levels

Symptoms of type 1 diabetes

As a result of beta cell attack, people with type 1 diabetes are insulin deficient. This can lead to the development of either **hyperglycaemia** or **hypoglycaemia**.

hyperglycaemia the state of having blood glucose levels above the normal range (>7.8 mmol/L)

hypoglycaemia the state of having blood glucose levels below the normal range (<4.0 mmol/L)

Hyperglycaemia

Insulin is important for the regulation of blood glucose levels – it facilitates the entrance of glucose into cells as well as the production of glycogen. Because glucose can't be absorbed by people with type 1 diabetes, they are at risk of hyperglycaemia. In the short term, this can cause a number of symptoms including:

- increased urination and excessive thirst – if levels of glucose in the blood are high, glucose can push through the walls of the glomerulus and end up in the kidney filtrate. The presence of glucose in the filtrate increases its osmolality, meaning that the normal osmotic processes that reabsorb water in the nephron don't function properly. As a result, water remains in the filtrate and a larger amount of dilute urine is produced (Figure 3). This can cause a person with type 1 diabetes to lose large amounts of water, become dehydrated, and feel thirsty
- excessive hunger and lethargy – because their cells aren't receiving the glucose they need to function properly, people with type 1 diabetes often feel tired and lethargic. In an attempt to correct the lack of glucose entering the system, the body stimulates the sensation of hunger
- weight loss – the loss of large amounts of water and the inability of cells to grow and function normally due to a lack of glucose can lead to weight loss in people with type 1 diabetes.

Image: Alexander Raths/Shutterstock.com

Figure 3 Back in the 'good old days' doctors used to have to taste people's urine to see if it contained glucose. An English doctor named Thomas Willis once wrote in 1674 that the urine of a person with diabetes was 'wonderfully sweet as if it were imbued with honey or sugar.' Fortunately nowadays a dipstick test can be used instead.

Lesson link

If urine doubt about the formation of urine and the regulation of water in the body, turn back to ***lessons 5D*** and ***6D*** to refresh your memory.

Hyperglycaemia can also have many long term consequences. Elevated levels of blood glucose in patients with long term uncontrolled diabetes damages blood vessels. Damage to the blood vessels can increase the risk of developing a number of conditions including:

- vision loss – the tiny vessels carrying blood to the eye become damaged and leaky, leading to swelling and reduced blood flow (Figure 4)
- heart disease and stroke – the blood vessels supplying the heart and brain can become damaged and blocked, causing cells to be deprived of oxygen and die
- tingling or numbness in the feet and/or hands – nerves are sensitive to elevated blood glucose levels and can become damaged
- prolonged wound healing – the damaged blood vessels in people with long term uncontrolled diabetes mean that injuries and wounds take longer to heal. Sometimes, in people with severe long term diabetes, their wounds simply don't heal at all
- kidney damage – the blood vessels that carry blood to the kidney are very small and sensitive, and can easily be damaged by increased blood glucose levels.

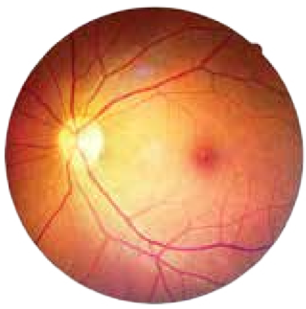


Image: Anukool Manoton/Shutterstock.com

Figure 4 In patients with long term uncontrolled blood glucose levels, the delicate blood vessels carrying blood to their eye can become damaged.

Hypoglycaemia

Hypoglycaemia occurs when blood sugar levels drop below 4.0 mmol/L. People with type 1 diabetes can become hypoglycaemic if they inject too much insulin, or if they exercise too much or don't consume enough glucose. In addition, because their alpha cells are impaired, people with type 1 diabetes don't produce normal levels of glucagon, meaning that they do not produce normal amounts of glucose via glycogenolysis in periods of fasting and their blood glucose level continues to fall.

Hypoglycaemia is a very dangerous condition. Without enough glucose, cells don't have enough energy to function. This can cause the individual to feel weak and dizzy, and can even result in them losing consciousness or dying if glucose levels aren't corrected quickly (Figure 5).

Image: Luis Molinero/Shutterstock.com

Figure 5 When hypoglycaemic, diabetic patients need to quickly elevate their blood glucose levels, usually by eating a lolly or drinking some juice. But remember, don't take candy from strangers, unless they're wearing a lab coat and/or you're hypoglycaemic. In which case, do!

Management of type 1 diabetes

Management of type 1 diabetes involves returning the patient's insulin levels, and therefore their blood glucose levels, back to normal and maintaining them within their homeostatic set points. The main way this is done is through insulin replacement therapy.

Insulin replacement therapy involves diabetic patients artificially altering their insulin levels to regulate their blood glucose levels. One way this can be done is by having patients measure their blood glucose levels via a finger prick test. If they are hyperglycaemic the patient calculates the amount of artificial insulin they need to inject themselves with to ensure normal homeostatic glucose regulation (Figure 6).

insulin replacement therapy the injection of insulin to maintain blood glucose levels within normal limits

There are many different types of artificial insulin available, and each works differently – some are said to be long-acting, ensuring consistent glucose uptake by cells over extended periods of time (typically about 24 hours); while others are short-acting, and begin working in the body very quickly after injection, resulting in high amounts of glucose being transported into cells over a relatively short period of time (usually between 5 – 8 hours). Typically, a person with type 1 diabetes will use both short- and long-acting insulin to maintain their blood glucose levels over the course of a day.

Image: goffkein.pro/Shutterstock.com

Figure 6 A person with diabetes injecting themselves with insulin

Alternatively, the levels of insulin can be managed by an insulin pump. This involves a sensor being placed under the skin that constantly monitors the blood glucose level of the patient. When levels rise above normal, the pump automatically injects the appropriate amount of insulin to return blood glucose levels back to normal (Figure 7).

Image: Roman Zaiets/Shutterstock.com

Figure 7 A diabetic man with an insulin pump attached

Hyperthyroidism 1.2.5.2

OVERVIEW

Hyperthyroidism is a condition caused by an overactive thyroid gland. As a result, increased amounts of thyroid hormones are secreted into the body, causing a wide range of symptoms.

THEORY DETAILS

The thyroid gland plays a key role in a number of different processes in the body. As such, its functioning is tightly regulated as part of maintaining homeostasis. Let's take a closer look at the thyroid gland now and find out exactly how homeostatic mechanisms regulate its function.

The thyroid gland

The **thyroid gland** is a small butterfly-shaped gland located in the base of the neck and is part of the **endocrine system**. It secretes two hormones – **triiodothyronine (T3)** and **thyroxine (T4)** – both of which are made from the amino acid tyrosine and iodine.

These hormones go on to have a wide range of effects throughout the body (Table 1). As such, the functioning of the thyroid gland is tightly regulated. Figure 8 depicts the overall thyroid regulation pathway.

thyroid gland a butterfly-shaped gland in the neck that produces hormones that influence metabolic rate

endocrine system the collection of glands in animals responsible for producing hormones that can be transported in the bloodstream to regulate distant organs/cells

triiodothyronine a hormone produced and secreted by the thyroid gland. Also known as **T3**

thyroxine a hormone produced and secreted by the thyroid gland. Also known as **T4**

Table 1 The role of thyroid hormones in the body

Component of body	Effect of normal level of thyroid hormones
Basal metabolism	Promotion of normal heat production and oxygen consumption by cells
Nutrient metabolism	Metabolism of glucose, lipids, and proteins
Nervous system	Development of the nervous system in a developing foetus, and allows for the normal functioning of the nervous system in adults
Cardiovascular system	Regulation of heart rate
Respiratory system	Regulation of respiratory rate
Musculoskeletal system	Development and function of muscles and bone
Gastrointestinal system	Aids in the regulation of muscle coordination and secretion of digestive juices
Reproductive system	The functioning of the reproductive system, including the thickening of the **endometrium** in females

endometrium the lining of the uterus

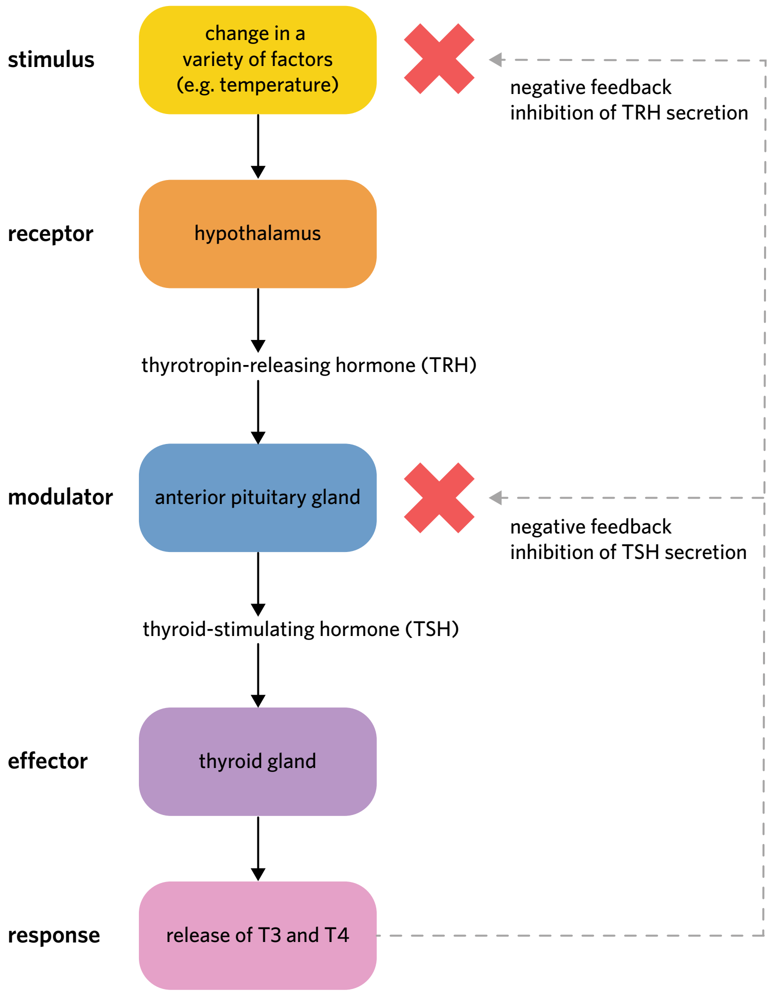


Figure 8 A general stimulus-response model overview of the thyroid gland

Lesson link

The hypothalamus is sensitive to a number of different stimuli. If we think back to ***lesson 6B***, we learned that when the body detects a decrease in core temperature it increases basal metabolism. The way it does this is that the hypothalamus increases the release of TRH, which goes on to cause the increased release of thyroid hormones that alter the body's metabolism.

In a healthy individual, the hypothalamus periodically releases **thyrotropin-releasing hormone (TRH)**, which stimulates the anterior pituitary gland to secrete **thyroid-stimulating hormone (TSH)**. This goes on to stimulate the thyroid gland, which then secretes T3 and T4. T3 and T4 inhibit the secretion of TRH and TSH via negative feedback – if thyroid hormones levels in the blood increase, both the hypothalamus and the pituitary gland release less TRH and TSH respectively; alternatively if thyroid hormone levels drop, they secrete increased amounts of hormones until the desired levels are reached.

Sometimes, this delicately controlled pathway can malfunction and lead to disease. One example of such a disease is **hyperthyroidism**.

thyrotropin-releasing hormone a hormone released by the hypothalamus that stimulates the anterior pituitary gland. Also known as **TRH**

thyroid-stimulating hormone a hormone released by the anterior pituitary gland that stimulates the thyroid gland. Also known as **TSH**

hyperthyroidism overactivity of the thyroid gland, resulting in increased production and secretion of thyroid hormones

What is hyperthyroidism and what causes it?

Hyperthyroidism is a condition in which the thyroid gland produces too much T3 and T4. Individuals are diagnosed with hyperthyroidism via a blood test – people with hyperthyroidism will have elevated T3 and T4 levels in their blood, as well as reduced levels of TSH (the increased levels of thyroid hormones inhibit the secretion of TSH via negative feedback, as shown in Figure 8).

There are a number of different causes of hyperthyroidism. One of the most common causes is an autoimmune disease called **Graves' disease**. The immune system of people with Graves' disease produces an autoantibody called **thyroid-stimulating immunoglobulin (TSI)**. This antibody recognises and binds to the TSH receptors on the thyroid, stimulating the thyroid to release T3 and T4. As such, people with Graves' disease have elevated levels of thyroid hormones as their thyroids are constantly being stimulated to release hormones (Figure 9).

Graves' disease an autoimmune disease that causes hyperthyroidism

thyroid-stimulating immunoglobulin the antibody present in Graves' disease that is responsible for overstimulation of the thyroid gland. Also known as **TSI**

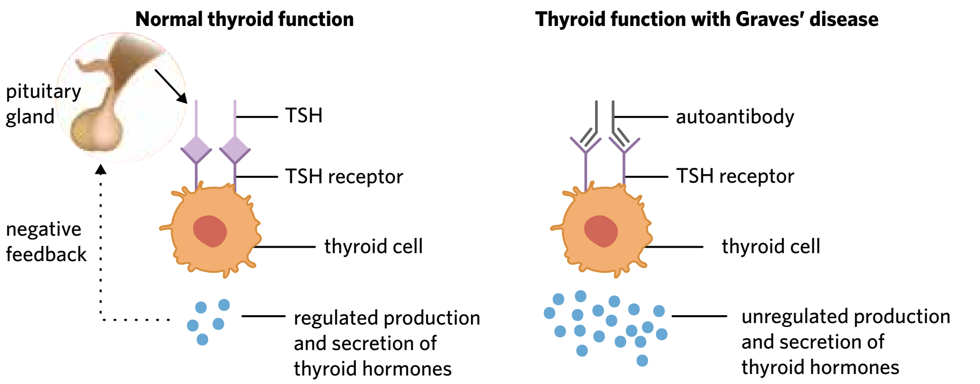


Image: Alila Medical Media/Shutterstock.com

Figure 9 In people with Graves' disease, an antibody binds to the TSH receptor and stimulates the thyroid gland to secrete hormones.

Symptoms of hyperthyroidism

Because thyroid hormones influence a variety of cells in the body, the symptoms of hyperthyroidism are many and varied. In general, excess thyroid hormones 'speed up' the body resulting in the symptoms shown in Table 2.

Table 2 The symptoms of hyperthyroidism

Component of body	Effect of elevated level of thyroid hormones
Basal metabolism	Increased metabolism, heat intolerance, sweating
Nervous system	Anxiety, irritability, difficulty sleeping
Cardiovascular system	Increased heart rate, palpitations, increased blood pressure
Respiratory system	Increased respiratory rate
Musculoskeletal system	Muscle pain, weakness, and atrophy; osteoporosis
Gastrointestinal system	Increased gastrointestinal motility, resulting in diarrhoea; vomiting
Reproductive system	Lighter menstrual flow and increased duration of menstrual cycle

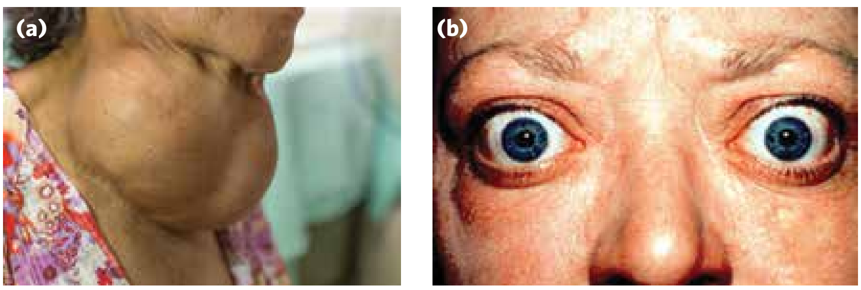


Image: Karan Bunjean/Shutterstock.com

Figure 10 People with hyperthyroidism may also have **(a)** an enlarged thyroid gland, known as a **goitre**; **(b)** people with Graves' disease might also experience **exophthalmos**, a condition in which their eyes bulge out of their sockets.

goitre a swelling in the neck caused by an enlarged thyroid gland

exophthalmos a symptom of Graves' disease in which the eyes of patients bulge out of their sockets

Theory in context

HYPOTHYROIDISM

In addition to secreting an excess of thyroid hormones, sometimes disease can occur when the thyroid produces reduced levels of hormones. This condition is called **hypothyroidism**, and results in 'the opposite' symptoms. Where in hyperthyroidism the body 'speeds up', in hypothyroidism the body 'slows down', resulting in symptoms such as weight gain, reduced energy levels, feeling cold, and poor memory and attention. The most common cause of hypothyroidism is iodine deficiency. Iodine is an important component of thyroid hormones, so if not enough iodine is consumed the levels of thyroid hormones drop. In a bid to increase the amount of iodine consumed in the diet, many foods such as table salt and bread have iodine added to them (Figure 11).

Image: digitalreflections/Shutterstock.com

Figure 11 It doesn't taste as good as chicken salt on chips, but iodised salt provides your body with the iodine it needs to synthesise thyroid hormones.

hypothyroidism a condition in which the thyroid gland is underactive, resulting in decreased production and secretion of thyroid hormones

Management of hyperthyroidism

There are a number of different approaches to managing hyperthyroidism depending on the cause. Some treatments aim to counteract the effects of increased hormones levels – for example, drugs like beta-blockers can be administered to reduce heart rate. Other medications called antithyroid drugs reduce the production of thyroid hormones.

Radioactive iodine is sometimes given to people with hyperthyroidism. Iodine is a key ingredient in the production of thyroid hormones, and is absorbed only by cells in the thyroid gland. By absorbing radioactive iodine, these cells are killed, reducing the amount of thyroid hormone produced and secreted. The most radical treatment option is surgical removal of the thyroid gland.

Some treatments for hyperthyroidism can result in hypothyroidism. To counter this, patients may need to take artificial thyroid hormones to increase their levels to within normal limits.

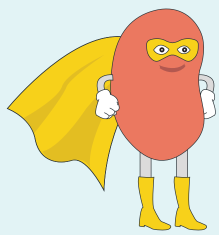
Memory device

Hyp**er**thyroidism makes things fast**er**, whilst hyp**o**thyroidism makes things go sl**o**w!

Theory summary

Diseases can arise when the processes of homeostasis malfunction. Type 1 diabetes occurs when the body's immune system destroys insulin-secreting beta cells in the pancreas, preventing the normal regulation of glucose. Hyperthyroidism occurs when the functioning of the thyroid gland becomes deregulated and produces excess amounts of thyroid hormones.

When a person with diabetes is hypoglycaemic, they need to quickly raise their blood glucose levels before they lose consciousness. This is where the humble jelly bean swoops in and saves the day. With their high sugar content, jelly beans can be used to quickly boost the blood glucose levels of these patients to within normal limits. So sure, whilst black beans and butter beans are 'healthier' for you, remember that there's only ONE member of the bean family who can save lives.



6E QUESTIONS

Theory review questions

Question 1

With type 1 diabetes, patients are no longer able to regulate the absorption of

A insulin.

B glucose.

Question 2

It is thought that type 1 diabetes occurs due to autoimmune destruction of

A alpha cells.

B beta cells.

Question 3

Fill in the blanks with the following terms.

- long-acting
- short-acting
- hypoglycaemia
- hyperglycaemia

In __________, patients have elevated blood glucose levels, whereas in __________ patients have low blood glucose levels. This can be managed using two forms of artificial insulin – __________ insulin, which acts for about 24 hours, and __________ insulin which acts for 5–8 hours.

Question 4

Which of the following are possible symptoms of hyperglycaemia? (*Select all that apply*)

I excessive urine production

II loss of consciousness

III feeling shaky

IV dizziness

V thirst

Question 5

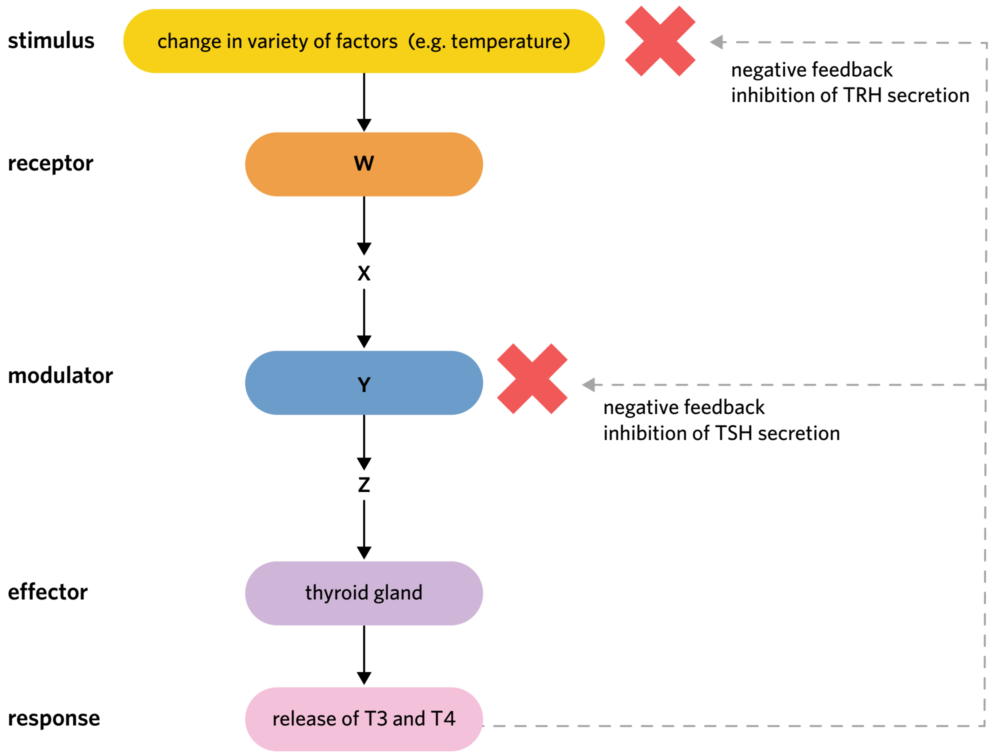
Hyperthyroidism occurs when the thyroid produces

A too much thyroid hormone.

B too little thyroid hormone.

Question 6

Label the parts of the stimulus-response model depicting the regulation of the thyroid gland.



Question 7

Which of the following are possible symptoms of hyperthyroidism? (*Select all that apply*)

I decreased duration of menstrual cycle
II palpitations
III weight gain
IV diarrhoea
V weakness

Question 8

Both type 1 diabetes and hyperthyroidism occur as a result of

A positive feedback.
B malfunctions in homeostasis.
C effector cells being overstimulated.

SAC skills questions

Scientific methodology comparison

Use the following information to answer Questions 9–15.

Hypothyroidism is a condition in which the thyroid doesn't produce enough thyroid hormones, and results in symptoms including hair loss, weight gain, fatigue, and depression. A team of scientists working in the United Kingdom wanted to examine whether there was any link between fluoridation of water and the incidence of hypothyroidism.

To do so, two methods were proposed by the team. In Method 1, the team would conduct an observational study in which they would focus on two areas of the United Kingdom, comparing an area with high levels of fluoridation to an area with a comparably low level of fluoridation. They would then compare the incidence of hypothyroidism between the two areas.

Method 2 involved the team sampling a large number of people with hypothyroidism in the United Kingdom, and grouping them according to a number of different factors including age, gender, health status, as well as whether they lived in an area with high fluoridation or not. They would then examine this data to see if there was a notably higher correlation between the level of fluoridation and the development of hypothyroidism irrespective of the other variables considered.

Question 9

In hypothyroidism the thyroid gland

A overproduces hormones.

B underproduces hormones.

Question 10

A symptom of hypothyroidism is

A fatigue.

B excessive urination.

Question 11

Fluoride and iodine belong to the same family of chemicals. Whilst fluoride has no major physiological function in the body, it is reasonable to hypothesise that in extremely high amounts

A fluoride may alter thyroid function.

B fluoride would have no effect on thyroid function.

Question 12

In both methods proposed the independent variable is

A the incidence of hypothyroidism.

B the level of fluoridation in water.

Question 13

The inclusion of other factors such as age and gender of participants in Method 2 addresses the potential impact on the findings in Method 1 caused by

A uncontrolled variables.

B independent variables.

C sources of error.

Question 14

Which method would produce a more scientifically accurate conclusion in regards to the relationship between water fluoridation and the development of hypothyroidism?

A Method 1

B Method 2

Question 15

In order for the scientists to conclude that there is a connection between fluoridation and hypothyroidism, they would need to demonstrate that

A in a laboratory thyroid cells die when exposed to high levels of fluoride.

B areas of high fluoridation have a significantly higher rate of hypothyroidism than areas of low fluoridation.

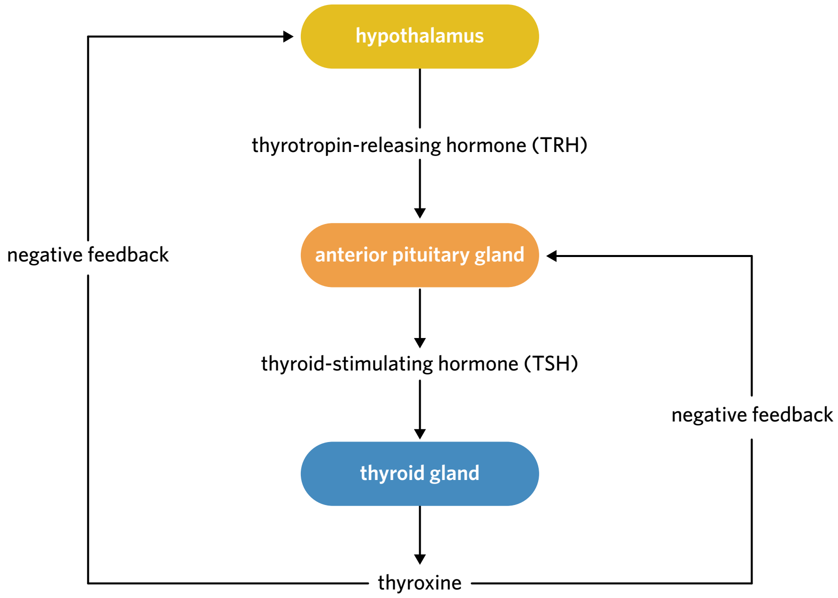
C exposure to higher levels of fluoridation leads to an increased likelihood of developing hypothyroidism irrespective of a person's age, gender, or health status.

Exam-style questions

Within lesson

Use the following information to answer Questions 16 and 17.

The following diagram shows the regulation of thyroxine secretion.



Question 16 (1 MARK)

A sufficient level of iodine is required by the thyroid gland to manufacture thyroxine.

It is reasonable to conclude that if a person who was previously iodine-deficient introduced sufficient levels of iodine into their diet

A their TRH levels would increase.

B their TSH levels would decrease.

C they would develop hyperthyroidism.

D their basal metabolic rate would decrease.

Question 17 (1 MARK)

When performing a blood test on a person with hyperthyroidism, you would expect to find

A decreased levels of thyroxine.

B decreased levels of TRH.

C a smaller hypothalamus.

D elevated levels of TSH.

Adapted from VCAA 2003 Exam 1 Section A Q14

Question 18 (3 MARKS)

Individuals with type 1 diabetes are treated with injections of a molecule that their body doesn't produce naturally. These injections are usually given several times each day.

A pump capable of delivering the molecule continuously in response to changing blood glucose concentration has been developed. The pump turns on and off automatically when the blood glucose changes.

a Identify the hormone that isn't produced by people with type 1 diabetes. (1 MARK)

b What would be the signal for the pump to turn off and cease delivery of the hormone? (1 MARK)

c Episodes of hypoglycaemia are reported to be less frequent in individuals when the pump is used rather than injections. Outline what is meant by the term hypoglycaemia. (1 MARK)

Adapted from VCAA 2004 Exam 1 Section B Q6

Multiple lessons

Question 19 (6 MARKS)

Regulation of blood glucose concentration relies upon insulin produced by specific cells in the Islets of Langerhans in the pancreas.

a State the type of cell responsible for the production of insulin in the pancreas. (1 MARK)

b Explain how insulin regulates blood glucose levels. (2 MARKS)

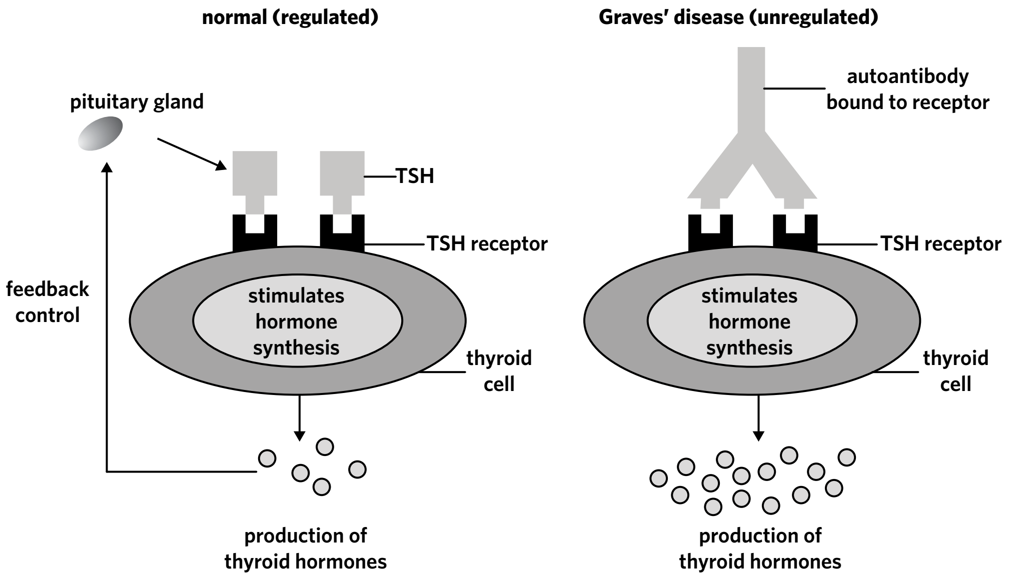
c Describe how type 1 diabetes affects the functioning of this cell, and the resultant effect this has on the homeostatic regulation of blood glucose. (2 MARKS)

d Insulin is secreted by the pancreas and regulates the activity of its target cell. To which group of molecules does insulin belong? (1 MARK)

Adapted from VCAA 2004 Exam 1 Section B Q6

Question 20 (5 MARKS)

The thyroid gland can be stimulated in a number of different ways. Graves' disease is an autoimmune disease in which the production of thyroid hormones by thyroid cells is unregulated. The following diagrams outline what occurs in regulated and unregulated thyroid cells. TSH stands for thyroid-stimulating hormone.



a How do autoantibodies alter the homeostatic regulation of the thyroid gland? (2 MARKS)

b The thyroid gland also gets stimulated during the process of thermoregulation when core body temperature decreases.

- **i** Outline the role played by the thyroid gland in thermoregulation. (2 MARKS)
- **ii** State one other response initiated by the body in response to a drop in core body temperature. (1 MARK)

Adapted from VCAA 2012 Exam 1 Section A Q20

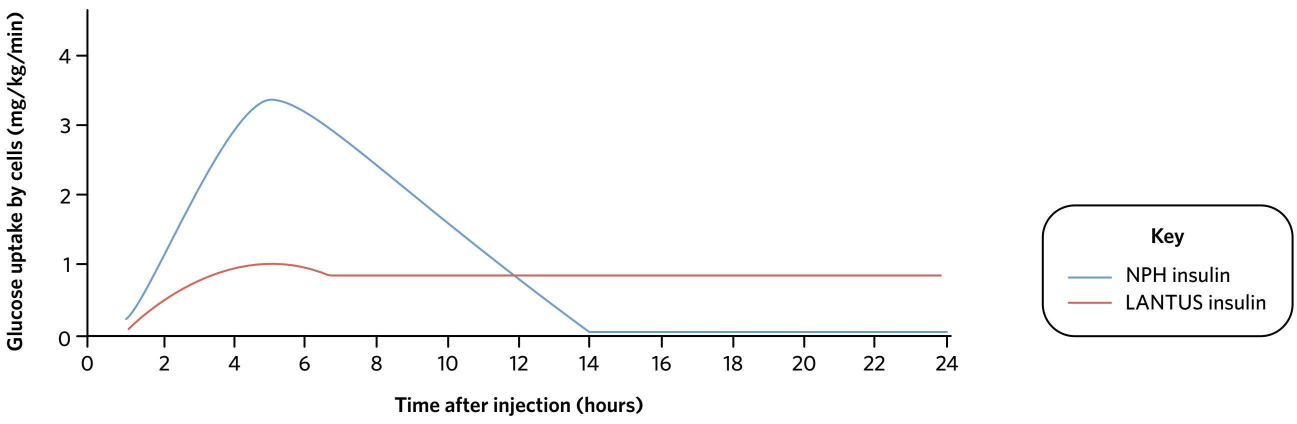
Key science skills and ethical understanding

Use the following information to answer Questions 21–23.

Insulin is a hormone involved in the regulation of blood sugar levels. Failure to produce insulin results in insulin-dependent diabetes, and persons with this disease must have regular injections of insulin. A common insulin used has been NPH insulin, which is administered between two to four times per day.

Recently the activity of a new type of insulin, called LANTUS insulin, has been tested and compared with NPH insulin. Participants in the test were divided into two groups. One group received NPH insulin, while the second group received LANTUS insulin. All participants received the same amount and concentration of the appropriate insulin.

The following graph shows the average results for participants in each of the two groups starting from one hour after the injection of insulin.



Question 21 (1 MARK)

After the injection, NPH insulin increased the glucose uptake by cells for

A 13 hours.

B 14 hours.

C 16 hours.

D 24 hours.

Question 22 (1 MARK)

Which of the following conclusions can be made based on the data provided?

A LANTUS insulin is better at regulating NPH insulin.

B After 6 hours NPH insulin no longer causes glucose uptake by cells.

C LANTUS insulin causes more glucose to be absorbed into cells than NPH insulin for 13 hours following the injection.

D At 16 hours after injection, the cells in a person with LANTUS insulin in their system will be absorbing glucose at a higher rate than a person with NPH insulin.

Question 23 (1 MARK)

A control group was not used because it was thought that depriving patients of insulin would expose them to unnecessary harm. Identify the bioethical principle that is likely to have informed this decision.

A justice

B integrity

C non-maleficence

D a consequences-based approach

CHAPTER 6 SUMMARY

Stimulus: core body temperature

Increased:

receptor	modulator	effector	response
thermoreceptors	hypothalamus	• sweat glands • small blood vessels in the skin • cerebral cortex • arrector pili muscles • cells	• sweating • dilation of arterioles • change in behaviour • flattening of hair • decrease in metabolic rate

negative feedback (increase in heat lost to environment and decrease in heat produced)

Decreased:

receptor	modulator	effector	response
thermoreceptors	hypothalamus	• skeletal muscle cells • small blood vessels in the skin • cerebral cortex • arrector pili muscles • cells • brown fat	• shivering • constriction of arterioles • change in behaviour • lifting of hair • increase in metabolic rate • burning of triglycerides

negative feedback (decrease in heat lost to environment and increase in heat produced)

Stimulus: blood glucose levels

Increased:

receptor and modulator	effector	response
Beta cells secrete insulin	• liver cells • skeletal muscles	• increased uptake of glucose • increased production of glycogen

negative feedback (blood glucose levels decreased)

Decreased:

receptor and modulator	effector	response
alpha cells secrete glucagon	liver cells	glycogen breakdown

negative feedback (blood glucose levels increased)

Stimulus: water levels in the body

Increased:

receptor	modulator	effector	response
• baroreceptors • osmoreceptors	hypothalamus suppresses the release of ADH	• decreased sodium reabsorption • thirst centre suppressed	• decreased water reabsorption • decreased water consumption

negative feedback (decrease in water levels)

Decreased:

receptor	modulator	effector	response
• baroreceptors • osmoreceptors	• kidney cells release renin • hypothalamus releases ADH	• increased sodium reabsorption • greater presence of aquaporins • thirst centre stimulated	• increased water reabsorption • increased water consumption

negative feedback (increase in water levels)

When homeostasis malfunctions

Type 1 diabetes

- Autoimmune destruction of beta cells in pancreas, resulting in inability to naturally produce insulin
- No longer able to homeostatically regulate blood glucose levels
- Can lead to development of hyperglycaemia (elevated blood glucose levels) and/or hypoglycaemia (low blood glucose levels)
- Typically managed with artificial insulin

Hyperthyroidism

- Overproduction and oversecretion of thyroid hormones by the thyroid gland
- Lack of homeostatic regulation of the thyroid

CHAPTER 6 SAC PRACTICE

SAC skills covered in this section:

✓ Case study analysis ✓ Data analysis ✓ Bioethical deep dive

THE NOT-SO-SWEET SIDE OF PREGNANCY (20 MARKS)

Pregnancy can cause a number of complications – swollen feet, needing to pee all the time, a sore back, weird cravings, not to mention the major complication of having a baby at the end of it. But did you know that women who are pregnant can also develop a type of diabetes called 'gestational diabetes'?

Gestational diabetes is a condition in which a pregnant woman develops high blood glucose levels during her pregnancy, despite not having diabetes prior to pregnancy. While it isn't exactly understood why the condition develops, many scientists believe that hormones associated with pregnancy interfere with the functioning of insulin, resulting in the development of insulin resistance.

The condition typically occurs in the last three months of pregnancy. Risk factors include being overweight, having a family history of diabetes, increased maternal age, and previously being diagnosed with gestational diabetes during an earlier pregnancy.

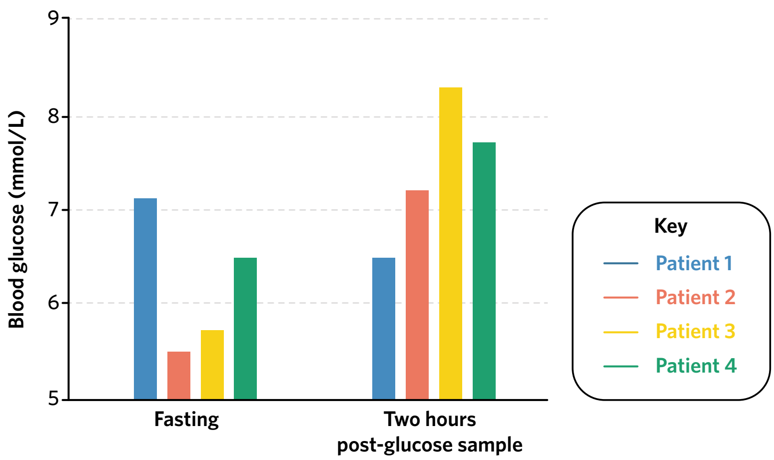
1 Explain the likely cause of gestational diabetes. (1 MARK)
2 Identify the cell type responsible for the production of insulin. (1 MARK)
3 Identify two short-term symptoms of hyperglycaemia. (1 MARK)
4 With reference to the normal homeostatic regulation of blood glucose, describe how hyperglycaemia would develop in a woman with gestational diabetes. (2 MARKS)

Testing for gestational diabetes is a two-step process. Firstly, pregnant women undergo a non-fasting glucose challenge test in which they drink 50 g of glucose in a flavoured drink over a ten minute period. One hour after drinking this solution, a specimen of blood is taken for measurement of plasma glucose levels. Women who have a glucose level of 7.8 mmol/L or more should then undergo an oral glucose tolerance test.

An oral glucose tolerance test requires the patient to fast (not eat or drink) for a period of 8 – 10 hours prior to the test. At the beginning of the test a blood sample is taken – this is called the fasting sample. The patient is then given a 75 g solution of glucose to drink within five minutes. After one hour, a second blood sample is taken, and another at two hours post-glucose consumption. The following table outlines how the results of this test are interpreted.

Reference intervals for conditions	Fasting sample	Two hour post-glucose sample
Normal (non-pregnant)	< 6.1 mmol/L	< 7.8 mmol/L
Impaired fasting glycaemia (non-pregnant)	6.1 – 6.9 mmol/L	< 7.8 mmol/L
Diabetes mellitus (non-pregnant)	≥ 7.0 mmol/L	≥ 11.1 mmol/L
Gestational diabetes	≥ 5.5 mmol/L	≥ 8.0 mmol/L

Four different women underwent an oral glucose tolerance test. Their results are shown in the graph.



5 Would a patient undertaking a glucose challenge test be allowed to have breakfast the morning of their test? Explain your reasoning. (1 MARK)

6 Explain the difference fasting would have on a blood glucose level result compared to non-fasting. (1 MARK)

7 Explain the trend seen in Patient 1's results, and account for what may have caused this. (2 MARKS)

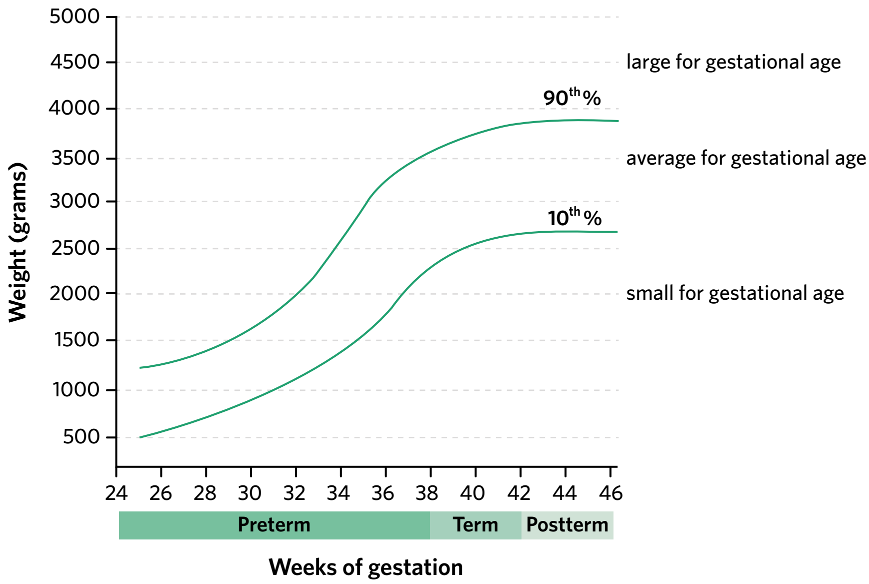
8 Complete the following table by interpreting the blood test results for Patients 2 – 4 based on the information provided. (3 MARKS)

Patient	Diagnosis
2	
3	
4	

9 Unfortunately, a medical student doing a rotation in the pathology department of the lab accidentally switched the labels of Patient 2 and Patient 3. Identify what type of error this represents. (1 MARK)

10 After this error was fixed, the medical student bumped the machine used to measure blood glucose levels, disturbing its sensor such that its measurements were 0.1 mmol/L higher than they should be. Identify what type of error this represents. (1 MARK)

Uncontrolled gestational diabetes can result in a number of complications during and after the pregnancy, including growth abnormalities for the baby. For example, babies born to women with gestational diabetes can be macrosomic, meaning that they are larger than average for their gestational age. The graph depicts the criteria for classifying babies as either small for gestational age, appropriate for gestational age, or large for gestational age.



Changes to lifestyle, such as regular exercise and improved nutrition, are known to be highly effective forms of managing and preventing gestational diabetes. However, if a woman's blood glucose levels do not respond to these changes, the use of medication or artificial insulin may be needed.

11 A few weeks after their oral glucose tolerance test, Patient 3 delivered their baby at 36 weeks of gestation. Their baby weighed 1.55 kg. Using the graph, state this baby's size in relation to gestational age. (1 MARK)

12 Another woman gave birth to their baby at 40 weeks gestation. State the weight range required for the baby to be classified as appropriate for gestational age. (1 MARK)

13 A number of medications used to treat diabetes can have damaging effects on foetal development. Explain the relevance of the bioethical concept of non-maleficence to a doctor prescribing diabetic medication to a pregnant woman. (2 MARKS)

14 A group of scientists wanted to study the effect of lifestyle changes on the development of gestational diabetes. They proposed dividing their volunteers into two groups, one of which would undertake a carefully controlled exercise program, whilst the other group would not be allowed to partake in any exercise programs.

Explain what a consequences-based approach to bioethics is and use it to describe how an opponent of this study might criticise this experiment. (2 MARKS)

CHAPTER 6 EXAM PRACTICE

30 min

Section A (6 MARKS)

Question 1 (1 MARK)

When considering the stimulus-response model, all effectors

A are cells.

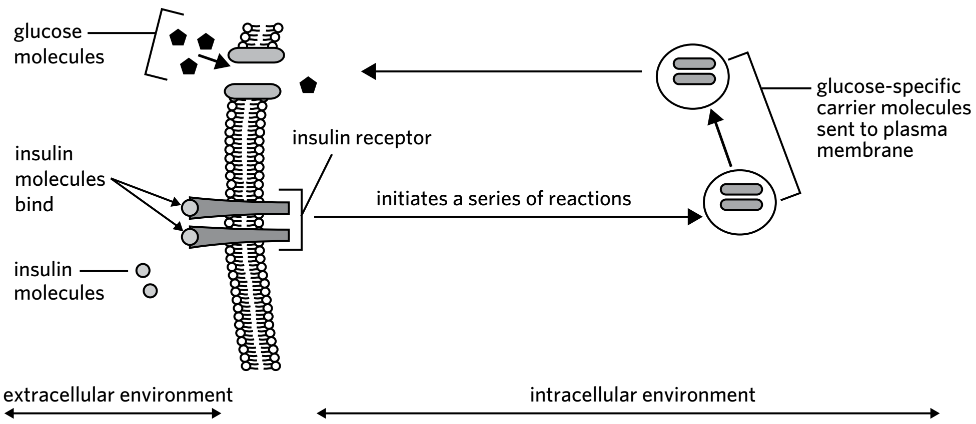
B are hormones.

C produce a response.

D are secreted by the hypothalamus.

Use the following information to answer Questions 2 and 3.

The diagram shows a summary of the steps in an insulin signalling pathway that result 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 detected no naturally occurring insulin in Shani's blood.

Question 2 (1 MARK)

From this information, it would be correct to conclude that

A the stimulus in this homeostatic system is the rise of blood glucose levels.

B the stimulus in this homeostatic system is the fall of blood glucose levels.

C the presence of glucose activates receptors on the cell surface.

D the insulin absorbed by the cell will be converted to glycogen.

Adapted from VCAA 2017 Section A Q17

Question 3 (1 MARK)

It is likely that Shani suffers from

A type 1 diabetes.

B hypothyroidism.

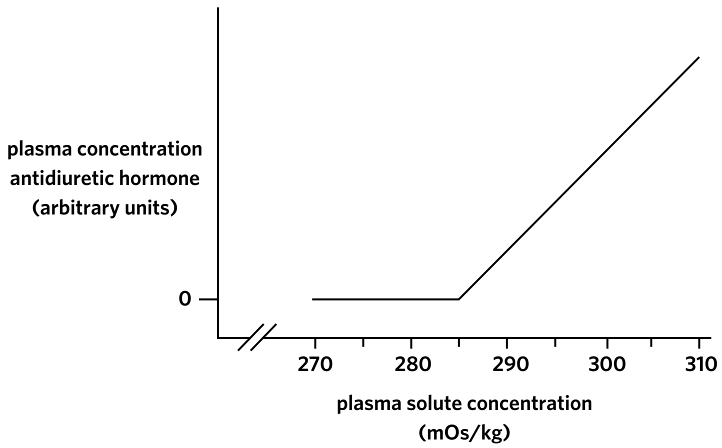
C type 2 diabetes.

D hyperthyroidism.

Use the following information to answer Questions 4 and 5.

Several hormones are involved in maintaining homeostasis in mammals.

Antidiuretic hormone is important in controlling water balance. The following graph shows changes in the concentration of this hormone as plasma solute concentration increases.



Question 4 (1 MARK)

Which organ of the body releases antidiuretic hormone?

A posterior pituitary gland

B anterior pituitary gland

C hypothalamus

D kidneys

Adapted from VCAA 2002 Exam 1 Section B Q4d

Question 5 (1 MARK)

Antidiuretic hormone will be being released at what plasma solute concentration?

A below 270 mOs/kg

B 270 mOs/kg

C 285 mOs/kg

D 290 mOs/kg

Adapted from VCAA 2002 Exam 1 Section B Q4c

Question 6 (1 MARK)

A person who consumes excessive amounts of iodine in their diet overproduces thyroxine.

It is reasonable to conclude that when a person consumes an excessive amount of iodine in their diet

A the secretion of TSH from the anterior pituitary will be decreased, and their basal metabolism will be decreased.

B the secretion of TSH from the anterior pituitary will be increased, and their basal metabolism will be decreased.

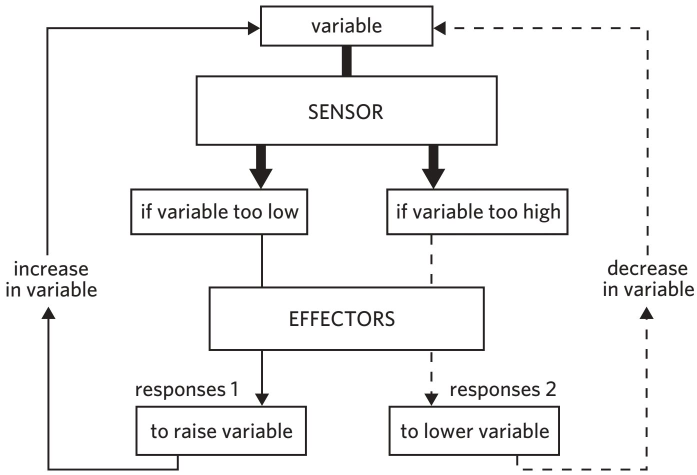
C the secretion of TSH from the anterior pituitary will be decreased, and their basal metabolism will be increased.

D the secretion of TSH from the anterior pituitary will be increased, and their basal metabolism will be increased.

Section B (14 MARKS)

Question 7 (7 MARKS)

The process of negative feedback is crucial to maintaining homeostasis. One way in which the general principle of homeostasis can be outlined is given in the diagram.



Adapted from VCAA 2005 Exam 1 Section A Q13

a Describe what is meant by the term 'homeostasis' and state how negative feedback contributes to it. (2 MARKS)

Adapted from VCAA 2012 Exam 1 Section B Q6ai

b Consider homeostasis in the context of thermoregulation.

i Identify two responses that could take place as response 2 in the diagram. (2 MARKS)

ii One example of an effector in this system is the smooth muscle in peripheral blood vessels. Explain how this effector brings about an increase in body temperature. (2 MARKS)

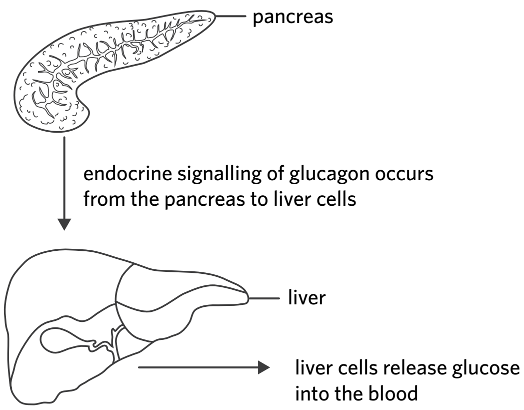
Adapted from VCAA 2002 Exam 1 Section B Q6bi

c State one variable, other than body temperature, that is under homeostatic control in mammals. (1 MARK)

Adapted from VCAA 2012 Exam 1 Section B Q6aii

Question 8 (7 MARKS)

After exercise, low levels of blood glucose can result in the release of glucagon (a hydrophilic hormone) 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.



a Another hormone is released by the pancreas. This hormone regulates the uptake of glucose into cells. State the name of this hormone and identify which cells it originates from. (2 MARKS)

b The hormone regulating glucose uptake increases intracellular glucose via facilitated diffusion. Describe how this hormone increases the facilitated diffusion of glucose. (2 MARKS)

Adapted from VCAA 2014 Section B Q3b

c Some individuals cannot make enough of the hormone that facilitates glucose uptake into cells and must have regular injections of this hormone. Different forms of this hormone have been produced by pharmaceutical companies. The table shows information on three forms of the hormone.

Form of hormone	Onset of action	Peak action	Duration
A	15 minutes	30 to 90 minutes	3 to 5 hours
B	30 minutes	2 to 4 hours	6 to 8 hours
C	4 to 8 hours	12 to 18 hours	24 to 28 hours

i State one advantage of Form A. (1 MARK)

Adapted from VCAA 2005 Exam 1 Section B Q7e

ii Often people who require injections of this hormone will use a combination of different forms. Explain why this is necessary referring to short-acting and long-acting forms of the hormone. (2 MARKS)

UNIT 1

AOS3

How do scientific investigations develop understanding of how organisms regulate their functions?

Survival of organisms requires control and regulation of factors within an organism and often outside an organism. Different types of cells and adaptations enhance an organism's survival in a particular environment, while homeostatic mechanisms maintain the internal environment.

In this area of study students adapt or design and then conduct a scientific investigation to generate appropriate qualitative and/or quantitative data, organise and interpret the data, and reach a conclusion in response to the research question.

The student-adapted or student-designed scientific investigation relates to knowledge and skills developed in Area of Study 1 and/or Area of Study 2.

Outcome 3

On completion of this unit the student should be able to adapt or design and then conduct a scientific investigation related to function and/or regulation of cells or systems, and draw a conclusion based on evidence from generated primary data.

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Image: Juice Verve/Shutterstock.com

HOW TO DESIGN AND CONDUCT A SCIENTIFIC INVESTIGATION

As part of your assessment for Unit 1, you will be asked to conduct your own scientific investigation in response to your own research question. The investigation can either be adapted from elsewhere, or designed entirely by you, but it must relate to something you have learnt over the course of Unit 1 regarding the function and/or regulation of cells or systems.

This task is set by the VCAA to allow students to demonstrate their ability to: (1) design an experiment, (2) generate their own qualitative and/or quantitative data and (3) come to a conclusion as to what their generated evidence suggests about their chosen area of study.

This sounds like a daunting task, we know. That's why we have included this lesson in your textbook to help you work through the process from start to finish. We are here to help you every step of the way, and have broken down this 'how-to' into three key stages to mirror pages 20 and 21 of the study design:

1 *Investigation design*

2 *Scientific evidence*

3 *Scientific communication*

We will even conduct a brief investigation of our own, and use that as an example throughout this guide for you to refer to. The first thing to do is decide on a research question. The research question we have chosen to explore is: ***'does the growth of an indoor mini fiddle-leaf fig (Ficus lyrata bambino) increase when exposed to more sunlight?'***

You can read this guide from start to finish, or simply refer back to certain sections of the guide whenever you are stuck on the corresponding section of your own investigation. You may also wish to refresh your knowledge of the key science skills from lesson 1A, or sharpen the tools in your bioethical toolkit from lesson 1B – good luck!

By the end of this investigation you should be able to either adapt or design (and then conduct) your own scientific investigation relating to the function and/or regulation of cells or systems.

A high quality investigation will demonstrate:

- *the generation of primary quantitative and/or qualitative data*
- *a full analysis and evaluation of the generated data*
- *identification and discussion of any limitations of both the data and/or the methodology*
- *a discussion of the relationship between the experimental results and broader scientific ideas, including a discussion of the implications of the results*
- *a final conclusion in response to the original research question.*

Stage 1: Investigation design

Stage overview

First things first, you must design your experiment. This is where we demonstrate the creative capabilities that are inherent to the key science skills (KSSs), which we learnt about in chapter 1. This stage involves several individual steps, from deciding on a research question, to defining relevant concepts and theory, and finally considering different techniques for generating data. We will look at these steps in detail in this section.
A lot of the information you develop in this stage will work well in the introduction and methodology sections.

A summary of the investigation design process is seen in the flow chart (Figure 1).

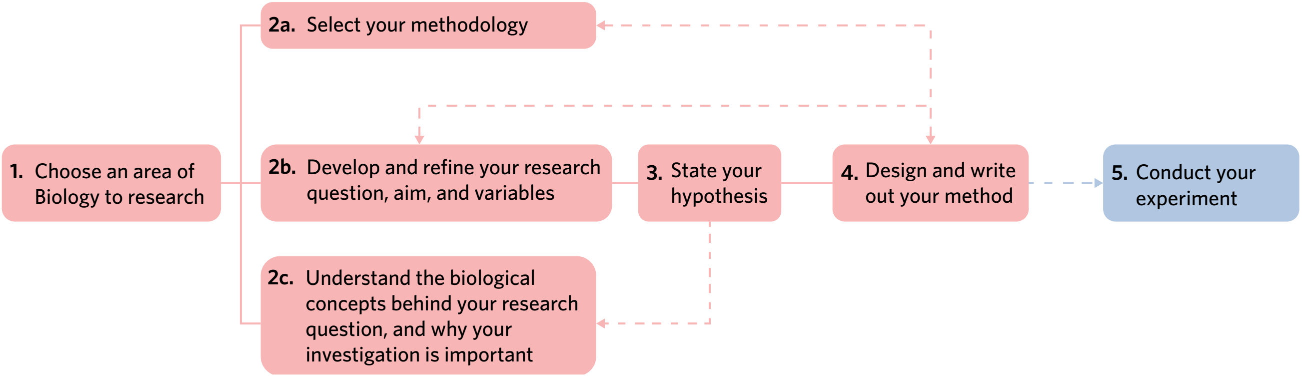

Figure 1 A flow chart showing the design process of your investigation. Note that we often return back to earlier steps in an effort to refine our investigation. The design process is incredibly important. Once you begin your research, it is much harder to change and revisit your methodology, so make sure to take your time with this stage!

Stage checklist

Across each stage of this guide, we will include the dot points that are explicitly mentioned by the VCAA on page 20 of the study design. As you work through this assessment, revisit these checklists to make sure you are including all of the required information at each stage.

For this section of your investigation you need to include discussion of each of the following:

- the biological science concepts specific to the selected scientific investigation and their significance, including the definition of key terms
- the scientific methodology relevant to the selected scientific investigation, selected from: classification and identification; controlled experiment; correlational study; fieldwork; modelling; product, process or system development; or simulation
- techniques of primary qualitative and quantitative data generation relevant to the investigation
- the accuracy, precision, reproducibility, repeatability, and validity of measurements in relation to the investigation
- the health, safety, and ethical guidelines relevant to the selected scientific investigation.

Step 1: Develop a research question

As mentioned, this task requires you to design your own scientific investigation in order to explore something you have learnt over Unit 1, specifically in regards to the functioning and/or regulation of cells and systems. Before you start, you must think of a research question you want to explore.

To do this, think back to the theory you've learned throughout the first 6 chapters of this textbook. Is there anything you enjoyed that you'd like to explore in more detail? Was there something that you learned that you thought was really interesting? Or, did you have a question about something you learned that you'd like to find an answer to? It is important to remember the criteria of a good research question. The criteria were explored in lesson 1A and included measures such as being testable, achievable, and specific.

Some topics to think about which relate to Unit 1 include:

- homeostatic regulation
- apoptosis and cell death
- the cell cycle (prokaryotic vs eukaryotic)
- the semi-permeability of the plasma membrane
- the role and function of different biological systems
- the way in which size and shape of a cell contributes to its function.

Example

COME UP WITH A RESEARCH QUESTION

Here in the Biology Team at Edrolo, we've had a problem over the past year. We've been trying to grow some nice indoor plants on our desks at Edrolo headquarters, however, no matter what we do they always seem to shrivel up and die. What makes things worse is that we can look over at the Psychology Team and see some indoor plants on their desks, and theirs are thriving. As the supposed experts on all things living, you can imagine this is quite embarrassing for us.

We noticed that Team Psych's desks were right in front of the office windows and that their plants were receiving a lot more direct sunlight than ours. We were reminded that plants get their energy from photosynthesis, a process that requires sunlight, and believed this to be the reason for our miserable plant growth. We wondered whether sunlight affects indoor plant growth, and if so, to what extent. To formulate a testable, achievable, and specific research question, we identified the type of plant we wanted to grow in the office, and came up with the following research question:

'Does the growth of an indoor mini fiddle-leaf fig (*Ficus lyrata bambino*) increase when exposed to more sunlight?'

Step 2: Understand the biological concepts behind the research question

An important part of designing your investigation is to clearly define the scope of your area of study by discussing any key biological concepts that are relevant to your research question. This is both for your benefit, and that of your reader. From your point of view, not only does it demonstrate that you've been paying attention in class, but defining key concepts also helps you better understand what is important to investigate, and what goes beyond your chosen research question. In other words, it helps you more effectively analyse the data you obtain, and decide what should be included in your final assessment. For your reader, on the other hand, who may not be as familiar as you with the chosen area of research, defining key terms and explaining the biological concepts that underpin your research will help them engage with and better understand your investigation.

Start by defining key terms in your research question, and then take a few sentences to summarise the most important concepts behind the question. So, for example, if your research question relates to malfunctions in homeostasis, some concepts you might want to explain in your introduction might include: (1) what homeostasis is and why it's important, (2) what regular homeostasis looks like, and (3) an explanation of different factors that influence homeostasis. This is to get your reader 'up-to-speed', so to speak, and to set up the rest of your investigation to be able to explore something new.

Example

You might decide to leverage information from other parts of the textbook, or even from previous studies.

'Previous research has demonstrated that healthy office plants increase average employee morale in a workplace setting (Larson et al. 1998). It is therefore important to understand the conditions in which indoor office plants flourish and grow. The mini fiddle-leaf fig (*Ficus lyrata bambino*) is a plant native to Africa that is widely used as an office plant in Australia. It is photosynthetic, meaning it uses energy from sunlight and turns it into usable chemical energy. The current understanding is that *F. lyrata bambino* grows best under indirect natural sunlight. This research hopes to determine at what distance from direct sunlight is best for vertical growth in the plant species.'

Step 3: Select the appropriate methodology and define your variables

Now that you've got your research question, it's time to figure out how to actually get to the answer by conducting a scientific investigation! This will require you to select the appropriate scientific methodology, which will help you in designing your specific method (the actual steps in your experiment). What is the best way to answer your research question? Is laboratory work and a controlled experiment going to give you the data you need to support or disprove your hypothesis? Or do you need to do fieldwork or modelling to get the information you need? It may be helpful to look back at lesson 1A again to refamiliarise yourself with the different scientific methodology types, and their strengths and weaknesses.

The study design mentions that your methodology should be selected from one of the following:

- controlled experiment
- correlational study
- fieldwork
- modelling
- process or system development
- simulation.

It may be useful to talk to your teacher about the types of methodologies they would like you to choose from, as they may want all students to undertake a controlled experiment. For the purposes of this guide, we will assume that you are using a controlled experiment. For more detail on the other methodology types, please refer to lesson 1A again (and speak to your teacher about your options).

Let's say you have chosen a controlled experiment. An important part of this methodology is defining the variables in your experiment. This is especially true of controlled experiments, which help us understand cause and effect by investigating the impact of an independent variable (IV) on a dependent variable (DV) whilst keeping all other variables constant (controlled variables). Make sure to clearly state each variable in your investigation.
To remind you, the variable that is being affected is the dependent variable (DV), while the variable that is being manipulated is the independent variable (IV). For example, we might investigate the impact of changing temperature (IV) on the rate of oxygen production from photosynthesis in plant X (DV). Here, we would set up an experiment where different specimens are exposed to different temperatures whilst ensuring that all other variables are the same (such as UV exposure, water exposure, air pressure etc.)

! *Example*

Because we are examining the impact of a single variable on another, we decided the best methodology to follow was a controlled experiment. We could have instead conducted fieldwork and observed plants outside, perhaps comparing the growth of plants in sunny patches with the growth of plants in shady spots. However, this method would have introduced a number of confounding variables that we couldn't control. Given that we wanted to be certain of the influence of light on plant growth, we decided to conduct a controlled experiment. It is important to discuss the reason for this decision in your final presentation.

We also defined our variables:

- **Independent variable (the thing we were going to change)** = the amount of sunlight our plants were exposed to.
- **Dependent variable (the thing that we were going to measure)** = the amount of plant growth.
- **Controlled variables (things we need to keep constant during our investigation)** = other factors that influence photosynthesis and plant growth, including water exposure, any fertilisers used, soil quality, and temperature.

Note that it is also important to define any units of measurement when describing your variables. We will return to this point in the communication section of this guide. We measure the amount of sunlight as (none, 10 m away, direct sunlight) while we measure the growth of the plant as height in millimetres (mm).

Step 4: State your hypothesis

Your hypothesis is a testable statement that predicts how your independent variable will affect your dependent variable. Based on your knowledge of the topic and your research, you should be able to come up with an idea of how altering your independent variable will influence your dependent variable. At the end of your experiment, the results you obtain will either be as you expected and support your hypothesis, or differ from what you expected and refute your hypothesis.

! *Example*

Based on our knowledge about plants and photosynthesis, we made the following hypothesis:

'The growth of a mini fiddle-leaf fig will increase when exposed to more sunlight.'

Step 5: Design your experiment

Now that you've selected the most appropriate methodology to answer your research question, it's time to actually figure out what you're going to do in your investigation. Exactly what your investigation's design is will depend on what methodology you've chosen. If you've chosen to do a controlled experiment, consider the following key components:

1. What will you be measuring in your experiment and how will you be measuring it? This includes how long your experiment will run for and how big your sample is.
2. What different conditions are you going to have in your experiment? How will you design your experimental groups to ensure these conditions are tested?
3. How will you be controlling for uncontrolled variables to ensure they don't impact your results? In other words, list your controlled variables.
4. How will you be addressing replication?
5. How will you prevent errors from occurring? Or, at the very least, how will you conduct your experiment so that their influence on your result is minimal?
6. What is the best way to generate a sample?
7. What ethical and safety guidelines do you need to be aware of before conducting your investigation?

Once you've addressed each of these questions, you can use your answers to help write your method. Use our example as inspiration for how to construct your method.

Lesson link

If you've decided to use a different methodology, turn back to ***lesson 1A*** to see what things you need to consider when designing your experiment.

Example

DESIGN YOUR EXPERIMENT

We answered the above questions as shown:

1. We will be measuring vertical plant growth using a tape measure to measure how high the plants are, from the surface of the soil to their stem tip, after two weeks of growth. We will have fifteen plants in total, with five plants exposed to each light condition.
2. We are going to manipulate our independent variable by having a variety of different light conditions – some plants will be placed in a cupboard and receive no light (Group A), some will be placed ten metres away from a window (Group B), and others will be placed directly in front of a window (Group C). Group A will serve as our control group.
3. We identified relevant controlled variables. For example, (1) we will ensure that the plants receive the same amount of watering, (2) they will be watered at the same time of day, (3) we will not provide any of the plants with fertiliser, and (4) we will ensure that all the plants are the same species and are of similar size and health.
4. As mentioned, there are five plants exposed to each light condition. This means we have five replicates per each light condition.
5. We will use the same tape measure and have the same person measuring all the plants. We will ensure the tape measure has clear 1 mm markings.
6. We will select plants at random from a pool of plants that are all of similar size and health and place them randomly into each light condition group.
7. Fortunately, we feel our investigation is quite safe. However, we do need to be careful to check if anyone is allergic to the plant we have chosen. We know that the sap of *Ficus lyrata bambino* is irritating to skin so we will need to provide our team with personal protective equipment (PPE) such as gloves to use while handling the plants.

Using these answers, we designed the following methodology for our scientific investigation. Note that not each question needs to correspond to a step in your methodology.

1. Randomly select 15 *Ficus lyrata bambino* plants of similar height and size.
2. Divide these plants into three groups – Group A, Group B, and Group C – and assign each plant a number within each group – e.g. plants A1, A2, A3, A4, and A5 are all in Group A, while plants B1–B5 are in Group B, and the same for Group C.
3. Measure the height from soil level to the tip of the stem of each plant using a tape measure and record these measurements. Ensure gloves are worn to protect from the plant's sap.
4. Water each plant with 20 mL of tap water.
5. Place all the plants from Group A into a cupboard with the door closed so they are in darkness, place the Group B plants on a table 10 metres away from a north-facing window, and place the Group C plants on a table directly in front of the same north-facing window.
6. After two weeks, have the same person measure and record the heights of each plant.

Step 6: Considering internal measures

The final step in designing your investigation is to consider the relevance of certain internal measures that are important for completing scientific investigations. It is important to think about how well your investigation satisfies these measures at the start of your process, prior to conducting your investigation, as well as at the end of the process, once you get back your results. We will remind you of some of these now, and invite you to return to these when it is time to present your findings. It is also encouraged to discuss these early in the piece, especially in your logbook, to demonstrate your preparedness to your teacher.

1. Accuracy: refers to how close your results are to the 'true' value of the quantity being measured. For example, if we know that plant species X typically photosynthesises optimally at a temperature of 35 °C, then we would expect our primary data to be as close to this value as possible (Figure 2).
2. Precision: refers to how close your results are to each other. Precise results indicate that your method is valid and reliable, and that you may be able to assume the same results would be found in a larger sample. If you get a wide spread of values across replicates, then results are imprecise. If replicates get similar results, your results are precise. For example, we would hope that each time we conducted the experiment, each replicate would be around the same value so as to indicate that our method is reliable.
3. Reproducibility: refers to how reproducible your results are. A reproducible experiment means that other scientists could follow your method and get the same results over and over again. For example, if another group of your classmates were given your methodology and asked to reproduce your experiment, they would be able to get the same results.
4. Repeatability: refers to how repeatable your results are. A repeatable experiment means that you personally could repeat your experiment and get the same results over and over again. In other words, if you did the exact same method again, you would get the same results each time.
5. Validity: refers to how valid your experimental design is. A valid experiment actually measures what it claims to be measuring. For example, if we are aiming to measure the effect of different temperatures on the photosynthesis rate of plant species X, then that is what we should measure, rather than looking at UV exposure, or different plant species.

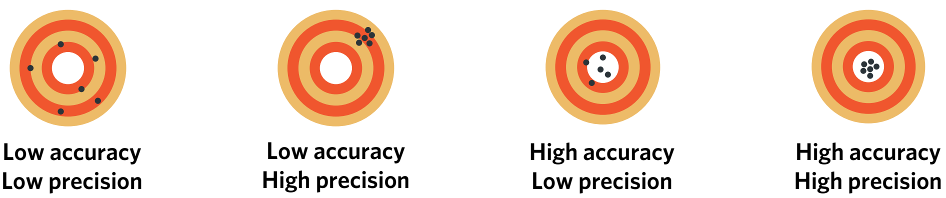

Figure 2 Accurate results are close to the true value, whereas precise results have very little spread around the mean value.

When discussing these internal measures, it is also important to identify any health, safety, and/or ethical guidelines that might be relevant to your selected investigation. This might include things like the sterilisation of your work station, the safe storage of equipment and materials, the storage of data and information about participants, obtaining informed consent and/or any other relevant considerations you think it might be important to mention. This can also be a good opportunity to introduce some of the bioethical concepts and approaches that were introduced in lesson 1B, and is a great opportunity to demonstrate to your teacher a full and considered investigation design.

Stage 2: Scientific evidence

Stage overview

Having followed the steps perfectly and designed a beautiful scientific investigation, it's now time to collect some scientific evidence to answer your research question. To do this, there are some steps we need to follow once more, and some individual points we need to ensure that we are discussing in our final presentation. Remember: by the end of this section you should have generated your own qualitative and/or quantitative data.

Stage checklist

For this section of your investigation you need to discuss and include each of the following:

- the distinction between an aim, a hypothesis, a model, a theory, and a law
- observations and investigations that are consistent with, or challenge, current scientific models or theories
- the characteristics of primary data
- ways of organising, analysing, and evaluating generated primary data to identify patterns and relationships including sources of error
- use of a logbook to authenticate generated primary data
- the limitations of investigation methodologies and methods, and of data generation and/or analysis.

Step 1: Establish a logbook

Before doing anything, it is important to set up a logbook that can be used while researching and collecting data. This helps you to look back on your research and identify the sources you have used. It also gives you a good place to record all of your results and write down any interesting findings/thoughts you have along the way. There is no set format for using a logbook, so it is important to identify what works well for you. You could take handwritten notes, or type up your research with links.

Take a look at what the VCAA has to say about the use of a logbook:

Example

THE VCAA ON LOGBOOKS

The use of a logbook reflects standard scientific practice. Students undertaking this study must maintain a logbook of practical activities in each of Units 1 to 4 for recording, authentication, and assessment purposes. All items in the logbook must be dated and clearly documented.

The logbook is submitted as a requirement for satisfactory completion in each of Units 1 to 4. Teachers must regularly sight and monitor the logbook, particularly for the student-designed practical and/or research investigations in Outcome 3 of Units 1 and 2, and Outcome 3 of Unit 4.

The logbook may be maintained in hard copy or electronic form. However, to avoid falsification and/or alteration of results, for assessment tasks it is recommended that students maintain a hard copy, as is commonly the practice in scientific research.

Step 2: Collect your data

It is important that you find a reliable, clear, and valid way to collect and record your data while conducting your experiment. Be sure to note down all the results you obtain in your logbook, even if they seem strange or odd. Additionally, it is important to record anything 'out of the ordinary' that happened while conducting your experiment – these events may influence your results, so you need to be aware of what they were and when they occurred.

When collecting your data, and later presenting it in your final presentation, it is also important to briefly demonstrate an understanding of the different types of evidence. In this investigation, you are being asked to generate appropriate qualitative and/or quantitative data. Make sure you clearly distinguish between these, and explain your decision for choosing the data type you did. To briefly remind you, quantitative data is relating to quantities, where we look at measures, counts and units. Qualitative data describes qualities, and is often in narrative form through interviews, observations, and descriptions.

Finally, it's important to make it clear that not all evidence is created equally. When we think of strong scientific evidence, we are typically referring to primary and/or secondary data that is empirical and measurable, and under the control of a formal research environment. Some scientific evidence might be stronger than others – for example, a controlled clinical trial with a large and randomised sample is considered stronger than a case study that uses a small sample. It is important to identify the strength of your own study in terms of sample size, and how representative it might be of a wider population or subset.

Example

COLLECT YOUR DATA

We measured the height of each plant in the three groups once at the start of the investigation, and then after two weeks of being in their respective positions. We recorded our findings in a table like shown:

Plant	Initial height (mm)	2-week height (mm)
A1	210	212
A2	214	217
A3	204	205
A4	212	212
A5	202	206
B1	220	231
B2	210	219
B3	213	224
B4	208	221
B5	211	222
C1	222	229
C2	214	234
C3	207	226
C4	215	235
C5	217	240

Observations

During initial measurement, plant C1 was knocked over and fell out of its pot. It was re-planted immediately and remained in the experiment.

Stage 3: Scientific communication

Stage overview

After you've conducted your investigation and collected your results, it's time to prepare a report that describes what you did. You will use the data you've collected in Stage 2 to answer your research question and either support or disprove your hypothesis.

Stage checklist

For this section of your investigation you need to demonstrate each of the following:

- the conventions of scientific report writing including scientific terminology and representations, standard abbreviations, and units of measurement
- ways of presenting key findings and implications of the selected scientific investigation.

Before you get started writing your practical report, check with your teacher to see if they have any specific guidelines for how you should write and structure the report. For example, your teacher might prefer you to not use personal pronouns such as 'I' or 'we', and may or may not require you to include an abstract.

Regardless of which form of presentation you use to present your investigation, you should focus on including the components outlined in Table 1.

Table 1 VCAA guidelines for the required content to be presented in a scientific investigation

Section	Content
Title	The question under investigation
Introduction	Explanation or reason for undertaking the investigation, relevant background biological concepts, a clear aim, and a hypothesis
Method	A summary that outlines the methodology and steps used in the investigation and is authenticated by logbook entries Identification and management of relevant risk, including the relevant health, safety, and ethical guidelines followed in the investigation
Results	Presentation of collected data/evidence in an appropriate format to illustrate trends, patterns, and/or relationships
Discussion	Analysis and evaluation of primary data Linking of results to relevant biological concepts Identification of outliers and their subsequent treatment Identification of limitations in data and methods, and suggested improvements
Conclusion	A conclusion that provides a response to the question of the extent to which the analysis has answered the investigation question, with no new information being introduced
References and acknowledgements	Referencing and acknowledgment of all quotations and sourced content as they appear in the report

Title

Your title can be your original research question, or a slight re-wording of it if you want to be fancy. It doesn't need to be long or complicated – in fact, the shorter and simpler the better!

Example

TITLE

Does sunlight affect the growth of *Ficus lyrata bambino*?

Abstract

An abstract is a short summary of your investigation that helps garner the attention and interest of your reader. The VCAA says it isn't compulsory to have an abstract, but it can be a good idea as it gives your audience a quick snapshot of what your report is about. Check with your teacher if you should be writing an abstract. One simple way to write an abstract is to summarise the main components of your report into a sentence each, and then work these together to make one cohesive paragraph.

Example

ABSTRACT

Office plants have a number of mood-boosting effects for employees, and sunlight exposure is known to affect plant growth. The effect of different amounts of sunlight on *Ficus lyrata bambino*, a popular office plant, was studied. Three groups of plants were each exposed to one of three different light conditions – full sunlight, a moderate amount of sunlight, and no sunlight at all. The plants in full sun grew far more in the space of two weeks than the other two groups. These results suggest that office plant placement should consider available sunlight to ensure optimal plant growth and therefore maximum benefit to workers.

Introduction

Your introduction should include a few different components – we'll look at each of these now.

Explanation or reason for undertaking the investigation

At the start of your introduction, you should begin by justifying and explaining the reason for your investigation. Why do your results matter? Why should anyone care about what you did? For example, our research question was to help us grow better office plants. Think back to why you were interested in the research, and go from there.

Linking your explanation to prior research is a good idea as it shows that you have thought about your investigation in the wider context of biology as a whole, and can prove that your investigation and findings are important. Based on your research, you might also be able to point out flaws with previous investigations that suggest your research is important and relevant.

There should be no doubt after reading your introduction that your investigation is one of the most important pieces of research that has ever been done... just like our study into optimal office plant growth which will change the way office plants are configured for the rest of time!

! *Example*

EXPLANATION OR REASON FOR UNDERTAKING THE INVESTIGATION

It is well understood that having indoor plants in an office space increases employees' mood and perceived comfort levels whilst at work *(Larsen et al., 1998)*. Perhaps more importantly, however, it has also been shown that an increased number of plants in the workplace decreases worker stress and reduces the amount of sick leave taken *(Bringslimark et al., 2007)*. As such, it is important to understand the conditions in which indoor office plants flourish and grow.

Background biological concepts

We mentioned in the investigation stage the importance of discussing background biological concepts relevant to your research. The introduction is likely where you will put it. Introduce the key aspects of theory from the course to demonstrate the relevance of your question to VCE Biology.

One way to think about which aspects of theory should be included is to think back to when you were designing your experiment – what aspects of theory did you use to formulate your hypothesis? Introduce these to your audience and link them to your research so that they can understand the biological theories and concepts relevant to your investigation.

! *Example*

BACKGROUND BIOLOGICAL CONCEPTS

One key environmental factor that influences plant growth is the amount of light that plants are exposed to. This is because plant cells obtain the glucose they use for cellular respiration via a process known as photosynthesis. In photosynthesis, plant cells utilise light energy to transform carbon dioxide and water into glucose, oxygen, and water. The simplified formula for photosynthesis is as follows:

$$6\ CO_2 + 6\ H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6\ O_2$$

Aim and hypothesis

After you've justified the reason for your investigation and provided the background information required to understand what you've explored, you can now introduce the aim of your investigation and the hypothesis you generated prior to commencing it. When you state your aim you can also introduce what the independent and dependent variables are, and your hypothesis will show the relationship you expected there to be between the two before you started your investigation. Note the emphasis on before – you should not be changing your aim or hypothesis once you've started.

It's important to remember that everything in your introduction is usually written in the present or future tense. This is because when you are presenting your investigation to an audience you are 'walking them through' what you did and found – as if you are conducting your whole investigation again but this time with them tagging along beside you. As such, when you are talking about your aims and hypothesis, you are talking as though these are things you haven't done yet rather than things that were already considered before you conducted your investigation.

> ***Example***
>
> **AIM AND HYPOTHESIS**
>
> This investigation aims to measure the effect of sunlight on the growth of the office plant *Ficus lyrata bambino*. Given the importance of light in the process of photosynthesis, it is hypothesised that increased amounts of sunlight exposure will cause plants to grow more compared to plants that are exposed to less sunlight or no sunlight at all.

Method

This section of your report is like a cooking recipe – it outlines the steps you undertook while carrying out your investigation and should be written in such a way that someone else could read it and replicate what you did. You can write your method in paragraphs or using dot points and can include diagrams to illustrate complex setups. Methods are usually written in past tense, but this is something you should check with your teacher.

Materials

Start by including a description of all the items you used to complete your investigation. You want to describe everything that another person would need to have in order to conduct the same experiment. You can write your materials either as a list or as a paragraph.

> ***Example***
>
> **MATERIALS**
>
> For this investigation, we used 15 healthy *Ficus lyrata bambino* plants selected at random from a larger population, a tape measure with millimetre markings, gloves, safety goggles, a cupboard and a watering jug.

Methodology

From there, it is now time to write out the full methodology of your investigation. You can write your methodology in paragraphs or using dot points and can include diagrams to illustrate complex setups. Methods are usually written in past tense, but this is something you should check with your teacher. Be sure to mention any risks or ethical issues you encountered and how you addressed them while conducting your investigation.

Example

METHODOLOGY

We randomly allocated the 15 selected plants into three groups – Group A, Group B, and Group C. Each plant was assigned a number within each group (e.g. Group A consisted of plants A1, A2, A3, A4, and A5). We then had one person measure the height of all the *Ficus lyrata bambino* from the surface of the soil to their stem tip using the tape measure. Given that the sap of *F. lyrata bambino* is a known irritant, we ensured that the measurer was wearing gloves and eye protection at all times.

Once the heights of all the plants had been measured and recorded, each plant was watered with 20 mL of tap water. All Group A plants were then placed in a cupboard with the door closed, all Group B plants were placed on a table 10 metres away from a north-facing window, and all Group C plants were placed on a table directly in front of the same north-facing window.

The plants were left in their respective positions for two weeks. After two weeks, we had the same person measure and record the heights of the *F. lyrata bambino* plants.

Results

Transform and present your data

The results section is where you can finally present your audience with your findings and observations. Importantly, though, do not interpret or explain these results yet – this is saved for the next section of the report. You are only presenting your data here as a way to highlight trends or patterns for your reader later in the discussion.

To do this effectively, the data that you present in your results section should be transformed – you should not be presenting raw data in your report. In order to figure out how to transform your data, think back to your research question – what do you need to know in order to answer it? Transformed data can be presented in a table or graph. Remember from lesson 1A that different types of data tend to suit different forms of graphical representation:

1. Line graphs and scatter plots are useful when presenting numerical data
2. Bar graphs and pie graphs are useful when presenting categorical data
3. Scatter plots are useful when comparing two variables.

Remember that typically, your x-axis will be your independent variable and your y-axis will be presenting your dependent variable measurements. Don't forget to give your tables/graphs clear titles and a figure number.

Example

RESULTS

Figure 3 shows the average initial and average 2-week heights of each group of plants. Group A had an initial average height of 208.4 mm which increased to 210.4 mm after two weeks. Group B had an initial average height of 212.4 mm which increased to 223.4 mm. Group C had an initial average height of 213.25 mm which increased to 233.75 mm.

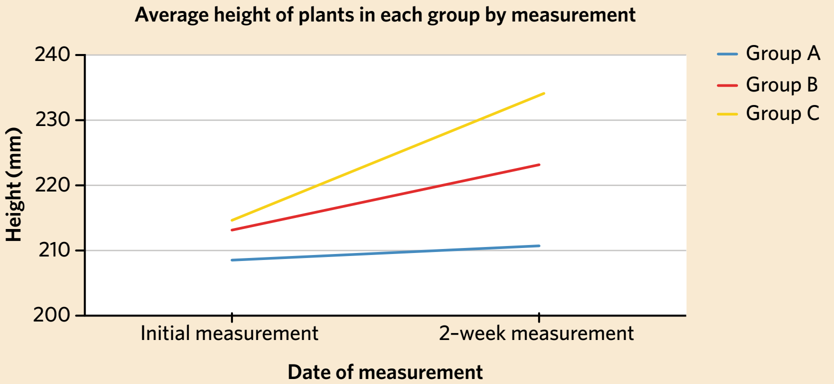

Figure 3 The average height of plants in each group by measurement date

Cont'd

Example

RESULTS

Table 2 depicts the average increase in height in each group as a percentage relative to the group's initial average height. It can be seen that plants in Group A grew an average of 0.96% relative to their initial height, plants in Group B grew an average of 5.18%, and plants in Group C grew an average of 9.61%.

Table 2 Recorded height measurements and the average percentage growth per group

Plant	Initial height (mm)	Average initial height (mm)	2-week height (mm)	Average 2-week height (mm)	Average percent growth of group relative to original height (%)
A1	210	208.4	212	210.4	0.96
A2	214		217		
A3	204		205		
A4	212		212		
A5	202		206		
B1	220	212.4	231	223.4	5.18
B2	210		219		
B3	213		224		
B4	208		221		
B5	211		222		
C1	222	N/A	229	N/A	N/A
C2	214	213.25	234	233.75	9.61
C3	207		226		
C4	215		235		
C5	217		240		

Discussion

The discussion of your report is typically the longest component and contains a number of different sections. We'll go through each of these here in detail.

Analysis and evaluation of primary data

Now that you have transformed and organised your primary data effectively, it is time to analyse and evaluate the strength of that transformed data in terms of your research question. In this first section, you want to restate your hypothesis, and suggest whether the data you've obtained supports or refutes your hypothesis. To do this, it is important to demonstrate discussion of the following:

Analysis

To analyse data you must compare the purpose of your investigation with the type of data you obtained – what is your research question and what type of data is needed to arrive at a meaningful conclusion? Assuming you designed your investigation effectively, the data you source should be able to lend itself well to the research question at hand. Keep in mind that you are being asked to create quantitative primary data. While other data (and other sources) may be leveraged to assist in answering the question, it is important to discuss the different types of data in your investigation and analyse which is most suited to answering your question. For instance, if my question relates to the optimal temperature for photosynthesis in plant species X, the most effective data is likely to be primary measurements taken during my experiment of photosynthetic outputs from my sample.

Evaluation

To evaluate the data you will judge the strength and limitations of your research based on the internal measures you considered earlier in this guide, as well as looking for any errors or uncertainties in both your method and the data you collect. Uncertainty might arise if the experiment is not repeatable, reproducible, or valid, or if you use other research that has not been peer-reviewed. Make sure to familiarise yourself with this terminology and use it throughout your final investigation.

Some common errors include:

- personal errors – mistakes made by the experimenter, such as counting incorrectly, rounding to the wrong decimal place, or labelling samples incorrectly
- systematic errors – affect the accuracy of the findings and occur when results differ from the true value by a consistent amount each time, typically due to faulty equipment or calibration
- random errors – affect the precision of the findings and are caused by unpredictable variations in the measurement process.

Some common types of bias include:

- confirmation bias – the tendency for researchers to only include information that supports their hypothesis or aim
- selection bias – the selection of participants is not randomised and the sample isn't representative of the wider population
- publication bias – when the outcome of a study determines whether it is published or not. Typically, journals only publish studies with 'positive' findings, and often fail to publish studies that report a negative result.

> **Example**
>
> **ANALYSIS AND EVALUATION OF PRIMARY DATA**
>
> It was hypothesised that increased sunlight exposure would result in increased plant growth. The results of this investigation support this hypothesis, with plants in Group C growing significantly more, relative to their original height, compared to plants in Groups B and A. Additionally, plants in Group B that were exposed to some sunlight grew more than plants in Group A that were not exposed to any sunlight.

Identification of outliers

Part of evaluating your data is identifying any outliers. If you noticed that any of your results appeared to be outliers, then you should comment on this in your discussion. If you chose to disregard these values during your analysis, make sure you state this clearly. Alternatively, if these outliers are still included in your analysis make sure your reader is aware that there are outliers that may alter the validity of your findings.

> **Example**
>
> **IDENTIFICATION OF OUTLIERS**
>
> Plant C1 did not grow as much as the other plants in Group C. This may be because, unlike all the other plants, plant C1 was knocked over during the experiment, resulting in all the soil and the plant itself falling out of the pot. This introduced an uncontrolled variable into the experiment, making it hard to compare the results obtained from plant C1 with the results of all the other plants. As a consequence, the results from plant C1 are no longer useful for answering the research question and have therefore been excluded from analysis in this investigation.

Linking of results to relevant biological concepts

In your introduction, you should have discussed the biological concept/s that are relevant to your investigation. It is important to raise these again in your discussion and use them to explain why you obtained the results that you recorded. This is called cross-referencing your results against relevant biological concepts. If you've done research on previous studies that are similar to your own and your findings support or differ from them, it is also a good idea to comment on this here.

Example

LINKING OF RESULTS TO RELEVANT BIOLOGICAL CONCEPTS

Given the importance of light in the process of photosynthesis, it is unsurprising that plants that are exposed to higher amounts of sunlight grew more in our investigation. It seems that the extra energy they were able to generate enabled their cells to grow and replicate at a greater rate compared to plants that were kept in darkness, resulting in greater growth during the recorded period of time.

Identification of limitations in data and methods, and suggested improvements

After you've claimed whether your results support the hypothesis, it's important to take a step back and evaluate whether or not your results are reliable and can be trusted. Consider if the method was flawed and, if so, whether extraneous or uncontrolled variables may have impacted the results. Can you think of any errors that may have occurred during the investigation? If so, what were they? This is part of the evaluation stage of your report, and demonstrates your ability to interact with your own generated primary data in an impartial and scientific manner.

After you've identified any potential limitations and the effect they may have had on your results, it's important to state how they could be addressed in future reproductions of your investigation. What could you change about the method that would make your results more accurate and precise? How could errors be avoided in the future?

Finally, it's good to finish your discussion by weighing up these potential limitations with the strengths of the investigation. Conclude by stating clearly whether or not your results and, therefore, your answer to your research question, can be relied upon.

Example

IDENTIFICATION OF LIMITATIONS IN DATA AND METHODS AND SUGGESTED IMPROVEMENTS

It is important to note that a number of factors may have influenced our result in this investigation. For example, the tape measure that was used, whilst having 1 mm markings, may not have been the most precise measuring tool available. As such, it may have introduced an element of random or personal error into our results, given the added difficulty of accurately measuring the plants. For future research, it would be advisable to use a more accurate measuring device, such as a laser measure or digital calipers, to get more exact measurements.

Additionally, plant height may not be the best way to measure the effect of increased photosynthesis on plants. Plants have extensive root systems, and it may have been that the plants that didn't grow as much vertically grew more roots instead. Additionally, plants may have been growing outwards rather than upwards, or, the stems of the plants may have been increasing in diameter. A different way of measuring the plants, perhaps one based on weight instead of height, may give a more accurate understanding as to the effect of sunlight exposure on plant growth. Furthermore, only one species of plant was studied in this investigation. It is possible that other types of plants may respond differently to different amounts of light.

Despite these limitations, the clear trend in our results suggests that exposing *Ficus lyrata bambino* to more sunlight does indeed increase its growth, and therefore we suggest it would also increase the growth of other types of office plants.

Conclusion

Lots of people worry about writing conclusions, but they really aren't that hard! Your conclusion should begin by restating your research question, and then state whether or not your hypothesis was supported or refuted by the data you collected. You then need to suggest avenues of further research based on your findings and how future study could address the limitations of your investigation. Finally, you should end your report by showing how your findings are important to society/the environment/the world in general – just like you did in the introduction. After your conclusion, your audience should be left feeling like your findings and conclusions are important and have ramifications in the real world.

Example

CONCLUSION

This investigation sought to understand the effect of variable amounts of sunlight exposure on the growth of *Ficus lyrata bambino*. It was hypothesised that plants exposed to higher levels of sunlight would grow more compared to plants exposed to less sunlight. This hypothesis was supported by the results, which showed that *Ficus lyrata bambino* plants exposed to more sunlight grew faster. Future research should aim to refine the measuring techniques used to measure the growth of plants, and potentially explore how other environmental factors influence plant growth. Future research might also explore plant growth in other plant species suitable for office life, as well as the effect of healthy plant life on office worker morale.

Nevertheless, it does seem that when placing plants in an office, consideration ought to be given to the amount of sunlight plants will be exposed to, as sunlight availability seems to be a key determinant of plant growth. Ensuring plants are provided with the ideal conditions to thrive is important, as their presence contributes greatly to the workplace atmosphere and employee mood..

References and acknowledgements

It is important to cite any sources that you used in your investigation at the conclusion of your report. Referencing can be complex, and there are many different styles you can use. Check with your teacher which style of referencing they would prefer you to use.

For VCE Biology, the APA and Harvard referencing systems are two of the most commonly used referencing styles. When referencing, it's important to note that these two styles have two types of citation styles – in-text citations and reference lists:

- In-text citations are used in the actual body of your investigation directly after you've referenced a source. You only need to have in-text citations if you are referencing a specific thought, claim, or finding from another source. For the most part, in-text citations are mostly found in your introduction and discussion, as this is where you explore other people's research.
- A reference list is a list of all the sources you've cited in your investigation. That means that you don't need to include every single website or book that you have read as part of your investigation, but only those which you actually used and cited.

Examples of APA and Harvard referencing are shown below. For more detail about referencing styles, you can visit the University of Melbourne citation website at: library.unimelb.edu.au/recite.

You can also choose to have an acknowledgements section at the end of your investigation. This isn't compulsory, but you can use it to thank anyone who has helped you conduct your investigation. Remember, though, this isn't your Oscars speech, so if you are going to have an acknowledgement section keep it brief!

Example

REFERENCES

APA style – in-text citation

'It is well understood that having indoor plants in an office space increases employees' mood and perceived comfort levels whilst at work (Larsen et al., 1998).'

APA style – reference list entry

Larsen, L., Adams, J., Deal, B., Kweon, B. S., Tyler, E. (1998). Plants in the workplace: the effects of plant density on productivity, attitudes, and perceptions. *Environment and Behaviour, 30(3)*, 261-281.

Harvard style – in-text citation

'It is well understood that having indoor plants in an office space increases employees' mood and perceived comfort levels whilst at work (Larsen et al., 1998, p.261).'

Harvard style – reference list entry

Larsen, L, Adams, J, Deal, B, Kweon, B. S & Tyler, E 1998, 'Plants in the workplace: the effects of plant density on productivity, attitudes, and perceptions', *Environment and Behaviour, vol. 30*, no. 3, pp. 261-281.

UNIT 2

How does inheritance impact on diversity?

In this unit students explore reproduction and the transmission of biological information from generation to generation and the impact this has on species diversity. They apply their understanding of chromosomes to explain the process of meiosis. Students consider how the relationship between genes, and the environment and epigenetic factors influence phenotypic expression. They explain the inheritance of characteristics, analyse patterns of inheritance, interpret pedigree charts, and predict outcomes of genetic crosses.

Students analyse the advantages and disadvantages of asexual and sexual reproductive strategies, including the use of reproductive cloning technologies. They study structural, physiological, and behavioural adaptations that enhance an organism's survival. Students explore interdependences between species, focusing on how keystone species and top predators structure and maintain the distribution, density, and size of a population. They also consider the contributions of Aboriginal and Torres Strait Islander knowledge and perspectives in understanding the survival of organisms in Australian ecosystems.

A student-directed research investigation into a contemporary ethical issue is to be undertaken in Area of Study 3. The investigation relates to the application of genetic knowledge, reproductive science, inheritance, or adaptations and interdependencies beneficial for survival. The investigation draws on key knowledge and key science skills from Area of Study 1 and/or Area of Study 2.

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UNIT 2

AOS1

How is inheritance explained?

In this area of study students describe the production of gametes in sexual reproduction through the key events in meiosis. They explore the nature of chromosomes and the use of genetic language to read and interpret patterns of inheritance and predict outcomes of genetic crosses.

Students explain how a characteristic or trait can be influenced by one gene, many genes acting together, and genes interacting with external environmental or epigenetic factors. They apply their genetic knowledge to analyse pedigree charts, determine patterns of inheritance, and predict outcomes of genetic crosses.

Outcome 1

On completion of this unit the student should be able to explain and compare chromosomes, genomes, genotypes and phenotypes, and analyse and predict patterns of inheritance.

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CHAPTER

7

Genetics

Key knowledge

- the distinction between genes, alleles, and a genome
- the nature of a pair of homologous chromosomes carrying the same gene loci and the distinction between autosomes and sex chromosomes
- variability of chromosomes in terms of size and number in different organisms
- karyotypes as a visual representation that can be used to identify chromosome abnormalities
- the production of haploid gametes from diploid cells by meiosis, including the significance of crossing over of chromatids and independent assortment for genetic diversity
- the use of symbols in the writing of genotypes for the alleles present at a particular gene locus
- the expression of dominant and recessive phenotypes, including codominance and incomplete dominance
- proportionate influences of genetic material, and environmental and epigenetic factors, on phenotypes

Image: vchal/Shutterstock.com

7A GENES AND CHROMOSOMES

If you've ever been to a family reunion, chances are you've probably been told that you have the same 'lanky legs' as your dad or the same smile as your grandmother. Perhaps you've even glanced over at poor Uncle Kevin and noticed the distinct lack of hair on his head, wondering what that means for your lovely luscious locks when you're his age. Should you be worried about going bald? Is there actually something connecting you to your family members that's influencing how you look? If so, what?

Image: Odua Images/Shutterstock.com

Lesson 7A

In this lesson you will learn about the structure and function of genes and chromosomes which make up our genome.

◀ *Prerequisite knowledge*

Years 7–10
There are specific differences within species and groups of organisms which can be explained by the transmission of particular characteristics from one generation to the next.

Lesson 4B
Cells go through what is known as the 'cell cycle', where a series of sequential events leads to the duplication of their genetic material (DNA).

Future applications ▶

Chapter 7
This chapter focuses on the significance of our genetic material, including the role of nature vs nurture in gene expression.

Year 12
Here you'll learn more details about the role and structure of genetic material, including the cellular processes involved in gene expression (transcription and translation).

Study design dot points

- the distinction between genes, alleles, and a genome
- the nature of a pair of homologous chromosomes carrying the same gene loci and the distinction between autosomes and sex chromosomes
- variability of chromosomes in terms of size and number in different organisms
- karyotypes as a visual representation that can be used to identify chromosome abnormalities

Key knowledge units

Genes to genomes	2.1.1.1
Chromosomes and karyotypes	2.1.2.1 & 2.1.4.1
Chromosomal variation	2.1.3.1

Genes to genomes 2.1.1.1

OVERVIEW

A gene is the basic biological unit within each of our cells that is responsible for the process of inheritance. Each gene is composed of specific sequences of deoxyribonucleic acid (DNA) and carries the genetic instructions required for the development of particular proteins.

THEORY DETAILS

Recapping DNA

Before learning more about genes, we should recall the basic structure and function of DNA. **Deoxyribonucleic acid (DNA)** sits inside the nucleus of your cells and is formed by the continuous pairing of base pairs into a longer, double-stranded **nucleic acid** chain (Figure 1).

These base pairs are part of individual nucleic acid molecules known as **nucleotide** monomers, each of which consists of the same basic structure (Figure 1a):

- a phosphate group
- a deoxyribose sugar
- a nitrogen-containing base, which can be one of four varieties:
  - adenine (A)
  - thymine (T)
  - guanine (G)
  - cytosine (C)

deoxyribonucleic acid (DNA) a double-stranded nucleic acid chain made up of nucleotides. DNA carries the instructions for proteins which are required for cell and organism survival

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

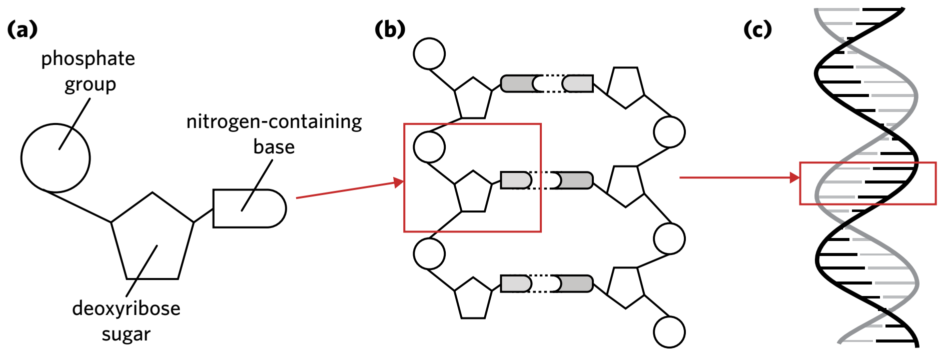


Figure 1 The building of a DNA molecule from **(a)** an individual nucleotide to **(b)** the pairing of bases into a **(c)** longer double-stranded chain of nucleic acids

From DNA to genes

A **gene** is a particular section of DNA that codes for the creation of an individual polypeptide chain. It acts like a set of instructions which a cell will then read to create the important protein molecules needed for a range of cellular functions, such as growth and regeneration. The order of bases in the double helix determines which protein gets made. For instance, the sequence 'ATG' will send different instructions than the sequence 'GGG'. You will learn more about this process in year 12.

Each person has two copies of each gene, one inherited from their mother and the other from their father. In total, there are roughly 25 000 different genes inside each of your cells. We call this collection of genes your **genome**, which houses all of the genetic information needed to build and maintain you: a complex organism.

gene a section of DNA that carries the code to make a protein

genome the complete set of DNA contained within an organism's chromosomes

Theory in action

Check out scientific investigation 7.1 to put this into action!

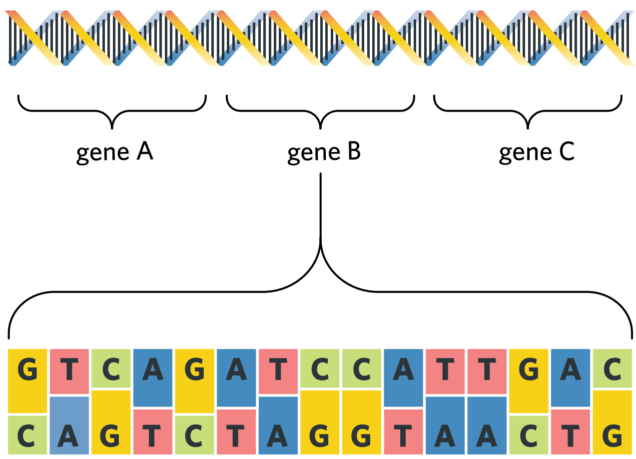


Figure 2 A visual representation of multiple genes along a double helix molecule of DNA

Alleles – are all genes the same?

allele alternate forms of a gene

Almost all genes are the same across every human being. However, a small number of genes (<1 per cent) are slightly different between people, which contributes to the immense differences we see from person to person. These differences are a result of what we call **alleles**, which are different forms of the same gene but with small differences in their base sequence.

For example, we each have genes that are responsible for the colour of our eyes. You might have green eyes whilst your best friend might have brown eyes. These differences are caused by differences in the alleles you each possess for the genes involved with eye colour (Figure 3).

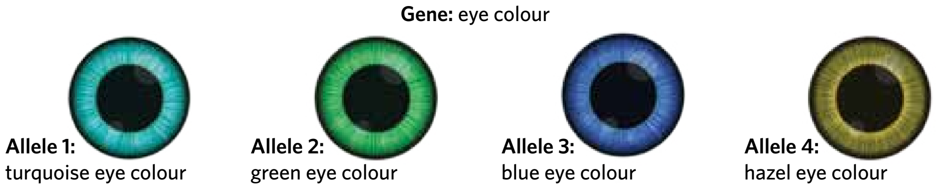


Image: Ron Dale/Shutterstock.com

Figure 3 The relationship between genes and the expression of different alleles

You'll notice in Figure 3 that there are more allele variations than the two that you and your friend might display. Instead of green eyes or brown eyes, perhaps another friend of yours has blue eyes or grey eyes. This is because genes, such as those involved in eye colour, may have multiple possible alleles.

However, only two alleles are present at the gene **locus** of any one individual, each of which is **inherited** from one parent – one from mum and one from dad. The allele that is ultimately expressed in your **phenotype** – that is, whether you have green eyes like your mum or blue eyes like your dad – will depend upon how these alleles interact with each other and which allele/s is dominant over the other. You will learn more about this in lesson 7C.

locus (pl. loci) the fixed position on a chromosome where a particular gene is located

inheritance the genetic transmission of traits from parent to offspring

phenotype the observable trait of an individual

haploid describes a single set of chromosomes (*n*)

Bringing it all together

An organism's genome is the sum total of all of its DNA. This is measured by the number of base pairs contained in a haploid set of chromosomes. For example, the human genome is around three billion base pairs in length (**haploid**), which equates to roughly 25 000 different genes. In comparison, *Anolis carolinens,* a type of green tree lizard native to the southern parts of the United States, has a genome of around two million base pairs and around 16 533 genes. Figure 4 summarises the distinction between the genome, genes, and alleles.

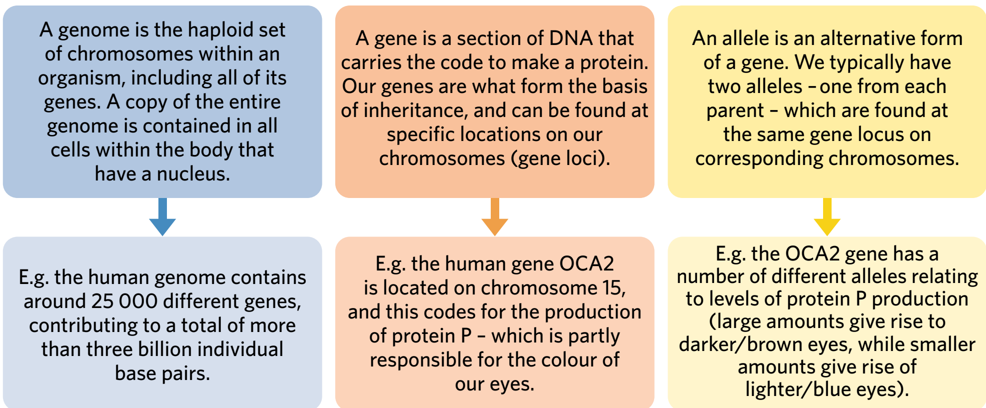


Figure 4 Distinguishing between a genome, gene, and allele

Chromosomes and karyotypes 2.1.2.1 & 2.1.4.1

OVERVIEW

An organism's genome sits inside the nucleus of each of their somatic cells in the form of DNA, which is then wrapped around proteins to form chromosomes. Chromosomes are arranged into homologous pairs based on the specific genes they possess. Because chromosomes are more condensed and easily visualised than DNA, biologists can analyse them using karyotypes.

THEORY DETAILS

What is a chromosome?

As mentioned, there are roughly 25 000 different genes inside each of your cells, composed of around three billion individual base pairs in total. This genetic information, while immense, is not stored randomly inside the nucleus.
Instead, each molecule of DNA is coiled tightly around **histone proteins** and packaged into thread-like structures called **chromosomes**. Human **somatic cells** mostly contain 46 chromosomes and therefore have a diploid number of $2n = 46$.

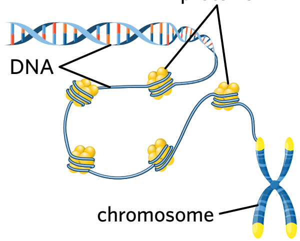


Image: Designua/Shutterstock.com

Figure 5 Coiling of DNA around histone proteins into chromosomal structure

histone protein highly basic proteins that associate with DNA inside the nucleus and help it condense into a chromosome allowing it to fit inside the nucleus

chromosome the structure made of protein and nucleic acids that carries genetic information

somatic cell any cell that is not a reproductive cell (such as sperm and egg cells). Somatic cells are diploid ($2n$), meaning they contain two sets of chromosomes – one inherited from each parent

chromatid one half of a replicated chromosome. Prior to cell division, chromosomes are duplicated and two copies join together at their centromeres (joined chromatids are known as sister chromatids)

Chromosome structure

Figure 6 shows the basic structure of a chromosome. Chromosomes vary in size depending on the number of nucleotides they contain. For example, chromosome 3 spans about 198 million base pairs and consists of roughly 1 000 genes, while chromosome 14 spans approximately 107 million base pairs and contains around 800 genes. Each individual gene has its own gene locus on the chromosome (Figure 10).

Table 1 The features of a chromosome

Feature	Description
Telomeres	A region of repetitive base sequences that is found at the end of every chromosome. It is used to protect the ends of chromosomes from fusing with other nearby chromosomes in the nucleus.
DNA molecule	Each chromosome is composed of a long DNA molecule that has been coiled tightly around histone proteins.
Centromere	A specialised sequence of DNA that holds together the two **chromatids**. It is very important for the process of meiosis, which you will learn about in lesson 7B.
Sister chromatids	The identical daughter strands of a replicated chromosome.
Short arm	Also known as the 'p arm' – this is the section of the chromosome that is shorter in length.
Long arm	Also known as the 'q arm' – this is the section of the chromosome that is longer in length.

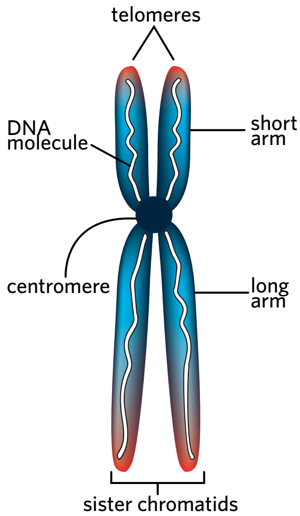


Image: Timonia/Shutterstock.com

Figure 6 A labelled chromosome (duplicated)

Lesson link

(a) The way in which chromosomes are often represented can be a little confusing. Typically, you'll often see chromosomes represented in an 'x-shape' like this:

(b) It is important to understand that while this x-shape is definitely a 'chromosome', a chromosome can also be represented like this:

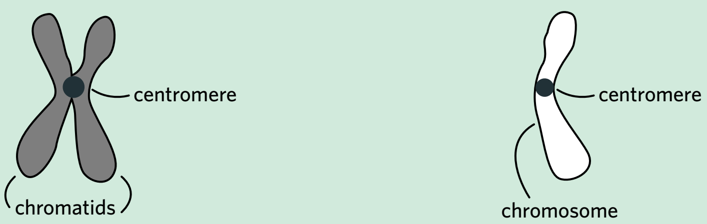


Figure 7 A chromosome after replication showing **(a)** two duplicated sister chromatids and **(b)** a single chromosome as it sits inside the nucleus during regular cellular function.

You'll notice that we call both of these representations chromosomes, but the left one has two chromatids connected by a centromere while the right one only has one chromatid. Both of these still only contain the genetic material of one of your parents, and are identical in every way, except the 'x-shape' representation depicts a chromosome after it has been duplicated during the S phase of cell division. You should recall from ***lesson 4B*** that the chromosome is only composed of a single chromatid (Figure 7b) from the end of mitosis through to the end of G1.

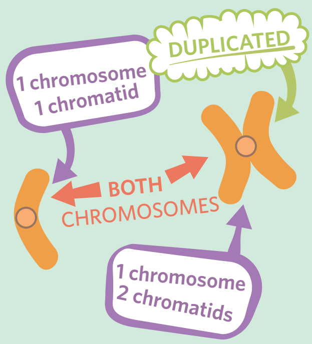


Figure 8 The different forms of a chromosome

Homologous chromosomes

We call each of the sets of 23 chromosomes within a human nucleus (one set inherited from your dad and the other from your mum) a pair of **homologous chromosomes** (Figure 9).

The criteria for homologous chromosomes are as follows:

1 they are the same in size and length
2 they have the same centromere position
3 they share the same genes at the same gene loci.

homologous chromosomes a pair of chromosomes of similar length, gene position, and centromere location. One of the pair is inherited from the mother (maternal chromosome) and the other from the father (paternal chromosome)

homologue a homologous chromosome

karyotype a visual representation of an individual's entire genome organised into homologous pairs

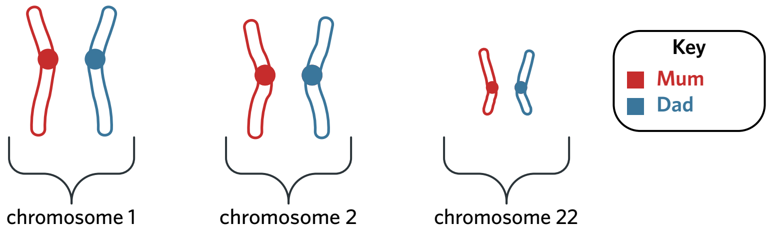


Figure 9 Basic representation of sets of homologous chromosomes

These sets of chromosomes, while not identical in base sequence, are paired and identified together as they contain the same genes. For instance, *OCA2* is the gene most associated with eye colour and is located at a specific region on chromosome 15, while *MC1R* is the gene most associated with hair colour and is located on chromosome 16. Importantly, each gene shares the same locus on each of the two **homologues**, allowing scientists to identify the exact location and base sequence for each gene of our genome (Figure 10).

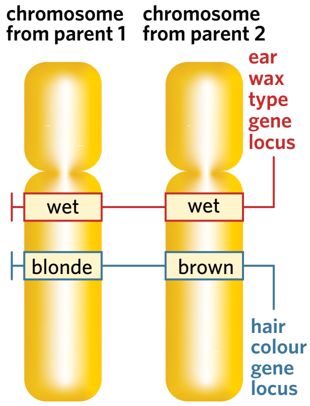


Figure 10 A set of homologous chromosomes showing the matching loci for two separate genes. This individual has two of the same alleles for ear wax type (wet), but different alleles for hair colour (brown and blonde).

Karyotypes – visualising chromosomes

Biologists can arrange chromosomes into a **karotype** or karyogram, which is a shared structural features and is used to check for possible genetic abnormalities. When reading karyotypes, scientists will check that the correct number of chromosomes are present and that the size and length of each chromosome are correct.

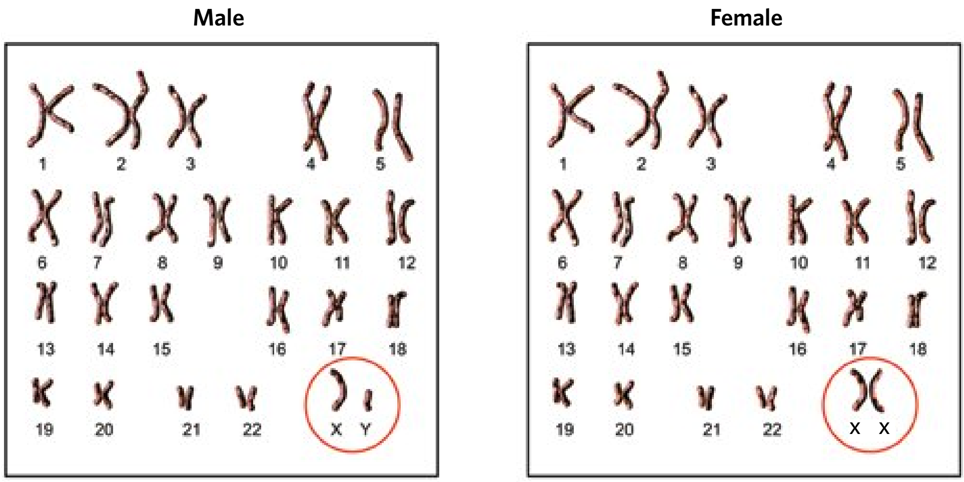


Image: Kateryna Kon/Shutterstock.com

Figure 11 Male and female karyotypes

As you can see, homologous pairs are arranged according to size. The pairs labelled 1–22 in Figure 11 are known as **autosomes**, each containing the genetic information for many thousands of genes. You will also notice that the final set of chromosomes (23) are labelled X or Y. These are known as **sex chromosomes**, and are responsible for determining the sex of an organism. In humans, two X chromosomes result in a female, whereas one X and one Y chromosome will result in a male.

autosome any chromosome (1–22) in humans that is not a sex chromosome

sex chromosome a chromosome responsible for determining the biological sex of an organism. In humans, sex chromosomes can be either an X or Y chromosome

Chromosomal variation 2.1.3.1

OVERVIEW

There is chromosomal variation across organisms both within a species and across multiple species. This helps scientists recognise genetic abnormalities and frames our understanding of the different genetic composition and degrees of relatedness between species.

THEORY DETAILS

Using karyotypes – separating species

The diploid chromosome number in human somatic cells is $2n = 46$. However, the diploid number across different species varies widely, as shown in Table 2. Scientists can use karyotypes to represent these differences in chromosome number and determine genetic differences between species.

Table 2 Diploid numbers across species

Species	Diploid number (2*n*)
Animals	
Jack jumper ant *(Myrmecia pilosula)*	2
Housefly *(Musca domestica)*	12
Cat *(Felis catus)*	38
Chimpanzee *(Pan troglodytes)*	48
Dog *(Canis familiaris)*	78
Butterfly *(Lysandra nivescens)*	190
Plants	
Garden pea *(Pisum sativum)*	14
Cabbage *(Brassica oleracea)*	18
Corn *(Zea mays)*	20
Coconut tree *(Cocos nucifera)*	32
Pineapple *(Ananas comosus)*	50
Fern *(Ophioglossum reticulatum)*	1 440

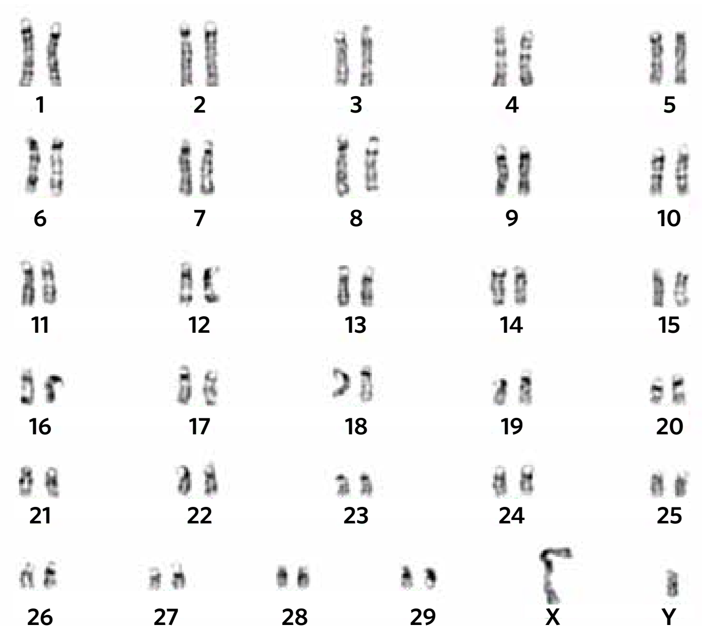


Figure 12 Karyotype of a cow ($2n = 60$)

Using karyotypes – detecting genetic abnormalities

Perhaps the most important use of the karyotype is to detect chromosomal abnormalities within species, such as **aneuploidy** and **polyploidy.**

Aneuploidy

Aneuploidy refers to a chromosomal abnormality in which an organism possesses an incorrect number of total chromosomes caused by the addition or loss of an individual chromosome. In humans, this would mean having more or less than the usual number of 46.

Depending on how many chromosomes are affected, we have different names to describe varying forms of aneuploidy. For instance:

- if an organism has one missing chromosome ($2n$-1), we call this **monosomy**.
- if an organism has one extra chromosome ($2n$+1), we call this **trisomy**.
- if an organism has two extra chromosomes ($2n$+2), we call this **tetrasomy**.

aneuploidy when a cell or organism varies in the usual number of chromosomes in its genome by the addition or loss of a chromosome

polyploidy when an organism contains additional sets of chromosomes in its genome

monosomy a genetic abnormality where an organism has one missing chromosome

trisomy a genetic abnormality where an organism has one extra chromosome

tetrasomy a genetic abnormality where an organism has two extra chromosomes

Theory in context

MONOSOMY

- Name: Turner syndrome
- Mutation: single X chromosome (often presented as XO)
- Incidence rate: 1 : 2 000
- Common symptoms: infertility, short stature, fused neck and head

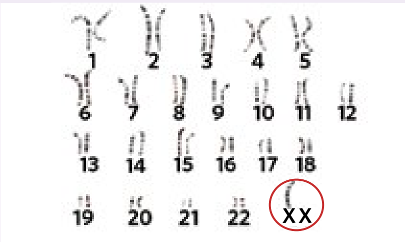


Image: Zuzanae/Shutterstock.com

Figure 13 Karyotype showing Turner syndrome

Figure 14 The webbed neck of a person with Turner syndrome

Theory in context

TRISOMY

- Name: Down syndrome (otherwise known as trisomy 21)
- Mutation: extra copy of chromosome 21
- Incidence rate: 1 : 1 000
- Common symptoms: delayed physical growth, possible heart defects, flattened facial profile, mild to moderate intellectual disability

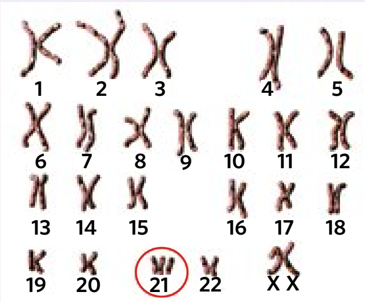


Image: Kateryna Kon/Shutterstock.com

Figure 15 Karyotype showing trisomy 21

Image: Denis Kuvaev/Shutterstock.com

Figure 16 Young girl with trisomy 21

Theory in context

TRISOMY

- Name: Klinefelter syndrome
- Mutation: extra X chromosome in males (XXY)
- Incidence rate: 1 : 650 males born
- Common symptoms: accelerated growth and taller height, small testes and reduced testosterone levels, delayed or incomplete puberty, decreased muscle mass, learning and intellectual disabilities, infertility

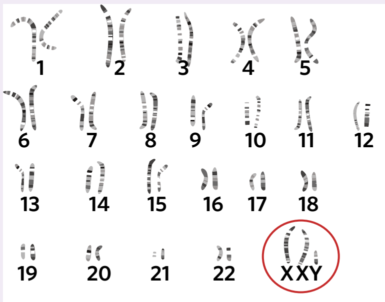


Image: Zuzanae/Shutterstock.com

Figure 17 Karyotype showing Klinefelter syndrome

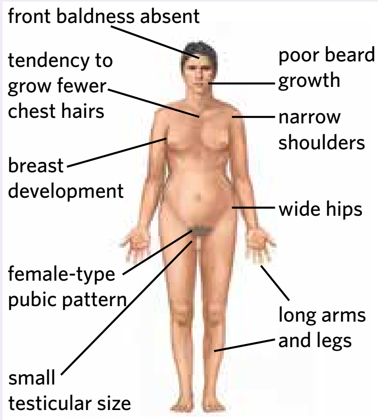


Figure 18 Common symptoms of Klinefelter syndrome

Theory in context

TETRASOMY

- Name: Tetrasomy X (otherwise known as XXXX)
- Mutation: two extra copies of the X chromosome (totalling 4)
- Incidence rate: there exists a community of around 100–150 confirmed cases worldwide. However, because females with the disorder rarely show symptoms, it is possible that a large majority of tetrasomy X cases go undiagnosed.
- Common symptoms: mild delay in physical development, delayed speech development, slight to moderate learning difficulties

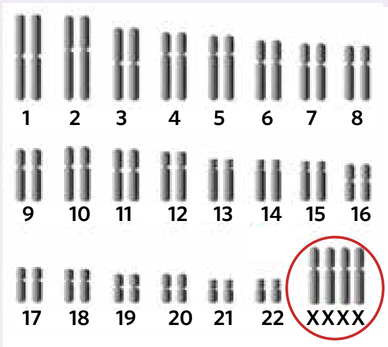


Image: Alila Medical Media /Shutterstock.com

Figure 19 Karyotype showing tetrasomy X

Polyploidy

Polyploidy refers to a chromosomal abnormality in which an organism has more than two sets of each chromosome. In humans, this would mean that rather than being diploid ($2n = 46$), the individual would be $3n = 72$ or more.

Polyploidy is typically lethal in humans, meaning that it is extremely rare for a foetus to survive to term. However, it is quite common for other organisms, especially plants, to thrive with additional sets of chromosomes. For example, one advantage of polyploidy includes increased size and hardiness in certain types of fruit. Even farmed Atlantic salmon are triploid. This makes the fish sterile, and also leads to a faster growth rate.

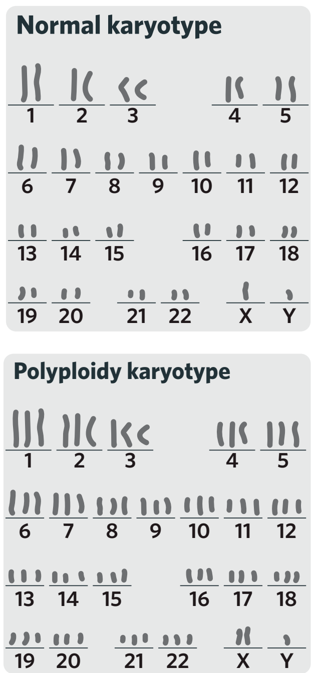


Figure 20 A comparison between a normal karyotype and a polyploidy karyotype

Theory summary

A gene is the basic unit responsible for the process of inheritance from one generation to the next. These genes, each composed of unique sequences of DNA, can be found at specific gene loci along a chromosome, which themselves pair together inside the nucleus of a cell to form homologous pairs. With this knowledge, scientists are able to karyotype the entire human genome in an attempt to identify and uncover genetic abnormalities in humans.

We display genetic features, such as our own unique hair and eye colour, thanks in large part to the genes that we inherited from our parents. The reason you and Aunty Helen need to put on extra sunscreen at the family barbeque and both have a face full of freckles is not because of ill-fated bad luck, but rather a complex process that can be traced back to specific genes in your genomes.

Image: Jet Cat Studio/Shutterstock.com

7A QUESTIONS

Theory review questions

Question 1

Fill in the blanks with the following terms. Terms may be used multiple times or not at all.

- chromosome
- nucleotides
- genome
- gene/s

The human __________ is contained within the nucleus of somatic cells, where each __________ is located at a fixed position along a __________. Each of these __________ are made up of specific sequences of __________ that code for the production of various proteins.

Question 2

Which of the following definitions best describes an allele?

A A particular form of a gene which biologists wish to express in an experiment.

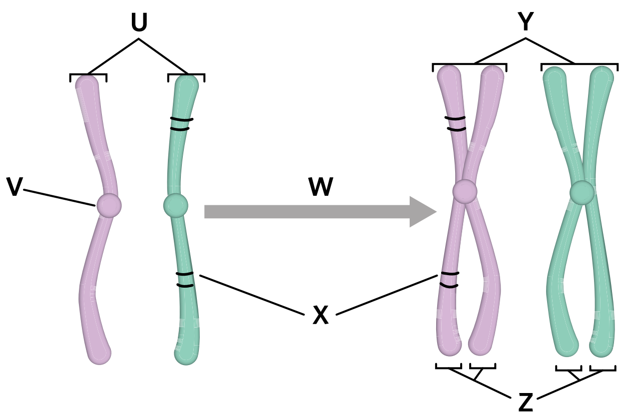
B The particular section of DNA responsible for the production of autosomes.

C A variant form of a gene with a unique nucleotide sequence.

Question 3

Label the parts of the following diagram from the list of terms. Terms may be used multiple times or not at all.

- homologous chromosomes
- sister chromatids
- centromere
- replication
- gene loci



Question 4

Which of the following does not describe a characteristic of homologous chromosomes? (*Select all that apply*)

I homologous chromosomes share the same sequence of nucleotides at each of their corresponding gene loci

II homologous chromosomes are identical copies of the same chromosome

III homologous chromosomes share the same genes at the same gene loci

IV homologous chromosomes each share the same centromere position

V homologous chromosomes are the same shape and size

Question 5

Which of the following options correctly describes what is being shown in the following karyotype?

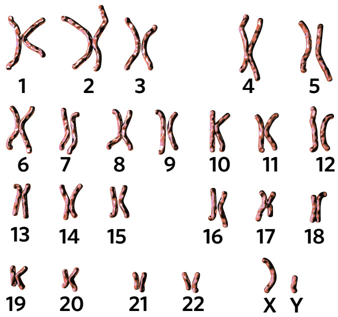


Image: Kateryna Kon/Shutterstock.com

A a female with trisomy

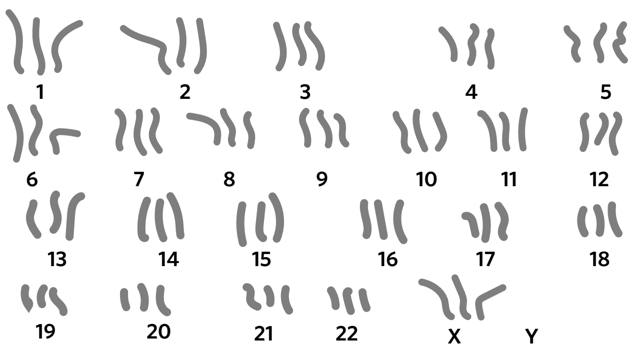
B a male with tetrasomy

C a male with no visible mutations

D a female with no visible mutations

Question 6

Which of the following options correctly describes what is being shown in the following karyotype?



A a female with tetrasomy X

B a female with polyploidy

C a male with trisomy 21

D a male with polyploidy

Question 7

Match the diploid number to the corresponding genetic abnormality.

Diploid number	Genetic abnormality
• $2n+1$	**I** ________ monosomy
• $2n+2$	**II** ________ polyploidy
• $2n-1$	**III** ________ tetrasomy
• $3n$	**IV** ________ trisomy

SAC skills questions

Bioethical deep dive

Use the following information to answer Questions 8–12.

In recent times, a person's genes have been considered as a possible explanation for certain types of anti-social behaviour, and have even been presented during criminal trials in an attempt to explain violent or impulsive crimes. For example, in the *State of Tennessee v. Davis Bradley Waldroup*, the accused had his conviction downgraded from murder to manslaughter following evidence that was given of a mutation in a particular gene called *MAOA.*

This gene, which is almost 92 000 base pairs long and located at position 11.3 on the X chromosome, provides the instructions for the creation of an enzyme called monoamine oxidase A. The enzyme plays an important role in the regular breakdown of serotonin, a neurotransmitter involved in mood regulation and emotion control in the brain.

The accused was shown to possess a mutation of this gene which caused a reduction in serotonin breakdown, and it was suggested that this had led to a range of behavioural problems such as increased aggression and violence. During his defence, a forensic scientist explained that the genetic makeup of the accused, combined with environmental factors during childhood, had left him at greater risk of violent behaviour as an adult.

Question 8

Which of the following statements is supported by the information provided?

A One possible explanation for a buildup of serotonin in the brain is mutated *MAOA.*

B Personal behaviour may sometimes be influenced by particular genetic factors.

C The accused possessed an allele for reduced monoamine oxidase A activity.

D All of the above.

Question 9

The term 'position 11.3' refers to which of the following?

A gene loci

B typical allele

C sex chromosome

D nucleotide sequence

Question 10

The concept of using genetic data to inform the area of criminal responsibility is a novel debate and requires the consideration of a number of bioethical approaches. Which of the following statements best reflects a duty-based approach to bioethics?

A 'While it may be interesting to consider genetic differences in offenders, it is more important to impose sanctions consistently. We must recognise that all people have a fundamental responsibility to act in a prosocial manner, regardless of any genetic abnormalities they might possess.'

B 'Murder is a serious crime that impacts severely on the family and friends of the victim. For that reason, people with mutations to their *MAOA* gene should be identified and monitored closely to avoid tragedies like this in the future.'

C 'It is incredibly important to consider the genetic makeup of criminals before deciding on an appropriate sanction. It would be unfair to ignore possible genetic differences that could be contributing to their offending behaviour.'

Question 11

The final sentence of the scenario shows the evaluation of a forensic scientist involved in the case. Which of the following ethical concepts are least likely to have informed his judgement?

A respect

B integrity

C duty-based approach

Question 12

A prominent biologist has recently suggested that all criminals be subjected to mandatory genetic screening to look for mutations similar to the one described in the scenario. Proponents of this suggestion argue that it would allow authorities to better identify high-risk individuals, and monitor them and their offspring for signs of serious violent behaviour and/or murderous tendencies.

How might the biologist's suggestion demonstrate non-maleficence?

A It acknowledges that science can help minimise criminality in our society by focusing on the causes of crime. Where serious violent crimes are concerned, genetic data of this sort may be of tremendous benefit.

B It acknowledges the responsibility of science to share its knowledge and understanding, regardless of the implications involved, so that the public can be as well-informed as possible.

C It acknowledges that all individuals have an intrinsic value and should not be forced into special treatment unless it is absolutely necessary.

D It acknowledges the need to always maximise benefits irrespective of possible harm.

Exam-style questions

Within lesson

Question 13 (1 MARK)

Genes are the basic biological unit responsible for the inheritance of genetic information. Which of the following is not true in regard to genes?

A Each gene always has exactly two possible alleles.

B Each gene can be found at a specific gene locus along a chromosome.

C All genes, regardless of species, are made of the same nucleic acid monomers.

D Some organisms have two copies of most genes, one on their maternal chromosome and one on the paternal chromosome.

Question 14 (1 MARK)

Humans typically have 46 chromosomes present in their somatic cells. How many of these 46 chromosomes are autosomal?

A 22

B 23

C 42

D 44

Question 15 (1 MARK)

Consider the following diagram of a particular cellular structure.

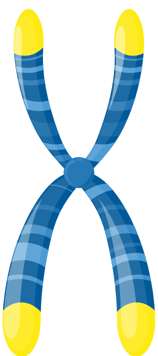


Image: Designua/Shutterstock.com

This structure is

A only made of DNA.

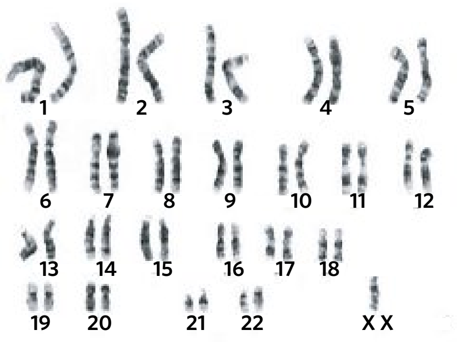
B held together by a telomere.

C inherited from two parent organisms.

D found in the nucleus of most cells inside the human body.

Question 16 (5 MARKS)

The image represents a karyotype of a woman's genome.



a Identify whether this woman's karyotype is the same as a typical human karyotype. Justify your response. (2 MARKS)

b Identify the two different types of macromolecules that would be found in the structures shown within the diagram. (1 MARK)

c Draw a labelled diagram of the general structure of a woman's nucleic acid monomer. (2 MARKS)

Adapted from VCAA 2014 Exam Section B Q9

Multiple lessons

Use the following information to answer Questions 17 and 18.

The diagram shows a cell at telophase.

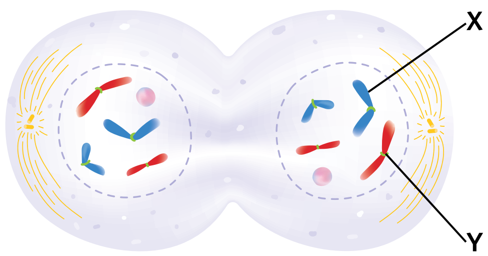


Image: Achiichii/Shutterstock.com

Question 17 (1 MARK)

The structure labelled X is a

A sister chromatids.

B centromere.

C spindle fibre.

D chromosome.

Question 18 (1 MARK)

The structure labelled Y is a

A sister chromatids.

B centromere.

C spindle fibre

D chromosome.

Question 19 (4 MARKS)

Achondrogenesis 1A is a genetic disorder that results in stunted growth and the shortening of all bones in the body of those affected. It is caused by a mutation to the *TRIP11* gene, which is responsible for the production of the proteins necessary for forming the Golgi complex within a cell. Individuals with mutations to the *TRIP11* gene fail to produce a protein called GMAP-210, which assists in the packaging and transport of important proteins, such as those responsible for the functioning of chondrocytes (skeletal cells), between the endoplasmic reticulum and the Golgi complex.

a As a result of a mutated *TRIP11* gene, which other organelle involved in protein transport around the cell is likely to be affected in sufferers of achondrogenesis 1A? (1 MARK)

b Explain how the impact of a mutated *TRIP11* gene might contribute to the symptoms shown in sufferers of achondrogenesis 1A. (3 MARKS)

Question 20 (2 MARKS)

Eukaryotic cells grow and replicate via the eukaryotic cell cycle.

a What stage of the cell cycle is responsible for the replication of DNA and the creation of identical sister chromatids? (1 MARK)

b Draw a pair of homologous chromosomes before this phase of the cell cycle. (1 MARK)

Key science skills and ethical understanding

Question 21 (9 MARKS)

Mr. Ted Rolla asked his class to investigate a hypothetical crime scene, where they were told to identify the murderer using DNA profiling based on skin cells that were found on the murder weapon. The specific sequence of DNA that was extracted from the skin cells and provided to students was as follows: CATGACAGACAGACAGACATACCC.

Jessica remembered notes that she had taken during one of Mr. Rolla's classes last week:

- Noncoding DNA (DNA sequence that does not code for proteins) is very useful for DNA profiling as it shows lots of variation between individuals. This is because a mutation in noncoding DNA rarely affects a person's phenotype and is therefore less likely to be eliminated through natural selection.
- In particular, DNA profiling often uses specific sections of noncoding DNA called short tandem repeats (STRs). These sections of DNA are where unit bases, typically two to five bases long, are repeated multiple times (e.g. ACTACTACT) at a given gene locus.
- Each person has a unique allele for an STR sequence which is defined by the number of repeated units they possess at that locus (e.g. person A might show six repeats – $[ACT]_6$ – while person B might show 15 – $[ACT]_{15}$).

During class, Jessica used a process called gel electrophoresis to separate and examine a specific sequence of DNA from three different suspects. She summarised her results in the following table:

Suspect 1	STR: $[GACA]_9$
Suspect 2	STR: $[GACA]_4$
Suspect 3	STR: $[GACA]_{37}$

a Identify the murderer based on Jessica's finding. (1 MARK)

b During the same class, students examined sections of STR in their fingertips. Jessica and her lab partner obtained the following results:

- Jessica's STR sequence: AATTCACGTCACGTCACGTCACGTCACGTCACGGA
- Lab partner's STR sequence: ATTCACGTCACGG

Describe the difference between the STRs of both Jessica and her lab partner in terms of the number of unit repeats. (2 MARKS)

c Jessica's lab partner explained that the specific STR sequence that the murderer possesses must be a gene that codes for increased *MAOA* activity. Explain why this assumption is incorrect. (2 MARKS)

d Still convinced that the murderer's STR sequence is responsible for increased aggression, Jessica's lab partner believes that the murderer's children should also have their DNA sequenced to determine whether they inherited the same STR. How might a consequences-based approach to bioethics respond in favour of this suggestion? (2 MARKS)

e Jessica believes that sequencing the DNA of the murderer's children would be unethical and intrusive. How might a virtues-based approach to bioethics support this conclusion? (2 MARKS)

7B MEIOSIS

Take a look at this picture of the Hemsworth brothers – Liam (left), Chris (middle), and Luke (right). Despite sharing the same parents, there are clear genetic differences between each of them. How can this be? How can siblings show such variance despite being born with genetic material from the same two parents?

Image: FeatureFlashPhoto/Shutterstock.com

Lesson 7B

In this lesson you will be learning about the process of meiosis, including its purpose and outcomes.

◀ *Prerequisite knowledge* | *Future applications* ▶

Years 7–10
Heritable characteristics which are transmitted from one generation to the next come from both parents and rely on the processes of fertilisation and meiosis.

Lesson 4B
Each eukaryotic cell goes through what is known as the cell cycle and produces two identical daughter cells as a result of the process of mitosis.

Lesson 9A
In sexual reproduction, the outputs of meiosis (gametes) are combined to produce a new living organism.

Year 12
In Year 12, you will consider the relatedness of species over time, including genetic changes arising through meiosis which can affect the allele frequencies of a population.

Study design dot point

- the production of haploid gametes from diploid cells by meiosis, including the significance of crossing over of chromatids and independent assortment for genetic diversity

Key knowledge unit

How meiosis works	2.1.5.1

How meiosis works 2.1.5.1

OVERVIEW

Meiosis is a specific type of cell division whereby a single cell divides twice to produce four unique daughter cells each with half the number of chromosomes of the original. These daughter cells are known as gametes, and are essential for sexual reproduction.

THEORY DETAILS

What is meiosis?

Meiosis is a specialised form of cell division that occurs in sexually reproducing organisms and is used to produce the **gametes** necessary for sexual reproduction. In humans, these gametes are sperm and egg (also known as ova) cells, which contain only one copy of each chromosome (n) and will fuse together during fertilisation to create two copies of each chromosome ($2n$) inside a developing **zygote**.

Meiosis involves a single cell dividing into four haploid cells, each of which is genetically different from one another. In humans, the dividing cell is known as a **germline cell** and is found in the **gonads** (testes for males and ovaries in females).

meiosis a specialised form of cell division used to produce gametes in sexually reproducing organisms

gametes reproductive cells that arise from germline cells and contain half the genetic material (n) of a somatic cell. The gametes in animals are sperm and egg cells

zygote the diploid cell formed by the combination of two haploid gamete cells

germline cell cells that are involved in the generation of gametes in eukaryotes

gonads the organs that produce gametes from germline cells. In humans these are the testes (male) and ovaries (female)

The process involves two distinct cellular divisions:

- meiosis I – which separates each homologous chromosome into two different cells.
- meiosis II – which separates each sister chromatid into four different cells.

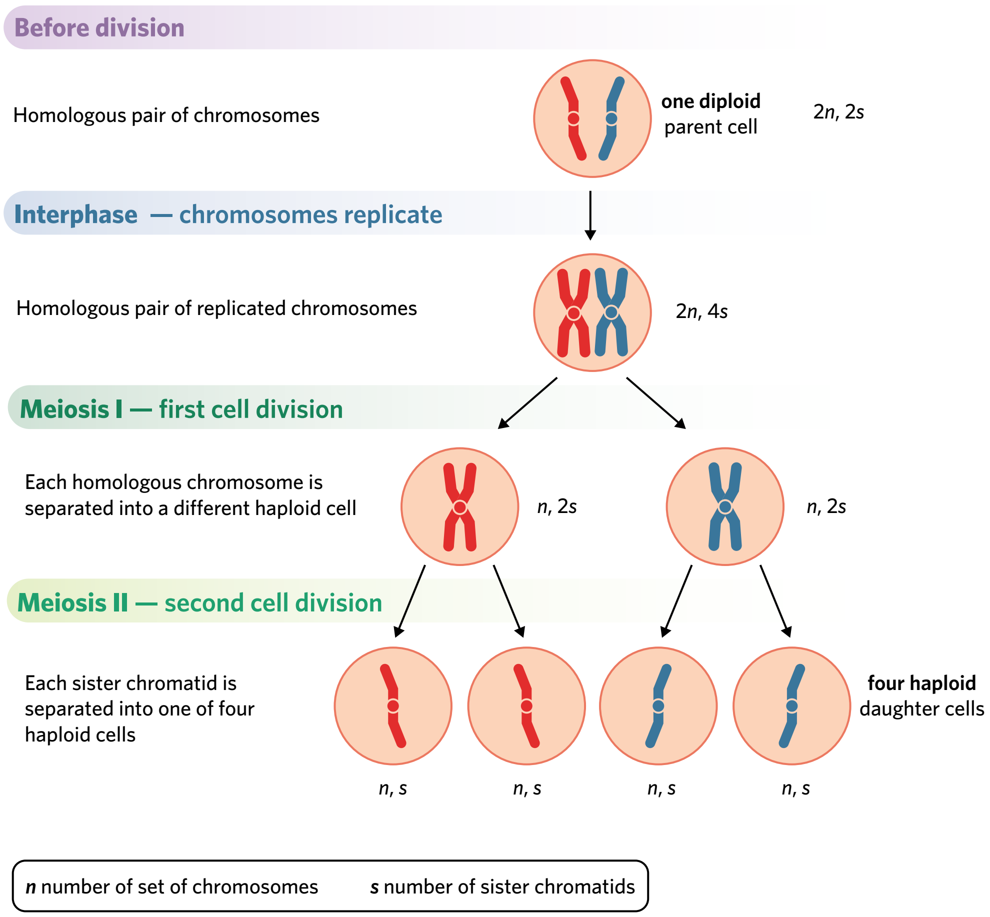


Figure 1 Visual summary of meiosis, including the inputs and outputs of each round of division

Meiosis versus mitosis

Mitosis, which is the primary type of cell division that you learned about in lesson 4B, is used by almost every cell in your body and results in the production of two identical copies of the original cell. Mitosis is important in facilitating development and growth and is also used to replace old or malfunctioning cells within our body with identical copies.

Meiosis, on the other hand, serves one specific purpose – to produce gametes which have exactly half the genetic material of the original cell. This is important for sexual reproduction so that when two gametes fuse during fertilisation, the resulting offspring does not inherit double the amount of necessary genetic material.

Table 1 A summary of the different inputs and outputs of mitosis and meiosis in humans

	Input (start of G1)	Output (end of cytokinesis)
Mitosis	1 × somatic cell ($2n$)	2 × identical somatic cells ($2n$)
Meiosis	1 × germline cell ($2n$)	4 × genetically unique gamete cells (n)

Meiosis I

Figure 2 shows each of the stages of meiosis I, which begins with a diploid germline cell and results in two genetically distinct daughter cells. These cells will then become the inputs for the second round of division in meiosis II.

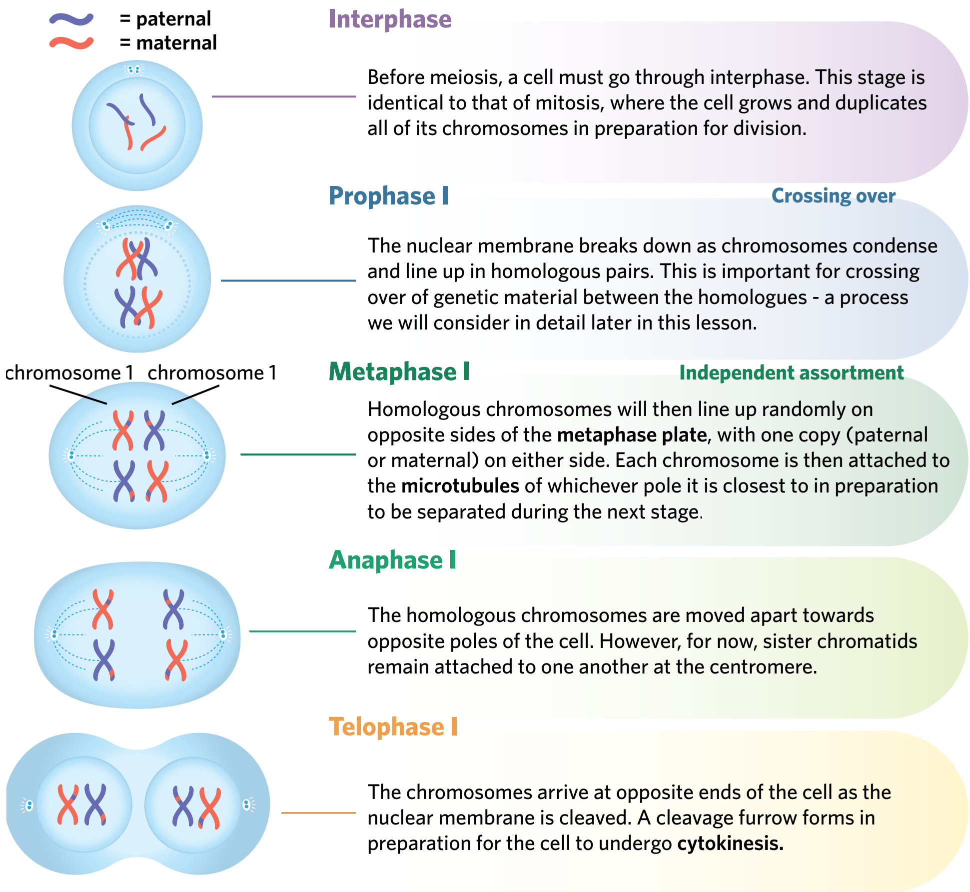


Image: Ody_Stocker/Shutterstock.com

Figure 2 Steps involved in meiosis I

metaphase plate the equator of a dividing cell where chromosomes will line up during metaphase

microtubules long tube-like fibre proteins that form part of the cytoskeleton of a eukaryotic cell and help give the cell its structure. Microtubules are used for a variety of cell movements, including transport of cell organelles and the movement of chromosomes during cell division

cytokinesis the division of the cytoplasm and formation of two daughter cells

crossing over the exchange of genetic material between non-sister chromatids during prophase I of meiosis, resulting in new combinations of alleles in daughter cells

chiasma the point/location of overlap between two non-sister chromatids

independent assortment the random orientation of homologous chromosomes along the metaphase plate during metaphase I

The aim of meiotic division is to produce gametes that are genetically distinct from each other, and from the parent cell from which they originated. This occurs thanks to intricate processes during meiotic division that contribute to increased genetic diversity in the resulting daughter cells. These are indicated in Figure 2 and include crossing over and independent assortment. These processes are described in Figure 3.

Crossing over

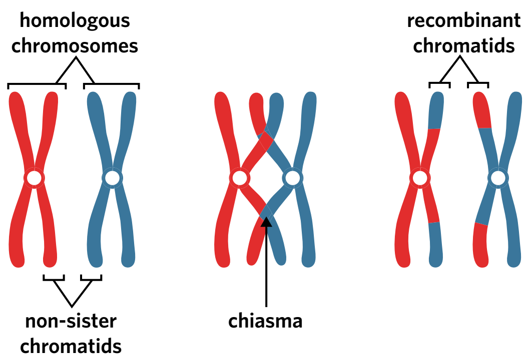
The exchanging of genetic material from one homologue to the other during prophase I. The homologous chromosomes will ‘cross over’ at a point called the **chiasma**, each swapping part of their DNA with the other.

Independent assortment

The random orientation of homologous chromosomes along the metaphase plate during metaphase I. Each pair of homologues line up randomly, irrespective of the orientation of other homologous pairs.

Why is this important for genetic diversity?

Crossing over results in the formation of new recombinant chromatids each with its own unique combination of alleles. This adds to the genetic diversity of the resulting haploid daughter cell as the sister chromatids that they will inherit are no longer identical.



Pairs of homologous chromosomes line up on opposite sides of the metaphase plate. The resulting combination of alleles in each daughter cell is randomised since what is inherited depends on which side of the metaphase plate each chromosome is positioned. The number of different combinations in humans is around 8 million (2^{23}).

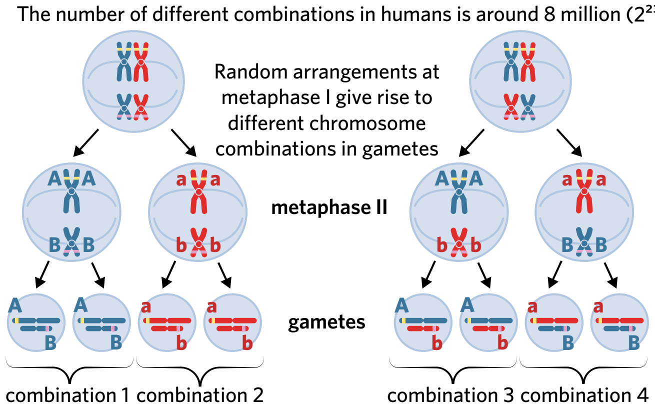


Image: Fancy Tapis/Shutterstock.com

Figure 3 Meiotic processes that increase genetic diversity

Meiosis II

Figure 4 shows each of the stages involved in the second round of meiotic division, which takes the haploid cells that were created in meiosis I and, by splitting each of the chromosomes into two sister chromatids, creates four separate haploid cells.

Theory in action

Check out scientific investigation 7.2 to put this into action!

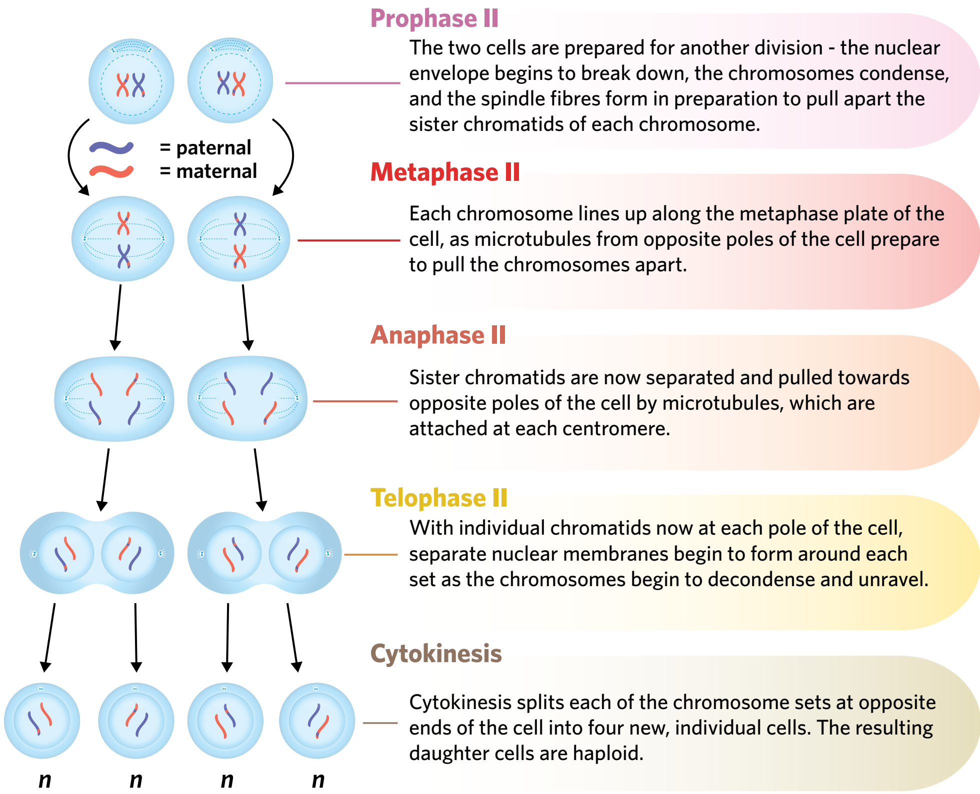


Image: Ody_Stocker/Shutterstock.com

Figure 4 Steps involved in meiosis II

Theory summary

Figure 5 depicts the entire process of meiosis, from a single diploid germline cell in interphase to the creation of four daughter cells, known as gametes. Gametes contain half the genetic information of the germline cell and are each genetically unique from one another. Meiosis increases the genetic diversity present in resulting gamete cells through two processes:

- crossing over in prophase I – which exchanges genetic material between chromosomes and results in recombinant chromatids.
- independent assortment during metaphase I – which allows homologous chromosomes to arrange randomly along the equator of the cell and results in the random splitting of chromosomes into different daughter cells.

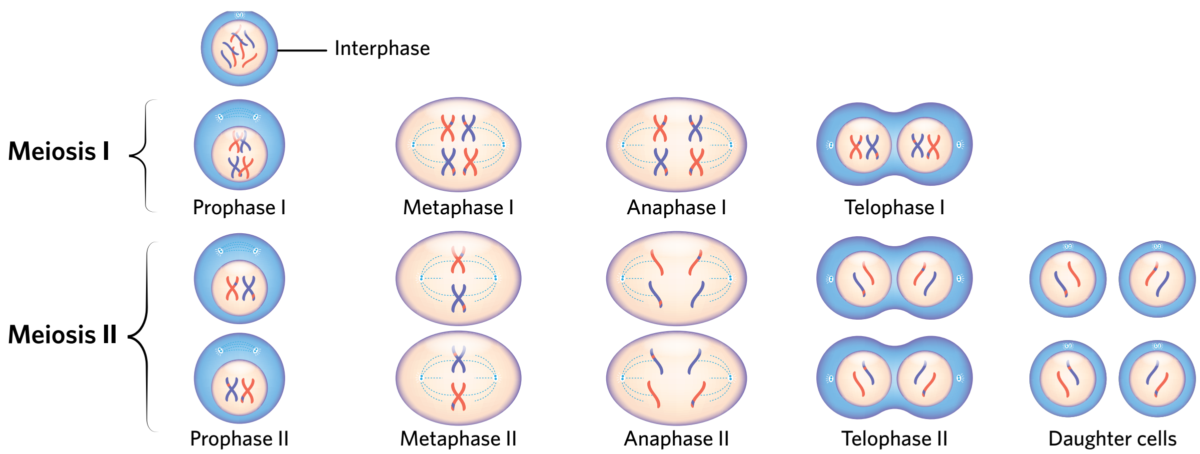


Image: Ody_Stocker/Shutterstock.com

Figure 5 The process of meiotic division including interphase, meiosis I, and meiosis II

We now know that offspring resulting from sexual reproduction can look significantly different to each other thanks to the increased genetic diversity resulting from meiotic cell division. This increased diversity is predominantly caused by the exchange of genetic material during crossing over in prophase I, and due to the random nature of independent assortment in metaphase I.

Thanks to the processes of independent assortment and crossing over, you and your sister have different DNA. This explains why your sister might have long, curly locks while you're stuck with a mop. Or indeed, why your brothers might be tall, international Hollywood megastars while you're not as tall.

7B QUESTIONS

Theory review questions

Question 1

Which of the following correctly summarises the outcome of one meiotic cell division?

A One diploid germline cell divides to create four haploid gametes.

B One diploid somatic cell divides to create four diploid gametes.

Question 2

Which of the following is true of the gametes created by meiosis?

A Each gamete is genetically unique from each other, but identical to the germline cell that they originated from.

B Each gamete is genetically unique from each other as well as from the germline cell that they originated from.

Question 3

Label the stages of meiosis I from the list of terms.

- prophase I
- telophase I
- anaphase I
- metaphase I

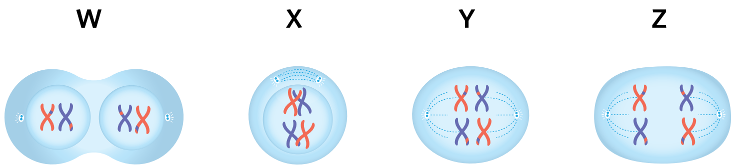


Image: Ody_Stocker/Shutterstock.com

Question 4

Fill in the blanks with the following terms.

- chiasma
- increases
- exchanging
- crossing over
- metaphase plate
- recombinant chromatids
- independent assortment

Meiosis __________ the genetic diversity of resulting daughter cells in a number of ways. Firstly, __________ occurs during prophase I and involves the __________ of genetic material between homologous chromosomes at a point called the __________. This results in the formation of __________ each with their own unique combination of alleles. Secondly, __________ involves homologous chromosomes lining up randomly on either side of the __________ during metaphase I and results in random inheritance of chromosomes.

Question 5

Order the steps to correctly describe the stages of meiosis I.

I Chromosomes arrive at opposite poles of the cell as the nuclear membrane is cleaved.
II The cell grows in size and duplicates all of its genetic material to prepare for division.
III Chromosomes line up at the equator of the cell and are attached to microtubules.
IV Homologous chromosomes are moved apart towards opposite poles of the cell.
V Chromosomes line up in homologous pairs and exchange genetic material.

Question 6

Which of the following stages are unique to meiosis II? *(Select all that apply)*

I The cell grows in size and duplicates its chromosomes in preparation for division.
II Cytokinesis cleaves the nuclear membrane of one cell into two daughter cells.
III Sister chromatids are separated and pulled towards opposite poles of the cell.
IV Single-chromatid chromosomes line up along the metaphase plate of the cell.

Question 7

This diagram shows a cell in metaphase I. The total number of chromatids shown in the diagram is

A four.
B eight.
C sixteen.
D hundreds.

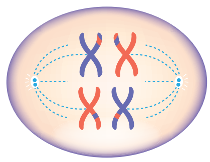


Image:Ody_Stocker/Shutterstock.com

Question 8

This diagram shows two cells in anaphase II. The total number of chromosomes shown in each cell is

A four.
B eight.
C sixteen.
D forty-six.

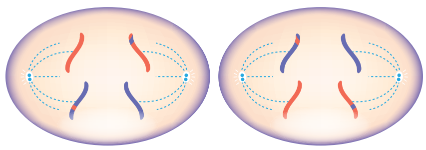
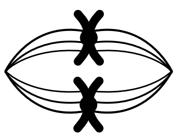


Image:Ody_Stocker/Shutterstock.com

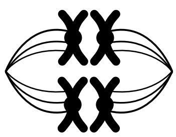
Question 9

Which of the following depicts a stage of cell division that is unique to meiosis?

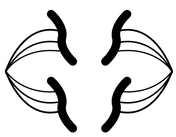
I



II



III



A I only
B II only
C II and III
D All are unique to meiosis

Question 10

The processes listed are all involved in meiotic cell division. Match the correct stage to the description provided.

Stages	Description
• interphase	**I** __________ DNA is replicated
• prophase I	**II** __________ segregation of sister chromatids
• anaphase II	**III** __________ separate nuclear membranes begin to form
• telophase I & II	**IV** __________ condensed chromosomes line up in homologous pairs

SAC skills questions

Bioethical deep dive

Use the following information to answer Questions 11–15.

There is often an overtly male-centric bias in biological research, which can sometimes be a barrier to fully understanding a particular concept or issue. Young et al. (2008), for instance, explained that nesting success in birds was better understood only once female-to-female bonding was acknowledged, and Gowaty (1997) suggested that research into female variability unlocked a better understanding of sexual selection theory.

The same is true in how we describe meiosis, which often explains the process specifically in terms of male gamete production (known as spermatogenesis). Instead, female gamete production, known as oogenesis, is quite distinct and involves a single oocyte (immature egg cell) dividing into one functional ovum and three polar bodies, which are themselves unviable. The first round of meiosis in females will occur during development as a foetus but will be halted until the individual hits puberty. This suggests that females are born with all of the primary oocytes they will ever have in life (roughly six million), and will eventually run out of their supply of viable eggs.

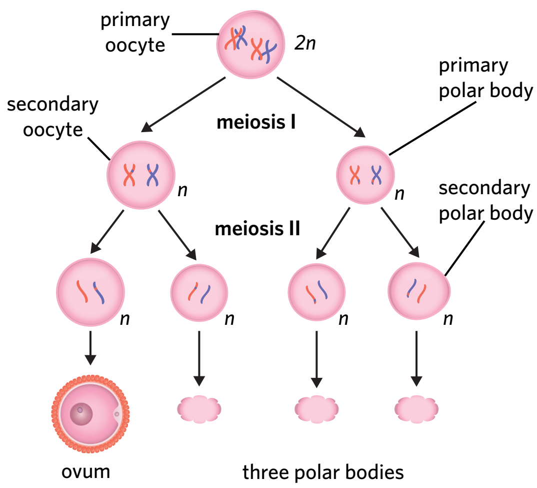


Image: Ody_Stocker/Shutterstock.com

Finally, the pattern of recombination that occurs during crossing over can also differ between males and females of the same species. As Brick et al. (2018) found, the female crossover rate was much higher than the male crossover rate in humans and in mice. Ultimately, these sex-specific differences in meiotic division are underrepresented due to a historic male-centric bias in biological research and are necessary considerations in developing a more complete understanding of an organism's biology, including their sexual behaviour.

Question 11

Which of the following correctly summarises the difference in functional gamete production between male spermatogenesis and female oogenesis?

A Both spermatogenesis and oogenesis result in the production of four viable gametes, each capable of transferring its DNA to the next generation.

B Spermatogenesis results in the production of four polar bodies, each capable of transferring its DNA, whereas oogenesis results in the production of three polar bodies.

C Spermatogenesis results in the production of four distinct functional gametes, each of which is capable of transferring its DNA to the next generation. Oogenesis, on the other hand, results in the production of only one functional gamete.

Question 12

Reference to past studies in the first paragraph best serve which of the following purposes in the above extract?

A examples of male-centric bias in zoological (animal) biology

B examples of the benefits of being aware of sex differences in research

C examples of female-focused studies showing better methodology than male-focused studies

Question 13

A recent article was published in a major newspaper. It was titled 'Every woman's biological clock – why conception is time sensitive'. With reference to the information in the extract, which of the following explanations best summarises the meaning behind the article's title?

A Oocytes develop while a female is still in the womb, and most scientists believe that this production stops once the individual is born.

B The higher frequency of recombination that occurs during cell division in females means that there is a specific time period in which zygote formation is actually viable.

C Oocytes are produced exponentially during the early stages of a woman's life, but meiotic division of these gametes does not occur until that individual reaches a particular age.

Question 14

The final sentence of the extract claims that sex-specific differences are underrepresented. Such underrepresentation undermines the ethical concept of integrity in which of the following ways?

A ignoring the fact that educators have a duty to act in a particular way

B limiting public knowledge and failing to commit to complete understanding

C failing to consider the consequences of a male-centric bias in scientific research

Question 15

According to the Department of Industry, Science, Energy, and Resources, the percentage of women working in STEM (science, technology, engineering, and mathematics) qualified occupations in 2019 was only 14%. Researchers suggest that this could be the result of gender stereotypes in STEM education, including the use of gender-biased language, teaching methods, and materials.

Which of the following sentences from the extract serves as an example of this type of gender-bias?

A 'often explains the process specifically in terms of male gamete production'

B 'the first round of meiosis in females will occur during development as a foetus'

C 'nesting success in birds was better understood only once female-to-female bonding was acknowledged'

D 'the pattern of recombination that occurs during crossing over can also differ between males and females'

Exam-style questions

Within lesson

Question 16 (1 MARK)

Various types of specialised cells were obtained from a research participant. The amount of DNA in each cell type was measured and the following results were obtained.

Cell type	Picograms of DNA
L	5.02
M	2.52
N	1.28
O	2.53

Based on the data obtained, it is reasonable to assume that the cell type most likely to be a sperm cell is

A cell L.

B cell M.

C cell N.

D cell O.

Question 17 (1 MARK)

The haploid cells created as a result of meiotic cell division each contain

A one copy of each gene.

B 23 copies of each gene.

C 46 copies of each gene.

D two copies of each gene.

Question 18 (2 MARKS)

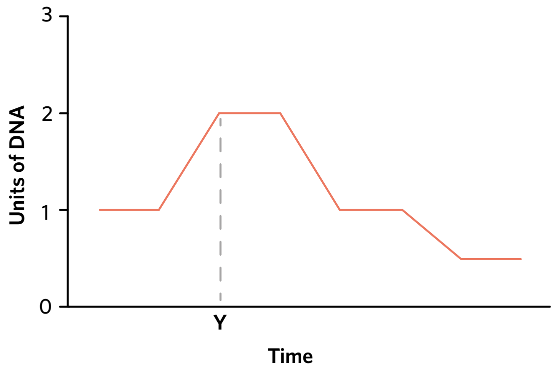
The yellow fever mosquito *(Aedes aegypti)* has a diploid number of six. Specific cells in the ovary of this mosquito undergo meiosis to produce haploid gametes.

a How many double-stranded chromosomes would be contained in the nucleus of a single germline cell before meiosis? (1 MARK)

b How many chromosomes would be contained in any one gamete at the end of a complete meiotic division? (1 MARK)

Question 19 (4 MARKS)

The following diagram represents changes to the amount of DNA that is present inside a human cell during cell division.



a Identify what type of cell division is being shown in the diagram. (1 MARK)

b The highest point of the graph is at 2 units of DNA.

  i Explain which stage of the cell cycle is being represented by Y. (1 MARK)

  ii Identify both the chromosome and chromatid numbers respectively at this stage of cell division. (2 MARKS)

Multiple lessons

Question 20 (4 MARKS)

Haplodiploidy is a sex-dependent inheritance system in which females develop from fertilised eggs, while males develop from unfertilised eggs. Many species of bee exhibit haplodiploidy, including the European honey bee *(Apis mellifera)*, whose females have a diploid number of 32.

a Based on the information provided, identify the chromosome number of male honey bees. (1 MARK)

b It is reasonable to conclude that a wing cell from a female honey bee would contain how many pairs of homologous chromosomes? (1 MARK)

c With reference to chromosome numbers, identify which type of cell division a male honey bee is likely to undergo when producing gametes for sexual reproduction? (2 MARKS)

Key science skills and ethical understanding

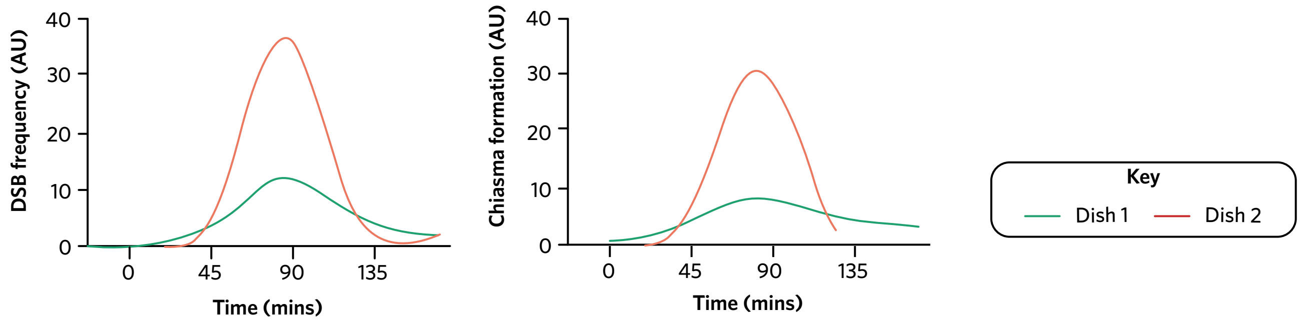
Question 21 (7 MARKS)

Grace wanted to investigate the activity of the protein Spo11 in stimulating recombination during prophase I. She made the following notes before designing her experiment.

- crossing over is triggered by double-strand breaks (DSBs), where both strands of a DNA double helix are cut by a protein called Spo11.
- the cell recognises DSBs as hazardous, causing the two chromosomes to come together to form a chiasma and rectify the DSB.

Grace incubated separate Petri dishes containing *Saccharomyces cerevisiae* (yeast) cells post-interphase for 45 minutes, ensuring the conditions were kept at 30 degrees Celsius with a pH of 5.0. After observing each dish under a light microscope post-incubation, Grace introduced a higher concentration of Spo11 to Petri dish number 2 and waited another 45 minutes before observing the cells once more.

Some of Grace's findings are represented in the graphs provided.



a Based on Grace's findings, what can be assumed about the relationship between Spo11 and the rate of recombination? (1 MARK)

b State whether Grace obtained qualitative or quantitative data. (1 MARK)

c Identify both the independent and dependent variables in Grace's experiment. (2 MARKS)

d What was the control used in Grace's experiment? (1 MARK)

e Grace believes that her findings have special relevance to the agricultural industry and plans to market a higher recombination frequency using her method to farmers growing yeast for commercial use in Australia. Grace argues that this would increase the genetic diversity of their products, and subsequently improve their sales to the Australian public.

State a possible opposition to Grace's method using the bioethical concept of respect. (2 MARKS)

7C GENOTYPES AND PHENOTYPES

Can you see the letter embedded within the image? For people with normal vision, an uppercase letter S should jump out immediately. However, for people with red-green colour blindness this becomes much more difficult. What about the other people in your class? Do you notice a difference between boys and girls?

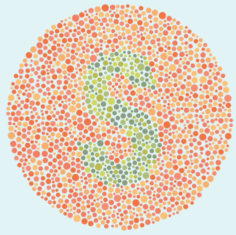


Image: LuckyBall/Shutterstock.com

Lesson 7C

In this lesson you will learn how to represent alleles using genotypes and how different forms of dominance affect genotype expression.

◀ *Prerequisite knowledge* | *Future applications* ▶

Years 7–10
Heritable characteristics can be transmitted from generation to generation and this pattern of inheritance can be understood with reference to dominant and recessive genes.

Lesson 7B
The process of meiosis, which involves diploid cells (2*n*) being split into independently assorted haploid (*n*) gametes, is essential for ensuring genetic diversity.

Chapter 8
Using your understanding of genotypes and gene expression, this chapter explores methods of predicting genetic outcomes through the use of monohybrid and dihybrid crosses.

Year 12
Deepen your knowledge from this lesson by understanding the role of nucleic acids in maintaining life, including DNA manipulation and the relationship between DNA and the human proteome.

Study design dot points

- the use of symbols in the writing of genotypes for the alleles present at a particular gene locus
- the expression of dominant and recessive phenotypes, including codominance and incomplete dominance

Key knowledge units

Dominant and recessive genotypes	2.1.6.1
Codominance and incomplete dominance	2.1.7.1
Sex-linked genotypes	2.1.7.2

Dominant and recessive genotypes 2.1.6.1

OVERVIEW

Not all alleles of a particular gene are expressed equally. In most cases one allele will be dominant and will mask the expression of the other allele in an organism's phenotype. We can represent this information using a genotype. Dominant alleles are written using capital letters, whereas recessive alleles are written with lowercase letters.

THEORY DETAILS

Homozygous vs heterozygous

Every **diploid** organism inherits a particular combination of two alleles from their parents. If an individual inherits two identical alleles from both their mother and father, they are said to be **homozygous** for that gene. For example, both parents might pass on the allele for hitchhiker's thumb (hyper-flexible thumb) to their offspring. In this case, the gametes produced by that individual will always contain the same allele for hitchhiker's thumb (Figure 1).

But what happens when an offspring inherits two different alleles for the same gene? For example, they might inherit an allele for hitchhiker's thumb from their mother but an allele for regular thumb flexibility from their father. We call a person with two different alleles for the same gene **heterozygous** for that gene. In this case, due to meiosis, the gametes produced by that heterozygous individual will be of two kinds – half having the allele for hitchhiker's thumb and half having the allele for regular thumb flexibility.

diploid having two sets (*2n*) of each chromosome, one from each parent

homozygous having identical alleles for the same gene on homologous chromosomes

heterozygous having different alleles for the same gene on homologous chromosomes

Figure 1 Hitchhiker's thumb

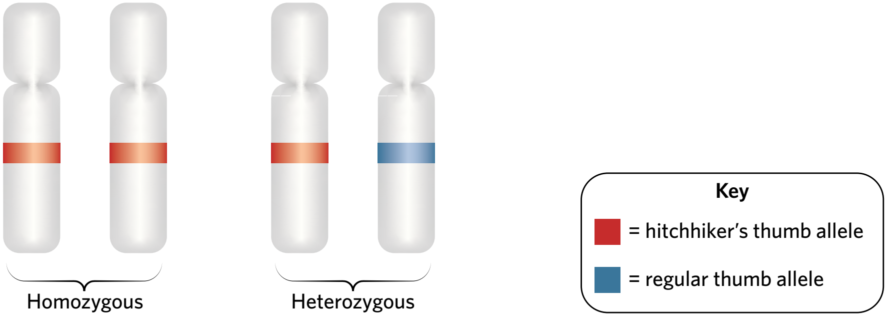


Figure 2 A visual representation of homozygosity and heterozygosity. Notice that the homozygote will always produce gametes that contain an allele for hitchhiker's thumb, whereas the heterozygote could produce gametes that contain either an allele for hitchhiker's thumb or an allele for regular thumb flexibility.

Dominant vs recessive alleles

In the case of a heterozygote, it is not immediately obvious which gene will be expressed. Instead, we must understand that alleles can be either dominant or recessive.

- A **dominant allele** can be thought of as the stronger form of a pair of alleles and is represented with a capital letter. We call it a dominant allele because it will always be expressed even if the individual only has one copy of that allele (as is the case with heterozygotes). For example, the allele for brown eyes is dominant, meaning that you only need to inherit one copy of the 'brown eye' allele from one of your parents to have brown eyes.
- A **recessive allele** can be thought of as the weaker form of a pair of alleles, and is represented with a lowercase letter. We call it the recessive allele because it will only be expressed if the individual has two copies of that allele (that is, if they are homozygous for the recessive allele). For example, the allele for blue eyes is recessive, meaning that you need to inherit two copies of the 'blue eye' allele (one from each parent) to have blue eyes.

This is called **complete dominance** – when a dominant allele is fully expressed in a **phenotype** and masks the expression of a recessive allele. Although a dominant allele may mask the expression of a recessive allele, a person who is heterozygous at a specific gene locus is still a **carrier**, meaning they are able to pass on the recessive allele to their offspring despite not displaying the trait.

Be careful not to assume that dominant alleles are always more common than recessive alleles. For example, achondroplasia, or dwarfism, is a dominant trait over the recessive trait for regular height. Despite this, roughly only 1 in 25 000 people have achondroplasia.

dominant allele the variant of a gene that masks the effect of a recessive allele of the same gene on a homologous chromosome

recessive allele the variant of a gene that is masked by a dominant allele on a homologous chromosome

complete dominance a pattern of dominance where only the dominant allele from the genotype of a heterozygous individual is expressed in the phenotype of that organism

phenotype the physical or biochemical characteristics of an organism that are the result of gene expression (or set of genes) and the environment

carrier an organism that has inherited a copy of a recessive allele for a genetic trait but does not display the trait due to it being masked by the presence of a dominant allele

Theory in context

SICKLE CELL ANAEMIA – HETEROZYGOTE ADVANTAGE

Sometimes an allele is disadvantageous for an organism's survival and will be bred out over time. However, in some unique cases, carrying a typically disadvantageous allele can actually confer an overall biological advantage for the organism. We call this a heterozygote advantage. This can help explain why harmful recessive alleles are able to persist in a population over time, hidden in fit heterozygotes, rather than being removed via natural selection.

One example of heterozygote advantage is the sickle cell trait, caused by a mutation in the gene encoding haemoglobin. The sickle cell trait is expressed according to incomplete dominance, where the mutated form of haemoglobin causes red blood cells to become sickle-shaped when exposed to low oxygen levels. The misshapen red blood cells can block capillaries and are bad at transporting oxygen. Two copies of the sickle cell allele leads to a high degree of sickling in the blood, causing the disease sickle cell anemia (SCA). SCA confers a strong resistance to malaria, but because SCA often results in premature death from damage to internal organs or stroke the disease is generally selected against.

Individuals who are heterozygous or homozygous for the normal type haemoglobin allele do not suffer from sickle cell anemia, despite heterozygous individuals displaying low levels of red blood cell sickling. However, due to this low level of sickling, heterozygous carriers of the sickle cell allele have greater malaria resistance than individuals homozygous for the normal haemoglobin allele. Furthermore, when infected with malaria the red blood cells of heterozygous individuals are more likely to sickle and become targeted by the immune system, conveying further resistance to the malaria parasite (Figure 3). This means that it is advantageous to be heterozygous in malarial regions, such as Africa and Asia. As a result, the deleterious recessive allele persists in populations, despite the deadliness of being homozygous for the sickle cell trait.

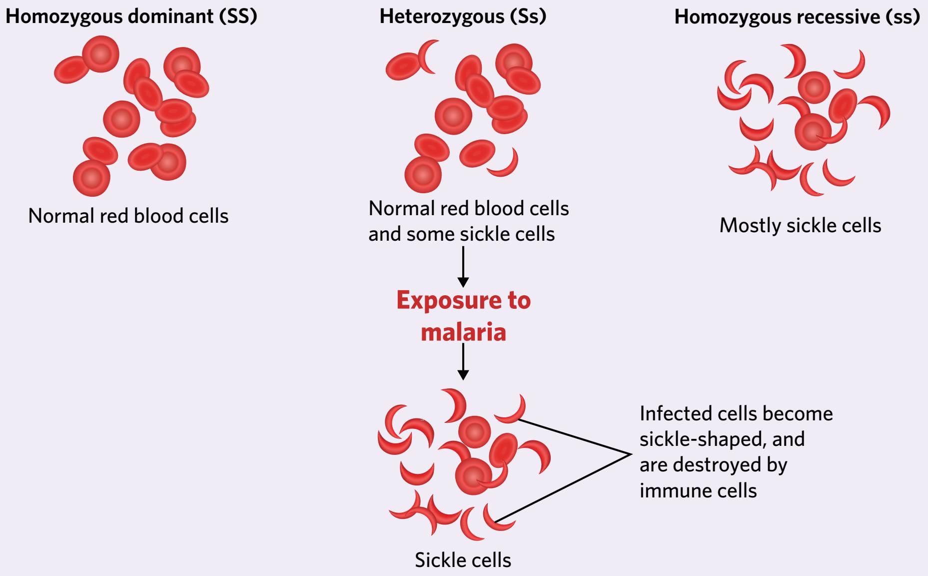


Figure 3 The genotypes and phenotypes for sickle cell anaemia

Genotypes – representing alleles

A **genotype** is denoted by a set of letters that show us if an individual is homozygous dominant, homozygous recessive, or heterozygous for a certain trait. We use capital letters to represent dominant alleles, and lowercase letters to represent recessive alleles (Table 1).

genotype the genetic composition of an organism at one particular gene locus, as represented using letter symbols

Table 1 The genotypes used to describe homozygosity and heterozygosity. The letter 'A' is used in this example, but any letter of the alphabet could be used.

Zygosity	Genotype
Homozygous dominant	AA
Heterozygous	Aa
Homozygous recessive	aa

Any letter of the alphabet can be used, although we typically use letters that relate to the trait in question (so we could use the letters T and t to describe the genotype for **t**humb flexibility).

Theory in context

EARLOBES

Some geneticists believe that earlobes are an autosomal trait controlled by a single gene. It is assumed that there are two possible phenotypes:

1 free earlobes, which hang below the point at which the ear attaches to the side of the head.
2 attached earlobes, which are smaller in size and attach directly to the side of the head without hanging.

Image: Peter Hermes Furian/Shutterstock.com

Figure 4 Free (left) and attached earlobes (right)

Free earlobes are the dominant allele (A), while attached earlobes are recessive (a). The possible genotypes that an individual can possess are shown in Figure 5. In this case, both the homozygous dominant (AA) and heterozygous (Aa) individual will show free earlobes, while only the homozygous recessive (aa) individual will show attached earlobes.

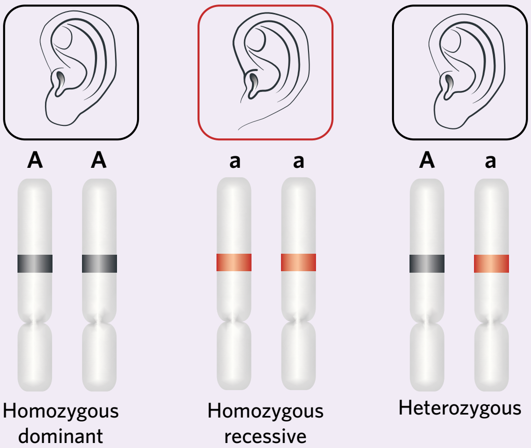


Image: Peter Hermes Furian/Shutterstock.com

Figure 5 Possible genotypes with respect to earlobes

Phenotypes – expressed trait

An organism's genotype will directly influence the observable characteristics and differences we see from individual to individual. We call an organism's observable features their phenotype, which encompasses things like the organism's physical form and structure, its behaviour, and even its internal biochemical processes.

An organism's phenotype is influenced both by its genotype and by the environment in which it lives, and is therefore susceptible to change over time. For example, a person's weight is influenced both by the genes they inherit and by factors such as food intake and exercise levels. You will learn more about this in lesson 7D.

Theory in action

Can you roll your tongue like the woman in Figure 6? Current research suggests that the ability to roll the tongue into a tube shape is controlled by a single gene that exhibits complete dominance.

In this case, we have two possible phenotypes: (1) being able to roll your tongue into a tube shape and (2) not being able to roll your tongue into a tube shape. These two phenotypes are controlled in large by the presence of two possible alleles – one for tongue rolling, which is dominant (T) and one for non-tongue rolling, which is recessive (t).

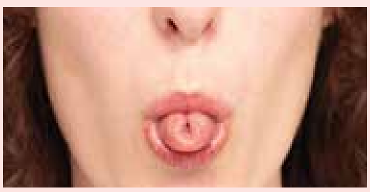


Image: Sruilk/Shutterstock.com

Figure 6 Visual depiction of tongue rolling

As an activity, count how many of your classmates can roll their tongue into a tube shape. Is it possible to determine each person's genotype for tongue rolling just by looking at them? Why or why not?

Codominance and incomplete dominance 2.1.7.1

OVERVIEW

Complete dominance is not the only pattern of dominance that can occur in relation to the expression of alleles. In some cases, a particular gene might show either codominance or incomplete dominance.

THEORY DETAILS

If a gene is inherited with complete dominance, only one allele from the genotype is expressed in the phenotype. For example, if a flower has the genotype 'Aa' in respect to petal colour – where capital 'A' is red petals and lowercase 'a' is white petals – then complete dominance would mean that the flower would exhibit red petals in its phenotype. However, there are two other patterns of dominance:

- **Codominance**, which occurs when both alleles from the genotype are fully expressed in the phenotype of a heterozygote. That is, both alleles can be thought of as dominant and neither allele can mask the expression of the other allele.
- **Incomplete dominance**, which occurs when neither allele from the genotype is fully expressed in the phenotype of a heterozygote, and the resulting observable trait is a 'blending' of both alleles.

Continuing with our example of flower petal colour (Figure 7), if the gene responsible displayed codominance, we would expect to see both red and white petals in a heterozygote. However, if the gene for petal colour showed incomplete dominance, heterozygotes would exhibit a brand new trait that was a mixture of red and white – say, pink.

Because neither allele is completely dominant in codominance and incomplete dominance, we have to write genotypes a little differently. Here, we use a standard capital letter that stays the same, and two different superscript letters to represent the two different alleles (Table 2).

Table 2 The letters used to describe homozygosity and heterozygosity for codominance and incomplete dominance. The letters A, B, and C are used in this example, but any letter of the alphabet could be used for the base letter or the superscripts, as long as they are different from each other.

Zygosity	Genotype
Homozygous option A	C^AC^A
Heterozygous	C^AC^B
Homozygous option B	C^BC^B

codominance a pattern of dominance where both alleles from the genotype of a heterozygous individual are dominant and expressed in the phenotype of that organism

incomplete dominance a pattern of dominance where neither allele from the genotype of a heterozygous individual is dominant and both are expressed in an intermediate phenotype

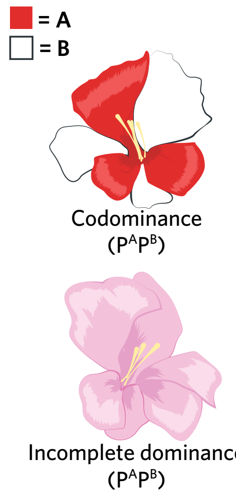


Figure 7 Visual representation of codominance and incomplete dominance

Theory in context

CODOMINANCE IN ACTION – ABO BLOOD TYPING

The human blood group system is known as the ABO blood grouping. It is under the control of a single gene with the following three alleles:

- I^A – presence of antigen A on red blood cells
- I^B – presence of antigen B on red blood cells
- i – neither antigen A or B on red blood cells

These three alleles contribute to four different possible phenotypes:

- Blood type A
- Blood type B
- Blood type AB
- Blood type O

The ABO blood system demonstrates codominance and complete dominance. The allele for blood type O is recessive to both other alleles, but neither allele A nor B show dominance over the other. This means that heterozygous individuals with the genotype I^AI^B will express both blood group A and B in their phenotypes (Figure 8). The possible genotypes and their associated phenotypes are:

- I^AI^A – Blood type A
- I^Ai – Blood type A
- I^AI^B – Blood type AB
- I^BI^B – Blood type B
- I^Bi – Blood type B
- ii – Blood type O

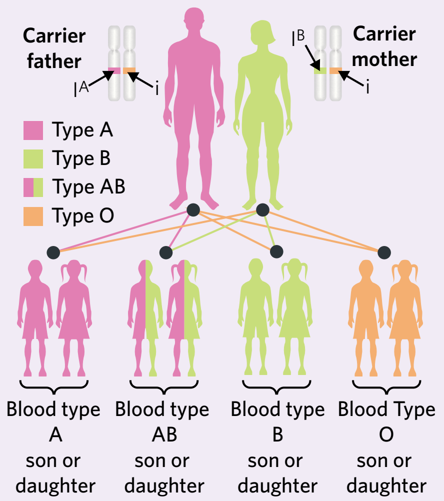


Image: udaix/Shutterstock.com

Figure 8 Blood types as an example of codominance

Theory in context

INCOMPLETE DOMINANCE IN ACTION – PINK SNAPDRAGONS

Consider the snapdragon, *Antirrhinum majus*, which you might see in your nanna's garden. If you cross a homozygous white-coloured snapdragon (C^WC^W) with a homozygous red-coloured snapdragon (C^RC^R), the resulting offspring (C^WC^R) will show a pink colour in its phenotype. This is an example of incomplete dominance, as a cross between two homozygotes has resulted in a heterozygote intermediate.

Image: Natalie Board/Shutterstock.com

Figure 9 A bunch of pink snapdragon flowers

Sex-linked genotypes 2.1.7.2

OVERVIEW

Sex-linked genes are represented differently to autosomal traits, and are written using superscript notation and their sex chromosome – e.g. X^AY.

THEORY DETAILS

So far we have considered genotypes and phenotypes with reference to autosomal traits. However, not all genes are inherited on autosomal chromosomes. Genes are also found on the sex chromosomes of an organism and are often closely related to the gender of that organism. These genes are known as **sex-linked genes**, and are represented differently in genotypes.

sex-linked genes genes that are located on a sex chromosome

X-linked traits a trait controlled by a gene that is located on the X chromosome

Y-linked traits a trait controlled by a gene that is located on the Y chromosome

What are sex-linked genes?

Sex-linked genes are genes present on either the X or Y chromosomes. However, the X chromosome is much longer than the Y chromosome, containing as many as 4 000 more genes. Therefore, when thinking about sex-linked inheritance, we are usually referring more specifically to **X-linked traits**, as these are far more common. **Y-linked traits** also exist, but are quite rare and only show up in males.

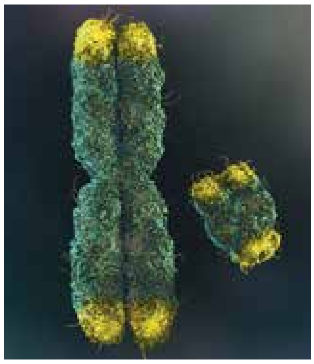


Image:Nathan Devery/Shutterstock.com

Figure 10 X (left) and Y (right) chromosomes

X-linked traits are also more likely to be expressed in males than they are in females. This is because each male only receives one copy of an X chromosome, which comes from their mother. Whatever allele a male receives on the inherited copy of their X chromosome is what is expressed in their phenotype, regardless of whether that allele is dominant or recessive. There is no corresponding allele on the Y chromosome to cancel out the effects of the allele on the X chromosome. This means that if the allele is faulty and causes a condition, then that male has a 100% chance of showing that condition.

However, males with X-linked traits or conditions are unable to pass the trait on to their sons. This is because if a male has a son, that son must receive their Y chromosome from their father. Affected males can only pass on the abnormal X-linked gene to their daughters (Figure 11).

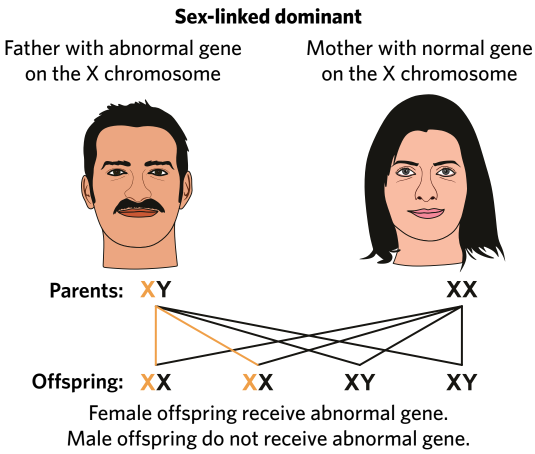


Image: udaix/Shutterstock.com

Figure 11 X-linked inheritance with an affected father

Sex-linked genotypes

Sex-linked genotypes are written differently, following a similar superscript notation as codominance and incomplete dominance. However, the standard base letter is always X or Y. This is because as well as communicating which allele is dominant or recessive, sex-linked genotypes need to also show which sex chromosome carries the allele.

For example, assume we are looking at the gene for red-green colour blindness, which is a recessive X-linked trait. We can write this as X^b – showing that the affected gene is carried on the X chromosome and is recessive (lowercase b). Genotypic variations are shown in Table 3.

Table 3 Genotypic variations for colour blindness

Phenotype	Genotype
Affected female	X^bX^b
Unaffected female (carrier)	X^BX^b
Unaffected female	$X^B X^B$
Affected male	X^bY
Unaffected male	X^BY

Because males only have one X chromosome, if they inherit the faulty gene that codes for colour blindness then they will be colour blind. This is because, unlike females, a male does not possess two X chromosomes, and therefore would not inherit a copy of the dominant allele for regular colour vision which would mask the effect of the faulty allele. This is why colour blindness is more common in men. It's important to note that females can still be colour blind – the likelihood of this happening, however, is much lower, given that they would need to inherit two faulty alleles instead of just one.

Theory in context

HAEMOPHILIA A

The *F8* gene is located on the X chromosome and provides instructions for a range of proteins that are essential for the formation of blood clots. After an injury, these clots protect the body by blocking damaged blood vessels and limiting further blood loss. However, people with a mutated *F8* gene are less able to create blood clots and are prone to excessive bleeding – a condition known as haemophilia A.

This condition is inherited in an X-linked recessive pattern. This means that the mutation that causes haemophilia A is a recessive allele that is inherited on the X chromosome of an organism, and will be masked by the normal *F8* allele. Because males only have one X chromosome, if that chromosome contains the mutated gene then they will show the condition, whereas females must inherit two copies of the faulty allele. A female with only one copy of the mutated gene is a carrier.

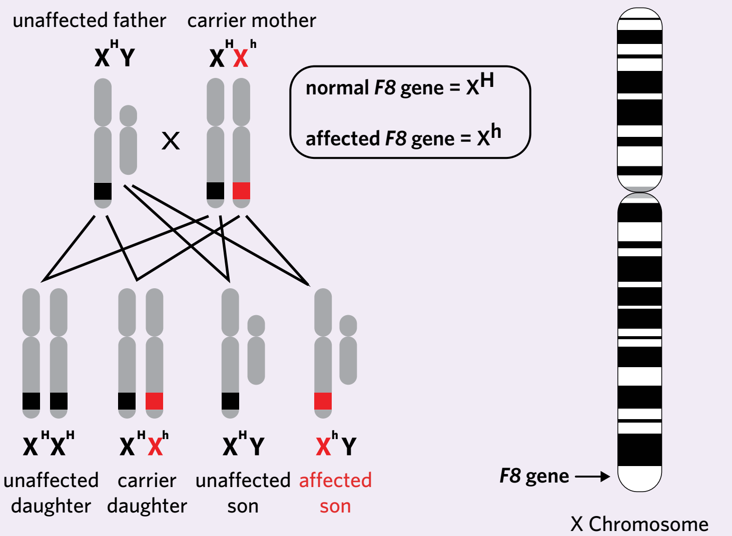


Image: Alila Medical Media/Shutterstock.com

Figure 12 Visual depiction of haemophilia A – an X-linked recessive trait

Theory summary

A genotype represents the allele combinations at a specific gene locus, and is written using letter symbols. Dominant alleles are represented with a capital letter while recessive alleles are represented with a lowercase letter.

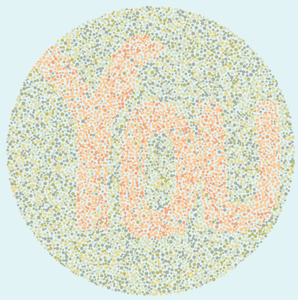
A phenotype refers to the physical or biochemical characteristics of an organism that arise from gene expression and the environment. Phenotypes may result from different types of dominance patterns:

- Complete dominance – dominant alleles completely mask the expression of recessive alleles.
- Codominance – both alleles are expressed.
- Incomplete dominance – neither allele is wholly expressed and instead an intermediate hybrid phenotype of the two is created.

Colour blindness affects males and females differently. Red-green colour blindness, for example, is the most common form of colour blindness and is said to affect around 8% of males and 0.5% of females of European descent.

This is because colour blindness is an X-linked recessive trait, meaning that males are much more likely to show the condition in their phenotype than females. As males only inherit one X-chromosome, they express whatever allele is present. On the other hand, females need to inherit two copies of the recessive trait to express the condition in their phenotype.

So, now that you know all this, who's going to smash the test tomorrow?



7C QUESTIONS

Theory review questions

Question 1

Which of the following correctly summarises the distinction between an organism's genotype and their phenotype?

A genotype refers to the alleles that an organism has inherited for a particular gene, while phenotype refers to all of an organism's observable traits

B genotype refers to any observable characteristics arising from an organism's genome, while phenotype refers to the expression of traits based on the environment

Question 2

Fill in the blanks in the following sentences.

An organism that has inherited identical alleles for the same gene on both of its homologous chromosomes is said to be __________ for that gene. Conversely, if an organism possesses two different alleles for the same gene then it is said to be __________ for that gene.

Question 3

Which of the following is true of a carrier? (*Select all that apply*)

I A carrier of an X-linked recessive trait can be male.

II The offspring of a carrier may express the disorder in their phenotype.

III A carrier of an autosomal recessive disorder will usually be asymptomatic.

Question 4

A homozygous plant with red petals (AA) mates with another homozygous plant with white petals (aa) and produces an offspring with pink petals. Based on this information, which type of dominance do the alleles for petal colour display?

A codominance

B complete dominance

C incomplete dominance

Question 5

If an organism displays a phenotype that is the result of incomplete dominance, that organism's genotype is

A heterozygous for all genes.

B heterozygous for that gene.

C homozygous recessive for that gene.

Question 6

Which of the following is not true of sex-linked genes? (*Select all that apply*)

I There are more genes on the X chromosome than on the Y chromosome.

II If a male inherits a recessive allele on his X chromosome it will not be expressed in his phenotype.

III X-linked traits are more likely to be expressed in females than they are in males, as females have two copies of the X chromosome.

IV If a male carries an allele for a particular disease on his X chromosome, he will only be able to pass on that abnormal X-linked trait to his daughters.

SAC skills questions

Case study analysis

Use the following information to answer Questions 7–12.

Inherited haematological (blood-related) disorders are prevalent across Africa, but are distributed differently across the continent. One such disorder is glucose-6-phosphate dehydrogenase (G6PD) deficiency, which is caused by a mutation in the *G6PD* gene and can lead to the premature breakdown of red blood cells in the body.

Normally, the *G6PD* gene provides instructions for making a protein that protects red blood cells from being damaged by certain types of molecules introduced by the environment. These molecules can come from malarial infection or a diet rich in fava beans. Due to the malfunctioning protein, red blood cells are more likely to be destroyed by these molecules leading to the development of haemolytic anaemia, a condition in which red blood cells are destroyed faster than they can be replaced. This leads to symptoms such as paleness, yellowing of the skin, dark urine, fatigue, and a rapid heart rate in affected individuals.

Recent data estimates that around 400 million people worldwide possess the G6PD protein deficiency. These numbers are concentrated largely in certain areas of Africa and Asia, where instances of malaria infections are high. Moreover, the deficiency occurs almost exclusively in males. For instance, approximately 1 in 5 boys in Malawi are deficient in the G6PD protein, while the number of affected females is comparatively much smaller.

Question 7

A deficiency in G6PD protein causes

A the premature breakdown of red blood cells.

B introduction of certain molecules that can be harmful to red blood cells.

Question 8

Malfunctioning of the glucose-6-phosphate dehydrogenase protein is known as

A haemolytic anaemia.

B G6PD protein deficiency.

Question 9

Based on the information provided about the prevalence of G6PD protein deficiency, it seems likely that the disorder is

A autosomal recessive.

B X-linked recessive.

Question 10

Which of the following genotypes best represents a male with G6PD protein deficiency?

A X^gY

B X^gY^g

C Gg

D gg

Question 11

Unlike homozygous recessive individuals, research has found that heterozygous carriers of the G6PD protein deficiency actually have added protection against severe malaria. How might this finding best explain the high prevalence of G6PD protein deficiency in African countries?

A Higher frequencies of latent haematological disorders such as G6PD protein deficiency might have occurred due to their relative protection against severe malaria, a condition that occurs in higher frequencies in African countries.

B Heterozygous carriers of the G6PD protein deficiency are still able to pass on the mutated *G6PD* allele to their offspring, despite showing no symptoms of the disorder.

C Two copies of an allele for normal *G6PD* functioning reduces the genetic heterogeneity of an organism and increases vulnerability to malaria.

Question 12

One symptom of G6PD protein deficiency is pale skin. This is most likely the result of

A a lack of vitamin B-12 being absorbed by the skin in African individuals.

B a lack of oxygen in the bloodstream resulting from a lower red blood cell count.

C increased oxygen in the bloodstream resulting from a higher red blood cell count.

Exam-style questions

Within lesson

Question 13 (1 MARK)

Assume a gene has two different alleles. The number of different genotypes possible at that gene locus is

A 3.

B 6.

C 8.

D 10.

Question 14 (1 MARK)

Assume a gene has four different alleles. The number of different genotypes possible at that gene locus is

A 3.

B 6.

C 8.

D 10.

Question 15 (1 MARK)

Molly has a recessive, sex-linked genetic disorder that impacts the functioning of her red blood cells. The two alleles controlling the trait are:

- A = regular functioning red blood cells
- a = affected red blood cells

Molly's genotype with respect to this gene locus is

A X^AX^a.

B X^aX^a.

C Aa.

D aa.

Question 16 (3 MARKS)

The ABO blood group system has the following three alleles:

- I^A-presence of antigen A on red blood cells
- I^B-presence of antigen B on red blood cells
- i-neither antigen A or B on red blood cells

I^A and I^B exhibit codominance, while i is recessive to both I^A and I^B.

A family of four children have the following phenotypes:

Child	Phenotype
1	Blood type A
2	Blood type AB
3	Blood type B
4	Blood type O

a Suggest the possible genotype/s of child number 2. (1 MARK)

b Suggest the possible genotype/s of child number 1. (1 MARK)

c Identify the phenotypes of the parents of these children. (1 MARK)

Question 17 (3 MARKS)

A gene in Hereford cattle is controlled by two autosomal alleles – H for having horns, and h for being hornless. Jeremiah, a hornless bull, was mated with Princess Leia, who had her horns removed as a young calf to stop her from injuring the other cattle in her pen. The mother of Princess Leia was homozygous recessive for this gene.

a Identify the genotype of Princess Leia with respect to horns. (1 MARK)

b The owners of Jeremiah and Princess Leia plan to have them mate and produce offspring. Based on the information given, suggest whether a child of these two cattle could be born with horns. (2 MARKS)

Multiple lessons

Question 18 (7 MARKS)

Khmer's mother and father had two children. Khmer is three years older than his sibling, and displays many differences when compared to his other immediate family members. In particular, Khmer is the only member of his immediate family that has an autosomal recessive condition. The alleles of the gene locus involved are D and d.

a Give a possible genotype for each of the four members of his family. (2 MARKS)

b Khmer's sibling was married and had a child with their partner, who did not display the condition. However, the offspring was born with the autosomal recessive condition. Based on this information, what can be inferred about the genotype of Khmer's sibling? Justify your response. (2 MARKS)

c The autosomal recessive condition that Khmer has inherited causes issues with his internal thermoregulation. In particular, Khmer's thermoreceptors often fail to communicate temperature changes to his hypothalamus.

  i In terms of the stimulus-response model, what role does the hypothalamus play in thermoregulation? (1 MARK)

  ii Briefly outline the regular stimulus-response model for thermoregulation in humans. (2 MARKS)

Question 19 (7 MARKS)

In some fly species, eye colour is determined by a gene on the X chromosome with two alleles. Such fly species follow the same pattern of sex determination as humans

- X^R = red
- X^r = white

a Identify the genotype of a male expressing the recessive phenotype. (1 MARK)

b A fly was identified as a heterozygote for eye colour. Based on this information, what can we assume about the sex of the organism? Justify your response. (2 MARKS)

c Identify the genotype and corresponding phenotype of a heterozygote for eye colour. (2 MARKS)

d Some fly species have a larger surface-area-to-volume ratio than other insects. Scientists argue that this will directly impact the fly's ability to retain water.

Explain the relationship between surface-area-to-volume ratio and water loss in flies. (2 MARKS)

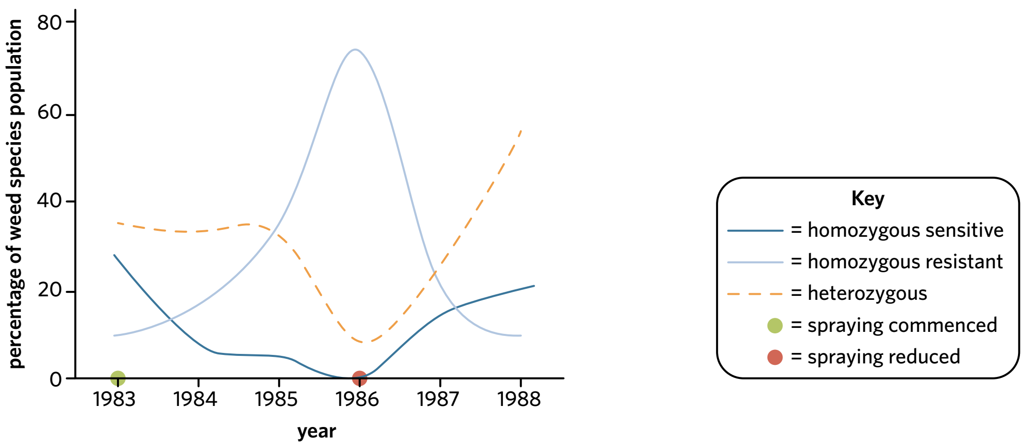
Key science skills and ethical understanding

Question 20 (12 MARKS)

In the mid-1980s, GCY was used as a herbicide against a particularly harmful weed species that was growing in large quantities in many Western Australian pastures. The sensitivity to the herbicide in the species of weed is determined by a single gene that has two alleles.

- allele 1: resistant to GCY
- allele 2: sensitive to GCY

GCY spraying commenced in 1983 and reduced significantly in 1986. Genotypic frequencies were measured across this period in a particular population of the weed species, and the results were tallied in the graph shown.



Adapted from VCAA 2010 Exam 2 Section A Q23

a Based on the data provided, describe the relationship that can be inferred between the GCY herbicide and the heterozygous weed population. (2 MARKS)

b Explain the peak of homozygous resistant weeds seen in 1986. (2 MARKS)

c One botanist claimed that the allele for sensitivity to GCY had completely disappeared from the population by 1986, when GCY spraying was at its highest. With reference to the data provided, explain whether this assumption is correct. (2 MARKS)

d The use of herbicides has been widespread since the mid 20th century, especially around farms where weed growth can be particularly disruptive to crops by competing for nutrients and pasture space. Nevertheless, some pockets of society oppose herbicide use on the grounds that it can have many unintended consequences, including unintended damage to habitats.

- **i** How might the owner of a weed-infested farm defend the use of herbicides using a consequences-based approach to bioethics? (2 MARKS)
- **ii** How might the leader of an anti-herbicide protest group oppose the use of herbicides using a consequences-based approach to bioethics? (2 MARKS)
- **iii** Suggest how a duty/rule-based approach to bioethics could inform the farmer's safe use of herbicides. (2 MARKS)

7D NATURE VS NURTURE

Take a look at the two boys in the picture. They are identical twins, which means they share the same DNA as a result of developing from a single fertilised ovum. Yet, despite sharing the same genome, the two boys will begin to show differences in their phenotype as they grow and develop.

How is this possible? How can two identical twins, with identical DNA sequences, display noticeable differences in their appearance?

Image: Vitalinka/Shutterstock.com

Lesson 7D

In this lesson you will learn that the expression of an organism's phenotype depends on their genes and the environment in which they live.

◀ *Prerequisite knowledge* | *Future applications* ▶

Years 7–10
The transmission of heritable characteristics from one generation to the next involves DNA and genes.

Chapter 7
Throughout this chapter you have learned about genes and chromosomes, including the observable expression of genetic information in an organism's phenotype.

Chapter 8
The next chapter will look further into the process of inheritance, including how to demonstrate the inheritance pattern of certain genes over multiple generations.

Year 12
Cellular processes, such as transcription and translation, are vital for the production of important proteins. Environmental factors influence these processes by altering gene expression.

Study design dot point

- proportionate influences of genetic material, and environmental and epigenetic factors, on phenotypes

Key knowledge units

The effect of the environment on phenotype	2.1.9.1
Epigenetics	2.1.9.2

The effect of the environment on phenotype 2.1.9.1

OVERVIEW

Phenotypes are influenced not only by an organism's genes, but also by the environment in which they live.

THEORY DETAILS

In the previous lesson, you learned that an organism's genes are expressed in their phenotype, and that different genes may show varying levels of dominance when expressed as observable characteristics. However, while we often describe genes as coding for a specific trait, such as a gene for eye colour or a gene for height, it is rarely as simple as a 1 : 1 ratio where one gene is responsible for one trait. Instead, most traits are controlled by a number of genes, each of which produces individual proteins that will interact with one another and contribute to the overall physical phenotype of the organism. It is these interactions between proteins, such as binding together to slow down or speed up a reaction, that contribute to the observable traits and characteristics of an individual.

However, as well as being impacted by genes and their proteins, an organism's phenotype may also be influenced by environmental factors such as temperature, light, nutrition, or predation. For example, when you are exposed to high levels of UV radiation, your skin colour may change or you may develop moles.

For this reason, it is accepted that an individual's phenotype is the product of not only its genetic material, but also of its **environment**. We call this idea **proportionate heritability**, where an organism's phenotype is explained partly by genes and partly by environmental factors.

environment the conditions and resources external to an organism with which that organism typically interacts

proportionate heritability the amount of phenotypic variance that can be explained by genes in a given population

Theory in context

PROPORTIONATE HERITABILITY – HEIGHT IN HUMANS

Scientists have tried to determine how much of the variation seen in human height can be attributed to genetic influences and how much to environmental factors like nutrition. According to the US National Library of Medicine (2020), the difference in height between individuals is around 70 to 80 per cent a result of genetic factors, while the remaining 20 to 30 per cent is due to nutrition and diet. In addition, results show that proportionate height heritability varies from one population to another depending on a person's ethnic background. This is because different ethnic populations have different genetic backgrounds and live in different environments where their diet and lifestyle vary significantly.

Image: Dragon Images/Shutterstock.com

Figure 1 So your mum wasn't lying when she said eating your veggies would make you grow!

Australian men have been found to exhibit a heritability proportion of around 80 per cent and an average height of 178 centimetres. This means that if we meet a man in the street who differs from the average height of the population, we can understand what fraction of the variance in his phenotype is caused by genetic differences and what fraction is due to his environment. For example, if an Australian man is 185 cm tall (7 cm taller than average), we might assume that 80 per cent of the extra 7 cm (5.6 cm) is due to his inherited genetic variation, while the remaining 1.4 cm is due to environmental influences, mainly nutrition.

Proportionate heritability tells us that an organism's phenotype can be entirely due to the environment – such as when someone dyes their hair a completely new colour. Other times, genes play the main role in determining phenotype. This is the case with blood types: if you're O-positive then you'll remain O-positive regardless of the environment you inhabit. Most of the time though, your phenotype is the result of a mixture of genetic influences and environmental influences. For instance, you can inherit genes that increase your risk of obesity, but remain a healthy weight with the right environment and behaviours. Further, you might inherit a genetic predisposition for a degenerative nerve disease, but regular recreational drug use might speed up the process by damaging the way nerve cells normally send, receive, and process information.

It is important to understand that these environmental factors will rarely affect levels of gene expression itself, such as the amount of protein that is produced. Instead, environmental factors will typically act in ways that influence the performance of an organism's proteins in their phenotype. Scientists describe this as modifying the function of proteins, rather than affecting the creation of the proteins themselves.

Theory in context

HIMALAYAN RABBITS

Himalayan rabbits possess a particular allele that codes for the production of the enzyme tyrosinase, which is responsible for speeding up the production of melanin. Tyrosinase is a heat-sensitive enzyme and is inactive at normal body temperature. This leads to no melanin production in the rabbit and leaves the organism with a white fur coat. However, the tyrosinase enzyme becomes activated when it is exposed to low temperatures, causing it to produce melanin. This, in turn, causes black fur to form on the rabbit, especially around the extremities which are areas that tend to be cooler.

Image: Linn Currie/Shutterstock.com

Figure 2 A Himalayan rabbit showing varying fur colouring. Notice the darker pigmentation around the extremities (ears and nose).

Note that in this example, the environmental stimulus (heat level) is not limiting the expression of the gene involved in the overall production of tyrosinase. Instead, changes in temperature influence the performance of the protein (tyrosinase) that is created, either by causing it to be activated or inactivated.

Epigenetics 2.1.9.2

OVERVIEW

Phenotypes are also influenced by epigenetics, which are molecular interactions with DNA that modify the expression of genes. These epigenetic mechanisms either boost or inhibit the transcription of genes into proteins.

THEORY DETAILS

What is epigenetics?

Earlier in this lesson, you learned that an organism's phenotype is a result of the interactions between its genes and its environment. These environmental influences will typically alter the performance of certain proteins. In some cases, however, environmental factors may cause changes to a gene that activate or deactivate the expression of that gene. This affects the amount of protein produced, which subsequently alters an individual's phenotype.

We call these changes **epigenetic** modifications, which can be thought of as the bridge between the environment and genotype. Environmental signals are translated into biochemical changes inside a cell that lead to increased or decreased **gene expression**. Ultimately, epigenetic factors influence gene expression by determining which genes are 'turned on or off', but they do not alter the actual DNA sequence. This is often in response to environmental changes, such as exposure to certain chemicals.

epigenetics changes to an organism's phenotype resulting from modifications to gene expression

gene expression the process of reading the information stored within a gene to create a functional product, typically a protein

transcription the process whereby a sequence of DNA is used to produce a complementary sequence of mRNA

translation the process whereby an mRNA sequence is used to produce a protein

How does epigenetics work?

A gene is expressed when the protein it carries the instructions for is built by a cell. This occurs through the processes of **transcription** and **translation,** which you'll learn more about in Unit 3. For now, you should know that:

1 transcription involves reading and copying out a gene sequence from a DNA molecule. This 'copy' of the gene (called mRNA) then moves out of the nucleus to ribosomes in the cytosol or on the rough endoplasmic reticulum for translation.

2 during translation, mRNA instructs the ribosome how to build the specific protein for which the DNA sequence codes.

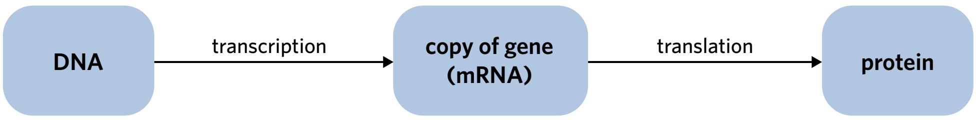


Figure 3 The process of gene expression involves transcription and translation.

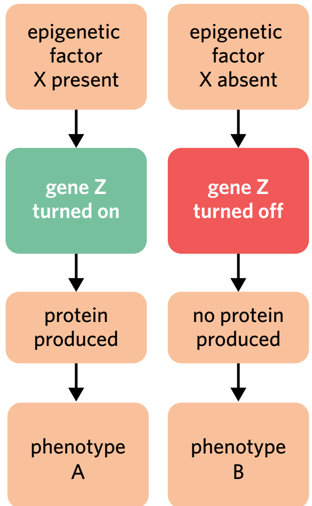


Figure 4 The presence or absence of an epigenetic factor can mean the same gene produces different phenotypes.

Epigenetic changes alter the process of transcription. They are caused by molecules that increase or decrease the amount of transcription of a particular gene and therefore alter the amount of protein that is produced. In this way, epigenetics can regulate the expression of specific proteins, which is important for a number of different areas of growth and development of organisms.

There are many different types of epigenetic modifications. Two types of epigenetic changes that you need to be aware of are:

1 **DNA methylation** – occurs when methyl groups (small hydrocarbon molecules) attach to certain nucleotides within the DNA sequence of a particular gene and alter levels of gene expression, typically by causing that gene to be silenced. DNA demethylation, in contrast, refers to the removal of methyl groups from a DNA sequence, and typically leads to a gene being expressed.

2 histone modification – occurs when histone-modifying enzymes known as histone methyltransferases (HMT) join methyl groups to histone tails and modify how tightly a DNA molecule is wrapped around it. If the DNA is condensed tighter around the histone, it makes it more difficult for the genes to be transcribed and less likely to be expressed. Alternatively, if the DNA becomes less tightly packed, the genes will be easier to transcribe and more likely to be expressed.

DNA methylation the process by which methyl (-CH_3) groups are added to particular nucleotides in a DNA segment so as to modify the expression of a gene

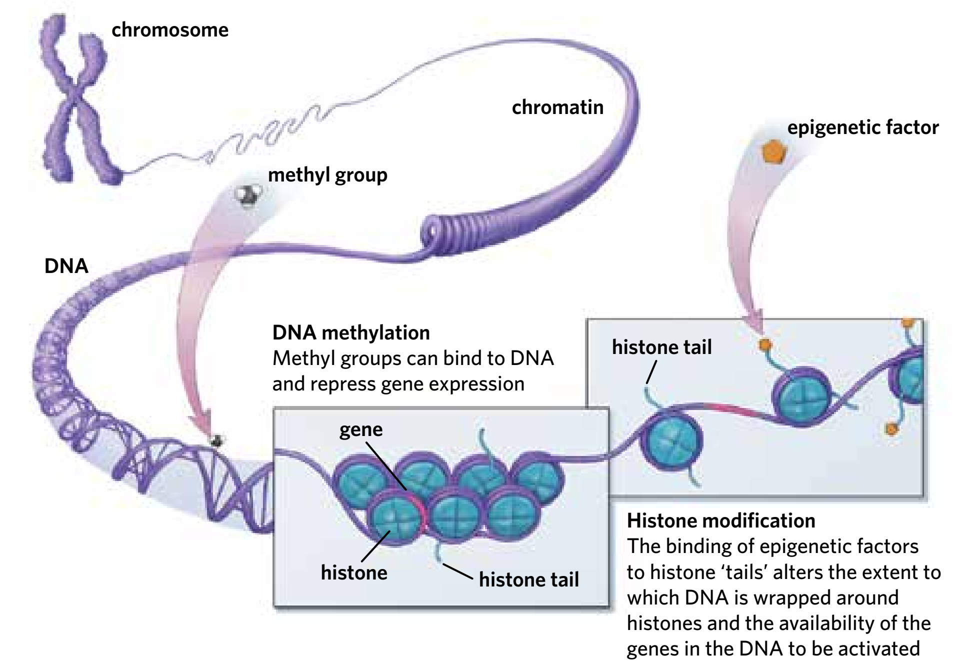


Figure 5 A visual representation of epigenetics altering the expression of a gene. Notice the binding of methyl groups to the DNA sequence (DNA methylation) as well as to histone tails (histone modification).

Lesson link

In ***lesson 7A*** you learned that histone proteins associate with DNA inside the nucleus of a cell and act as a spool to which DNA wraps around and is condensed into chromatin.

Memory device

Think of methyl groups kind of like a switch. When methyl groups attach to parts of our DNA sequence, they are telling our cells – 'don't read this section' – which in turn means that the associated proteins are not created.

Image: tuulijumala/Shutterstock.com

Figure 6 A light switch representing the functionality of methyl groups in gene expression.

Theory in context

EPIGENETICS AND FRUIT

Epigenetic factors play an important role in agriculture, particularly in the growth and ripening of fruit. For example, Liu et al. (2008) found that during times of ripening, methyl group levels in the genome of fruits drop by around 30% – therefore promoting the expression of genes involved in ripening. The chemical trigger that controls this process in many fruits is the hormone ethylene, which can also be made into a gas for commercial use by farms.

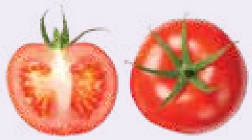


Image: Bozena Fulawka/Shutterstock.com

Figure 7 Juicy, ripe tomatoes. Is there more or less methylation on the DNA of these fruits compared to unripe tomatoes?

The importance of epigenetics

Epigenetics plays a number of essential roles in the cells of our body. These include:

- helping to control cell differentiation – despite containing the same DNA, not all of the cells inside an organism are the same. Different cell types, whether they be skin cells, bone cells, or muscle cells, all look unique and serve tissue-specific functions. The development of these different cell types is regulated largely by epigenetic mechanisms that turn off unneeded genes and promote expression of required genes.
- providing a mechanism for a developing organism to respond to its environment – epigenetic modifications act as a rapid feedback mechanism by which an organism can respond to changes in their environment. For example, during hot weather, plants require proteins that help reduce heat shock. The genes for these proteins are stimulated by high temperatures to demethylate, activating transcription and ensuring more of these useful proteins are synthesised.

Lesson link

Epigenetics plays an important role in much of our body's growth and development. This includes foetal development and stem cell differentiation (***lesson 4D***) and our adaptations for survival (***lessons 10A*** and ***10B***).

Epigenetics across generations

Epigenetic changes can be passed onto daughter cells during mitosis. This means that they could affect an individual organism throughout the entire course of its life. For that reason we describe epigenetic features as being **somatically heritable**, in that they are able to be passed on from somatic cell to somatic cell indefinitely across the lifespan of an organism. It's also one of the reasons why identical twins become increasingly different as they age – not only are their genes being switched on or off by exposure to different environmental factors, but those changes are also being passed onto new cells as they grow and regenerate.

somatically heritable genetic traits or alterations to a cell which are inherited by daughter cells during the course of regular mitotic cell division

Most epigenetic changes in an organism are erased when gametes are formed, meaning that they tend to be isolated to an individual organism and not passed on via sexual reproduction to that organism's offspring. This makes sense, as we know that epigenetic features are not caused by genetic alterations to an individual's genome.

Nonetheless, current research suggests that a small proportion of the epigenetic changes that accumulate over a lifespan may in fact remain during the production of gametes. This would mean that those epigenetic traits would pass onto the next generation, and suggests that our upbringing and the decisions we make as young adults could potentially impact our future progeny. The ethical and legal implications that flow on from epigenetic research could prove immense, as we learn more about how what we are exposed to can physically alter our gene expression, internal cellular processes, and resulting phenotypes and gametes.

Theory summary

An organism's phenotype is determined by a complex interplay between its genes, the environment, and epigenetic factors. Each of these factors has a proportionate influence over the physical and biochemical characteristics of an individual, and are summarised in Table 1.

Table 1 Summary of the different factors that influence phenotypes

Factor	How it influences phenotype	Heritable?
Genes	• Genes carry the instructions necessary for the creation of proteins • These proteins, once created, will interact with each other and will contribute to the overall phenotype of the organism	Yes
Environment	• Environmental factors such as temperature, nutrition, and sunlight affect phenotype • They might directly affect physical appearance (e.g. dying hair a new colour) or affect the performance of proteins (e.g. tyrosinase in Himalayan rabbits)	No
Epigenetics	• Environmental factors can cause epigenetic modifications • These epigenetic modifications influence levels of transcription of a gene, often by methylation or histone modification • By affecting transcription, epigenetic modifications influence how much of a protein product is made	Somatically heritable, although some epigenetic changes may also be passed onto offspring during reproduction

Identical twins can show marked differences in their phenotype as a result of the influence of their environment over their gene expression and the epigenetic modifications each has accumulated throughout their lives. This impact can be measured using twin studies, which can track changes to the phenotypes of identical twins as they are exposed to different environments.
Twin studies are useful in uncovering potential heritability proportions for given genes.

7D QUESTIONS

Theory review questions

Question 1

Which of the following provides the most complete summary of the influences on an organism's phenotype?

A An organism's phenotype is influenced by the interaction between their genes and their environment.

B An organism's phenotype is influenced by the interaction between their genes and their environment, as well as any epigenetic modifications that may selectively influence the expression of their genes.

Question 2

Which of the following is true of proportionate heritability? *(Select all that apply)*

I Proportionate heritability for a given gene in a population is liable to change over time.

II Geneticists use proportionate heritability to help determine how much certain environmental factors contribute to changes in phenotype.

III Proportionate heritability tends to be uniform across a species, regardless of geographical location and selective pressures like diet and nutrition.

Question 3

Fill in the blanks with the following terms.

- phenotype
- performance
- environmental

Temperature, nutrition, and predation are all examples of potential __________ factors that could influence the __________ of proteins. For this reason, we say that the environment in which an organism lives and grows can significantly influence that organism's __________.

Question 4

In the case of Himalayan rabbits, which is the best example of an environmental influence on phenotype?

A darker fur colour in rabbits, especially around the extremities

B exposure to lower temperatures causing the production of darker pigmentation

C the enzyme tyrosinase, which is a heat-sensitive enzyme responsible for catalysing the production of melanin

Question 5

Which of the following is not true of DNA methylation?

A Hydrocarbon molecules bind to particular nucleotides.

B Methylation changes the function of a gene by altering its sequence.

C Methylation typically serves to repress gene expression rather than amplify it.

D Methyl groups present on a DNA molecule tend to survive mitotic cell division.

Question 6

Epigenetic changes are said to be somatically heritable. This means that they

A are able to be inherited from generation to generation.

B are reversible, especially in offspring that inherit the epigenetic feature from their parents.

C are able to persist within an organism across most of its lifespan due to being passed on to replicated cells.

Question 7

Fill in the blanks with the following terms.

- activated
- expression
- DNA methylation

Epigenetic modifications influence the __________ of a gene in a number of different ways. For instance, exposure to certain chemicals may impact on whether or not a gene is __________, and can cause sequences of DNA to be switched off in a process known as __________.

Question 8

Which of the following correctly describes the relationship between the environment and epigenetic changes?

A Environmental changes alter the expression of certain genes, while epigenetics change the DNA sequence of those genes.

B Epigenetic changes are an example of environmental influence on an organism's phenotype. As with all environmental changes, epigenetics influence the performance of genes without altering gene expression.

C Epigenetics can be understood as the bridge between the environment and gene expression, where environmental influences like chemical exposure can lead to biochemical changes to an organism's genome.

SAC skills questions

Bioethical deep dive

Use the following information to answer Questions 9–14.

As epigenetic research has advanced, so too have the number of legal issues associated with it. For example, a growing body of state and federal level statutes on environmental regulation, including the *Industrial Chemicals Act 2019* and more broadly, the *National Clean Air Agreement 2015*, explore the risks associated with chemical exposure. While these government initiatives do not explicitly call for epigenetic testing by manufacturers, the assessments they involve could foreseeably incorporate this in the future. Such chemical testing could raise critical issues surrounding how we define 'toxicity', as manufacturers may be increasingly responsible for reporting whether their products could have adverse epigenetic effects on their consumers.

The impact of epigenetics on public health could also raise a variety of ethical concerns. For example, toxic chemicals and airborne pollutants are not distributed randomly throughout society, but instead follow a socioeconomic trend whereby exposure is more heavily linked to poorer communities in industrialised and urban areas. As such, if future research demonstrates that epigenetic changes more readily affect the most vulnerable members of society, governments and industry will be morally obliged to work to remove environmental risk and prevent harmful exposure.

Question 9

Which of the following best summarises the first paragraph of the extract?

A Recent legal developments introduced by state and federal governments have placed stringent epigenetic regulations on businesses and manufacturers, including testing and researching of their products and services.

B Interesting legal implications might begin to arise as epigenetic research continues to grow, especially regarding the responsibility of manufacturers to be aware of possible epigenetic consequences associated with their actions.

Question 10

Which of the following best summarises the second paragraph of the extract?

A Epigenetics also raises interesting ethical questions, including how it could impact the health and wellbeing of different groups within society. Future research might inform governments and manufacturers on how industry disproportionately affects vulnerable members of society.

B One ethical concern associated with epigenetic research is how low-socioeconomic communities might respond differently to the same epigenetic changes faced by middle-class communities. Research funding ought to be prioritised in labs that consider closing this gap and identifying the genetic differences between these communities.

Question 11

'Toxic chemicals and airborne pollutants', as used in this extract, are possible examples of

A potentially harmful epigenetic factors that could change the expression of a gene/s.

B environmental factors that are more common in industry than in any other part of society.

C necessary byproducts of industrial growth that are unlikely to have any biological effect on gene expression.

D potential epigenetic factors that could activate the expression of a gene, particularly by loosening chromatin and increasing the rate at which DNA is transcribed.

Question 12

At a recent forum examining the interplay between epigenetics and industry, a molecular geneticist explained that some epigenetic alterations, such as changes to levels of DNA methylation, occur naturally without any particular exposure to toxic chemicals or airborne pollutants. What's more, the geneticist also explained that many of the toxic exposures themselves are highly transient and reversible.

How might the comments of the geneticist best be explained by reference to the ethical concept of integrity?

A It is important to be committed to the complete understanding of an issue before making a judgement. This involves the honest reporting and scrutiny of all information available, regardless of whether it is favourable to an individual's personal position on the matter.

B It is important to acknowledge that each individual has their own personal value and autonomy. While epigenetic testing might be beneficial for the safety of some members of our community, other individuals may be asymptomatic or unaffected by the presence of epigenetic alterations.

C It is important to recognise that scientists have a duty to act in a way that maximises the good for the most people. This means that while testing might be advantageous for some epigenetic changes, they are largely inconsequential given that many epigenetic features are naturally occurring.

Question 13

The final sentence of the first paragraph explains that 'chemical testing could raise critical issues surrounding how we define toxicity'. How might a supporter of epigenetic testing respond to this concern using a consequences-based approach to bioethics?

A 'There will always be harm involved in industry. So long as the harms to consumers do not outweigh the benefits associated with the product, then concerns regarding the need for chemical testing are unjustifiable'.

B 'Thoughtful consideration into the impact on industry is important before implementing widespread chemical testing, especially in regards to how it might impact on the healthy sales and business of manufacturers'.

C 'The health of consumers is of the utmost importance. The time and cost involved for manufacturers to be aware of the potential epigenetic impacts of their actions are minuscule, and widespread reporting and assessment of product safety is simply non-negotiable'.

D 'It is important to consider the impact of industry on the health and wellbeing of its consumers. We must ensure adequate awareness of the potential harms involved, both for manufacturers and the general public, so as to maximise the potential for positive outcomes across all of society'.

Question 14

Which of the following bioethical concepts most accurately reflects the tone of the second paragraph?

A Justice – researchers have an obligation to ensure that no unfair burden is placed on a particular group as a result of a particular practice or action.

B Integrity – researchers have an obligation to continually search for a better understanding of epigenetic factors and to best communicate that information to all relevant parties.

C Non-maleficence – researchers have an obligation to accept that current industry practices inflict the least harm possible in the course of achieving a net positive outcome for society.

Exam-style questions

Within lesson

Question 15 (1 MARK)

Which of the following best describes an environmental impact on phenotype?

A An individual is born with cystic fibrosis after inheriting the recessive allele from their parents.

B Whales are born without teeth and therefore need to engulf large amounts of water to ingest sea life.

C After ingesting a meal, lipases (digestive enzymes) within your stomach will catalyse the breakdown of fats.

D After surgery, a doctor will administer morphine that binds to pain receptors and limits the uptake of signalling molecules in the brain.

Question 16 (1 MARK)

Gene X is highly activated and is producing increased amounts of Protein Y. Researchers have linked the increased activity to a methyl group attached to a specific histone tail associated with Gene X. Based on this information, it can be assumed that

A the methyl group has attached to an individual nucleotide within the DNA sequence of Gene X and has silenced that gene.

B the methyl group has attached to an individual nucleotide within the DNA sequence of Gene X and caused that gene to be more active.

C histone methyltransferases (HMT) have joined a methyl group to the histone protein which loosens the associated DNA molecule and increases its accessibility for transcription.

D histone methyltransferases (HMT) have joined a methyl group to the histone protein which condenses the associated DNA molecule and decreases its accessibility for transcription.

Question 17 (5 MARKS)

Genistein is a plant-based compound that mimics the function of oestrogen in the body. It is found in high concentrations in soy-based products and has been linked to increased instances of cancer when consumed at high quantities. Varying levels of genistein is thought to be a possible factor in explaining the lower incidence of certain types of cancer in Asian populations compared with Western countries.

a Using your understanding of proportionate heritability, how might the difference in cancer incidence rates between Asian and Western countries be explained? (2 MARKS)

b Studies have been conducted on agouti mice, where pregnant mothers were given dietary genistein supplementation during gestation at levels similar to those of humans with high-soy diets. Results showed that offspring exhibited changes to fur colour that were not otherwise associated with their genotype. The change was found to be significantly associated with increased methylation of nucleotides along the genes involved in determining coat colour.

Image: Eric Lesslee/Shutterstock.com

i Explain what is meant by the term 'methylation'. (1 MARK)

ii Justify whether the offspring in this study are likely to exhibit the same epigenetic change to their coat colour throughout the course of their life. (2 MARKS)

Multiple lessons

Question 18 (5 MARKS)

The interplay between epigenetics and physical performance is an interesting area of emerging research. Potential implications of epigenetic influences in elite endurance athletes include increased oxygen intake and lactic acid breakdown.

For example, some studies have linked inherited DNA hypomethylation (a loss of methyl group) to subsequent growth in muscle density. Many of these studies also noted that increased bouts of targeted physical exercise can stimulate an increase in the volume of myofibers (muscle cells) within muscle tissue.

a What do the findings of this study suggest in terms of the relationship between hereditary and environmental factors in muscle mass growth? (2 MARKS)

b Myosin is a specific form of molecular protein that plays an important role in the functioning of myofibers. It aids in muscle contraction and is a central component of the filament found in skeletal muscle cells.

i Which two cell organelles are most likely involved in the synthesis of myosin? (1 MARK)

ii Suggest what impact DNA methylation could have on the functioning of myofibers in regular skeletal muscle cells. (2 MARKS)

Key science skills and ethical understanding

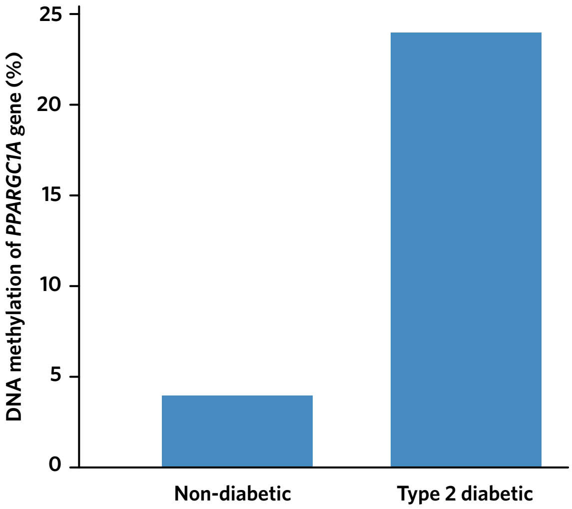
Question 19 (8 MARKS)

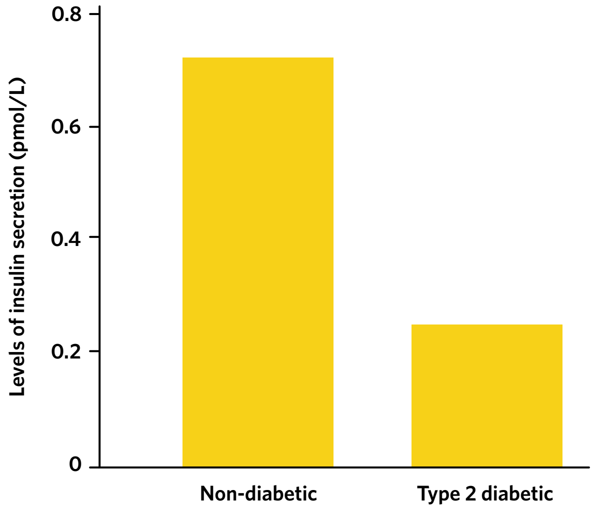
Some researchers have suggested a connection between epigenetic changes and type 2 diabetes. In particular, links have been drawn to a particular gene called *PPARGC1A*, which plays an important role in glucose-stimulated insulin secretion in human pancreatic cells. Much of the findings suggest that epigenetic mechanisms could influence the expression of this gene and alter insulin secretion in diabetic patients.

Ted Rolla is a researcher interested in considering the role of DNA methylation in limiting insulin secretion in type 2 diabetics. As an experiment, Ted obtained pancreatic islet (hormone-producing) cells from 30 separate donors – 15 non-diabetics and 15 type 2 diabetic patients. To test if the different groups had different DNA methylation and insulin responses, Ted incubated the cell cultures at 37 °C for 60 minutes in separate Petri dishes containing 6.6 mmol/L glucose solution.

After incubation, the following measures were taken:

- levels of DNA methylation along the *PPARGC1A* gene. This was measured by the number of methylated sites found along the DNA sequence of the gene.
- levels of insulin secretion. This was measured by the concentration of insulin (pmol/L) found in the solution after incubation.





a Name the control used by Ted in this experiment. (1 MARK)

b Explain what Ted's results suggest about levels of DNA methylation in regular pancreatic cells. (2 MARKS)

c Explain what the findings suggest about the relationship between the expression of the *PPARGC1A* gene and levels of insulin secretion in pancreatic cells. (2 MARKS)

d Suggest one possible limitation of Ted's experiment. (1 MARK)

e Suggest how the ethical concept of respect could apply to Ted in his preparation for this experiment. (2 MARKS)

CHAPTER 7 SUMMARY

Distinguishing between a genome, a gene, and an allele

A genome is the haploid set of chromosomes, including all of its genes. A copy of the entire genome is contained in all cells within the body that have a nucleus.	A gene is a section of DNA that carries the code to make a protein. Our genes are what form the basis of inheritance, and can be found at specific locations on our chromosomes (gene loci).	An allele is an alternative form of a gene. We typically have two alleles – one from each parent – which are found at the same gene loci on corresponding chromosomes.
E.g. the human genome contains around 25 000 different genes, contributing to a total of more than three billion individual base pairs.	E.g. the human gene *OCA2* is located on chromosome 15, and codes for the production of protein P – which is partly responsible for the colour of our eyes.	E.g. the *OCA2* gene has a number of different alleles relating to levels of protein P production (large amounts give rise to darker/brown eyes, while smaller amounts give rise of lighter/blue eyes).

The importance of karyotypes

The given image is a karyotype, which organises an individual's entire genome into sets of homologous chomosomes. These are pairs of one maternal and one paternal chromosome that share the same genes and are of similar size.

We can learn a lot from looking at a karyotype, including:

- **Species**: this is a human – it has 23 pairs of homologous chromosomes and diploid number (2*n*) of 46.
- **Gender**: this is a male – it has one X and one Y chromosome. We call the X and Y chromosomes sex chromosomes, and all other chromosomes autosomes.
- **Genetic health**: this individual does not appear to possess any obvious genetic abnormalities, and has a standard diploid number of 46. We can use karyotypes to check for disorders relating to aneuploidy (incorrect total number of chromosomes – e.g. 47) or polyploidy (incorrect number of sets of chromosomes – e.g. *n* or 3*n*).

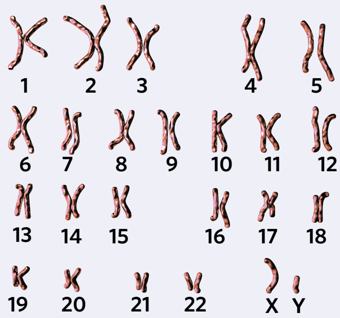


Image: Kateryna Kon/Shutterstock.com

Proportionate influence on a phenotype

Genetics
The foundation for the phenotype is the genome - which is the complete set of DNA that codes for all the proteins necessary for an organism to function.

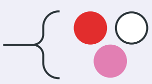
Environment
Phenotype is influenced by environmental factors like temperature and nutrients - which affect the performance of those proteins coded for by DNA.

Epigenetics
Phenotype is also influenced by epigenetic factors - which modify the expression of DNA and often alter the amount of protein produced.

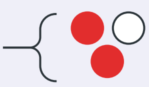
Phenotype
An organism's phenotype is all of its physical and biochemical characteristics. This includes all of the features that we can see – such as height and skin colour – as well as the organism's internal functions – such as the action of their nerves and body systems.

Patterns of dominance

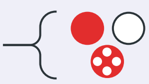
Incomplete dominance — **neither allele** of a heterozygote is dominant and both are expressed in an intermediate phenotype



Complete dominance — **one allele** of a heterozygote is dominant and is expressed in the phenotype of that organism



Codominance — **both alleles** of a heterozygote are dominant and expressed in the phenotype of that organism



Meiosis

Meiosis is a specialised form of cell division used to produce gametes in sexually reproducing organisms.

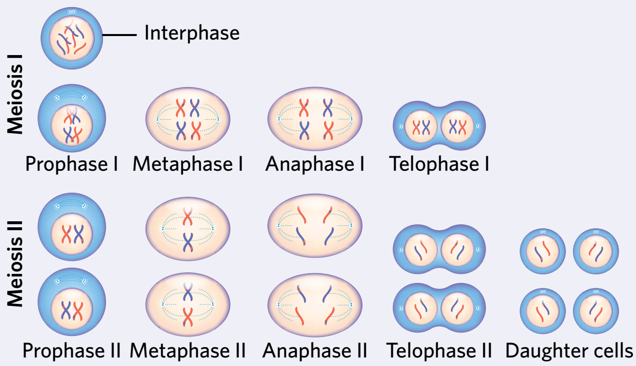


Image: Ody_Stocker/Shutterstock.com

CHAPTER 7 SAC PRACTICE

SAC skills covered in this section:

✓ Scientific methodology comparison ✓ Bioethical deep dive ✓ Data analysis

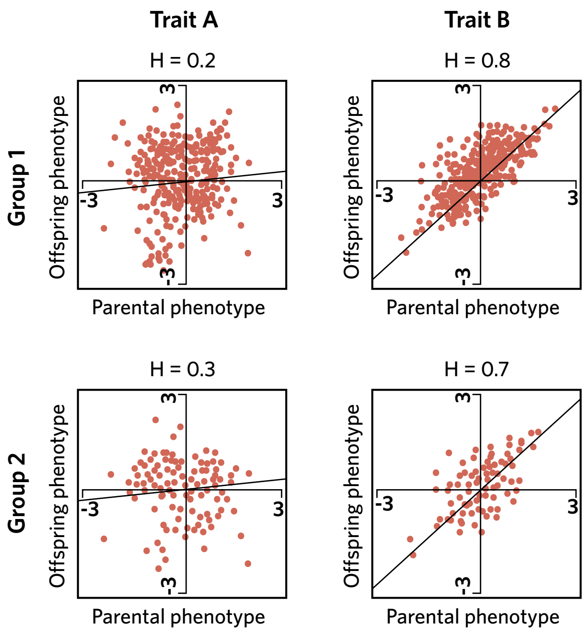
PROPORTIONATE HERITABILITY (15 MARKS)

Modelling heritability

Proportionate heritability is typically defined as a ratio, where the value of heritability (H) lies between 0 and 1. For example, if a trait is controlled entirely by genetics without showing any environmental variation, we say that that trait has an H value of 1.0. Estimating heritability can be extremely difficult for researchers, as it often involves observing the phenotypes of different organisms and then retrospectively assessing environmental influences that may have already occurred without being observed by the researchers themselves.

Nonetheless, one method for arriving at a ratio of proportionate heritability is by comparing data between the expected phenotypic resemblance between relatives, and the actual observed phenotypic resemblance between those relatives. Traditionally, this has been estimated from simple correlation studies between offspring and their parents, full and half-siblings, as well as between twins.

Two groups of geneticists from separate research laboratories have decided to produce computationally-derived scatterplot models using large-scale, empirical family data on two traits. To do this, each group has entered the values of the offspring phenotypes on the y-axis, and the average value of two parental phenotypes for each offspring on the x-axis. From there, the researchers conduct a linear regression analysis to arrive at a heritability ratio for the two traits. Their results are shown in the scatterplots, where A is a trait with low heritability and B is a trait with high heritability.



1 Based on the scatterplots of the two groups, which set of family data shows the highest heritability value? (1 MARK)

2 Based on the scatterplots of the two groups, suggest one limitation of Group 2's modelling. (1 MARK)

3 At the conclusion of their research, both groups agreed that a high heritability ratio can still entail a great deal of phenotypic variability. Even if H = 1.0, the phenotypes of offspring and parents are not identical. With reference to the process of meiotic cell division, explain how this is possible. (2 MARKS)

Genetics and university success

A large body of research has suggested that a person's genetics is a significant contributing factor to their level of achievement during school, not only in early childhood but also late into tertiary education. This research has led to a significant push to better understand the proportionate heritability behind university success. For example, a 2014 study by Krapohl et al. indicates that the genetic features of personality, intelligence, and mental health account for as high as 0.75 of the heritability responsible for GCSE scores – a score given to secondary school students in the United Kingdom.

More recently, researchers have spent time attempting to arrive at a heritability ratio for university success. One such study, conducted by Smith-Woolley et al. (2018), which used a sample of 3 000 individuals and 3 000 twin pairs, suggests a genetic influence on university entrance exam achievement (0.57), university enrolment (0.51), university quality (0.57), and university achievement (0.46). Consequently, the study suggests that between 43% and 54% of the differences in the university success of their sample were due to environmental factors. However, when these figures were broken down further, it was shown that the main environmental influences were 'individual-specific', such as friends and social status, rather than environmental factors that twins might share, such as family environment.

4 The data show that individual environmental factors, such as friendships, have a larger influence on university success than shared environmental factors such as family environment. Using a consequences-based approach to bioethics, outline how this information might influence an intervention aimed at increasing university success. (1 MARK)

Similar research has shown that the importance of genes on schooling success varies depending on where a child grows up. For example, in low-socioeconomic areas, studies have shown that environmental factors are more influential in determining university success than genetic factors.

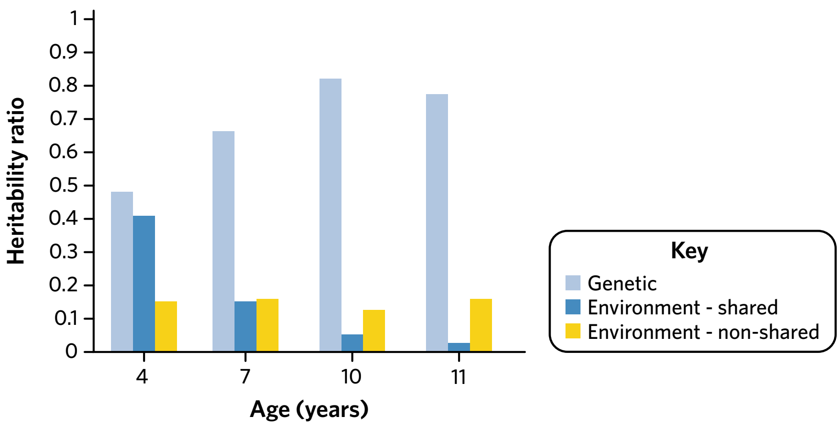
5 Using the bioethical concept of justice, explain the significance of this finding. (1 MARK)

6 Using the findings of this study, the government has decided to allocate more resources to schools in under-resourced areas. With reference to the bioethical concept of non-maleficence, what is one thing the government will need to consider when designing this plan? (2 MARKS)

Increasing heritability as we age

Genetic research has shown that the heritability ratios of different traits are not fixed. For example, Haworth et al. (2008) conducted repeated twin analyses of the body mass index (BMI) of more than 7 000 children and showed that the heritability ratio for BMI increased from 0.48 at age 4 to 0.78 at age 11. It was also found that a specific gene, the *FTO* gene found on chromosome 16, was a strong genetic correlate for BMI levels. The association between the *FTO* gene and BMI levels also became stronger during childhood, and increased in parallel to heritability.

This increase meant that the proportionate influence of environmental factors also changed, including shared twin factors such as socioeconomic status and family lifestyle, as well as non-shared factors such as individual friendship groups. These findings, along with the genetic heritability ratios from ages 4 to 11, are summarised in the graph.



7 Identify the independent and dependent variables in the Haworth et al. study. (2 MARKS)

8 Outline two strengths of using twins in this experiment. (2 MARK)

9 Based on the graph provided, describe the change in genetic heritability between the ages of 7 and 10. (1 MARK)

10 Based on the graph provided, describe the change to the heritability ratio of shared environmental influences between the ages of 4 and 7. (1 MARK)

11 Based on the information provided, describe the relationship between the *FTO* gene and BMI levels in young children. (1 MARK)

CHAPTER 7 EXAM PRACTICE

30 min

Section A (4 MARKS)

Question 1 (1 MARK)

Consider the following diagram which models a change in alleles between homologous chromosomes over time. This gene is located on chromosome 13.

Which of the following conclusions is not supported by the information provided?

A The individual is heterozygous for this gene.

B The alleles share a corresponding gene locus.

C The gene is located on an autosomal chromosome.

D The gene displays a pattern of incomplete dominance.

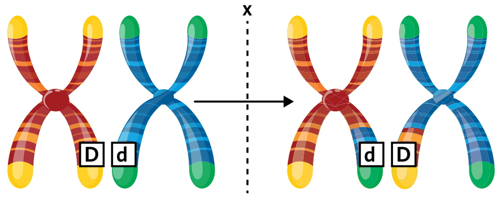


Image: Designua/Shutterstock.com

Use the following information to answer Questions 2 and 3.

Haemophilia A is a recessive genetic disorder that causes individuals to bleed much more than normal. The severity of the symptoms depends on the level of a particular protein in the blood that helps cause blood clots. The protein is called coagulation factor VIII (FVIII), and is controlled by a gene that is located on the X chromosome. The gene has two alleles, one for regular FVIII production and one for haemophilia A.

Question 2 (1 MARK)

The genotype of a female with haemophilia A could be

A X^HX^h.

B X^hY^h.

C X^HX^H.

D X^hX^h.

Question 3 (1 MARK)

A female carrier of haemophilia A

A possesses an allele for regular FVIII production.

B passes the allele for haemophilia A to all her sons.

C passes the allele for haemophilia A to all her daughters.

D will have the same phenotype as a female with haemophilia A.

Adapted from VCAA 2017 Exam Section A Q29

Question 4 (1 MARK)

In some autosomal recessive conditions in humans, the homozygous recessive genotype results in death before the individual reaches reproductive age and has no chance to pass on their allele to an offspring. However, despite this, the allele for the recessive trait is still maintained in the population over time. This is most likely due to

A random mutations to the gene in each generation.

B homozygous dominant individuals having more offspring in each generation.

C heterozygotes having some biological advantage that makes them fitter than homozygotes.

D heterozygotes being much more common than both homozygous genotypes, and having more offspring in each generation.

Section B (16 MARKS)

Question 5 (7 MARKS)

Meiosis contributes to genetic diversity, which in turn has benefits for sexual reproduction and the genetic diversity of a population.

a During prophase I, crossing over and recombination occur between homologous chromosomes. Describe the impact of recombination on a population. (3 MARKS)

b Explain the importance of independent assortment for the purpose of meiotic cell division. (2 MARKS)

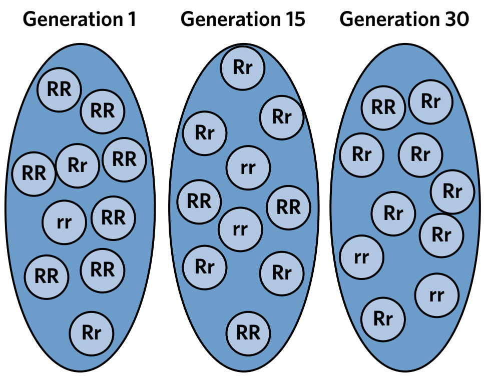
c In humans, if a fertilised egg splits early in its development, two genetically identical offspring may be produced. We call these two offspring identical twins, as they form from the fertilisation of a single ovum and share identical genetic material.

  i Outline the diploid number of each identical twin. (1 MARK)

  ii Given the information provided, how might the differences between identical twins that arise post-birth be explained? (1 MARK)

Question 6 (3 MARKS)

The following diagram shows the gene pool of a flowering plant population over 30 generations.



a Identify the genotypes of both homozygotes in Generation 1. (1 MARK)

b With reference to the change in allele frequencies, explain how a heterozygote advantage could account for the change in recessive alleles between Generation 1 to Generation 15. (2 MARKS)

Question 7 (6 MARKS)

Freckles are small spots of a darker skin pigment called melanin, and are controlled mainly by a gene called *melanocortin 1 receptor* (*MC1R*). When the *MC1R* gene is active, it stimulates the production of a form of melanin pigmentation known as eumelanin, which makes darker skin that is protected from ultraviolet (UV) radiation. However, when the gene is not activated, the cells inside the organism will produce a different form of melanin pigmentation called pheomelanin, which causes the appearance of freckles.

a Based on the information provided, what are the two possible alleles with respect to the *MC1R* gene? (1 MARK)

b When the MC1R protein is blocked there is a buildup of pheomelanin which causes the freckles to form. Parents who have freckles tend to have children with freckles also. Based on this information, suggest which pattern of dominance is responsible for the appearance of freckles. (1 MARK)

c Reduced *MC1R* function is positively associated with an individual's risk of developing cutaneous malignant melanoma (CMM), a type of tumorous skin cancer. Additionally, studies have shown that the epigenetic silencing of multiple genes, such as *CDKN2A*, which produces a tumour-suppressing protein called p14(ARF), increases a person's risk of developing CMM.

  i Explain DNA methylation and its relationship to gene silencing. (2 MARKS)

  ii Based on the information provided, describe the relationship between the p14(ARF) protein and the likelihood of developing CMM. (2 MARKS)

CHAPTER

8

Inheritance

Key knowledge

- predicted genetic outcomes for a monohybrid cross and a monohybrid test cross
- predicted genetic outcomes for two genes that are either linked or assort independently
- pedigree charts and patterns of inheritance, including autosomal and sex-linked inheritance

8A MONOHYBRID CROSSES

Huntington's disease is a genetic neurological condition that typically does not show symptoms until 30–40 years of age, at which point it can cause cognitive and psychological decline. Huntington's disease is an autosomal dominant disorder, which means inheritance of only one copy of the mutated allele is required to develop this disease. Genetic testing can predict whether you will develop the disease. If one of your parents tested positive for the disease, what does this mean for you?

Image: Tashatuvango/Shutterstock.com

Lesson 8A

In this lesson you will learn how to predict genotypes of offspring using monohybrid crosses and how we can discover the genotype of a parent using a test cross.

◀ *Prerequisite knowledge*

Years 7–10
Genetic information is passed on from parents to offspring.

Lesson 7C
The conventions used to write genotypes are required to complete monohybrid crosses.

Future applications ▶

Lesson 8B
A dihybrid cross works similarly to a monohybrid cross, except we predict genotypes of two genes instead of one.

Lesson 8C
Pedigree charts show a trait's inheritance across many generations.

Study design dot point

- predicted genetic outcomes for a monohybrid cross and a monohybrid test cross

Key knowledge units

How to perform a monohybrid cross	2.1.10.1
Monohybrid test crosses	2.1.10.2

How to perform a monohybrid cross 2.1.10.1

OVERVIEW

Monohybrid crosses show how certain traits are passed down from parents to their offspring. By completing a Punnett square, we can predict the genotypes and phenotypes of offspring resulting from a monohybrid cross, for both autosomal and sex-linked traits.

THEORY DETAILS

In chapter 7, you learned about alleles and the notation we use to describe genotypes. A **monohybrid cross** explores how alleles are passed down from parents to their children.

monohybrid cross a genetic cross performed to observe the inheritance of alleles and phenotypes for a single gene

Autosomal complete dominance Punnett square

A cross between two heterozygotes results in three possible genotypes in the offspring. Figure 1 demonstrates the allelic inheritance of a monohybrid cross between two individuals heterozygous for the widow's peak gene (Ww), where W = widow's peak allele and w = straight hairline allele. Each parent passes on one of the two possible alleles via their gametes. Since half of the mother's gametes contain the dominant allele, W, she has a 50% chance of passing on the dominant allele, W. Similarly, she has a 50% chance of passing on the recessive allele, w. The same odds apply for the father since he is the same genotype as the mother. From here, we can predict the possible genotypes in their offspring.

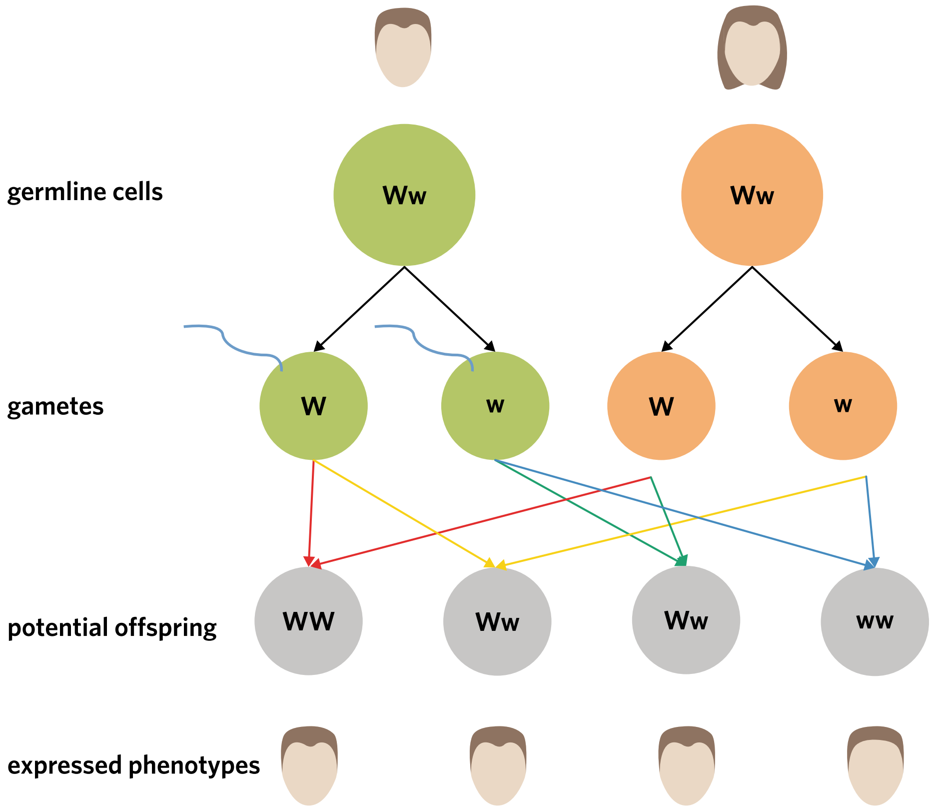


Figure 1 Diagram to summarise how to predict potential offspring genotypes for the widow's peak trait

Unfortunately, Figure 1 is messy and hard to read. **Punnett squares** are easy to read and clearly predict offspring genotypes and genotype frequencies from a monohybrid cross.

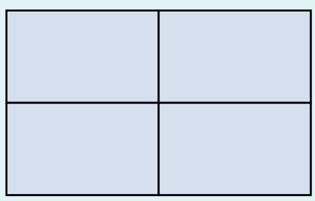
Punnett square a square diagram used to predict the genotypes of offspring

How to complete an autosomal complete dominance Punnett square:

1. Assign letters to each allele
2. Draw a 2 × 2 grid
3. Write each of the father's alleles above one column
4. Write each of the mother's alleles beside one row
5. Complete the cross to determine the potential offspring genotypes. Ensure you write the dominant allele first in heterozygous offspring
6. Calculate the fractional proportions of each potential genotype by determining the frequency of each genotype then dividing it by the total number of squares (4). Multiply this fraction by 100 to determine the percentage of each genotype
7. Determine the phenotype of each offspring by looking at the genotypes. To calculate the fractional proportions of each phenotype, determine the frequency of each phenotype then divide it by the total number of squares. Multiply this fraction by 100 to determine the percentage of each phenotype.

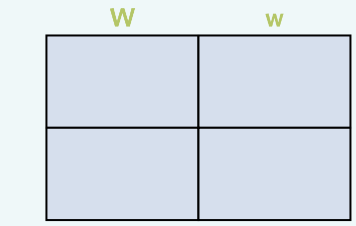
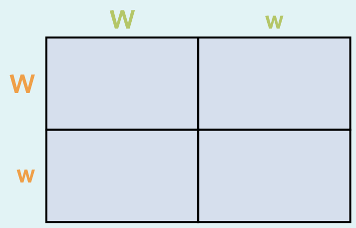
(Note: steps 3 and 4 are interchangeable, and it doesn't matter what side the mother and father's alleles are placed.)

Table 1 Worked example of how to complete a Punnett square for widow's peak with two heterozygous parents

1 Assign letters to each allele	W = widow's peak w = straight hairline
2 Draw a 2 × 2 grid	

cont'd

Table 1 Continued

3 Write each of the father's alleles above one column	
4 Write each of the mother's alleles beside one row	
5 Complete the cross to determine the potential offspring genotypes. Ensure you write the dominant allele first in heterozygous offspring	
6 Calculate the fractional proportions of each potential genotype by determining the frequency of each genotype then dividing it by the total number of squares. Multiply this fraction by 100 to determine the percentage of each genotype	Total squares = 4 Number of homozygous dominant (WW) offspring = 1 Number of heterozygous (Ww) offspring = 2 Number of homozygous recessive (ww) offspring = 1 Percentage of homozygous dominant offspring = $1 \div 4 \times 100 = 25\%$ Percentage of heterozygous offspring = $2 \div 4 \times 100 = 50\%$ Percentage of homozygous recessive offspring = $1 \div 4 \times 100 = 25\%$
7 Determine the phenotype of each offspring by looking at the genotypes. To calculate the fractional proportions of each phenotype, determine the frequency of each phenotype then divide it by the total number of squares. Multiply this fraction by 100 to determine the percentage of each phenotype	Total squares = 4 Number of combinations with widow's peak (WW and Ww) = 3 Number of combinations with straight hairline (ww) = 1 Ratio of widow's peak to straight hairline = 3 : 1 Percentage of offspring with widow's peak = $3 \div 4 \times 100 = 75\%$ Percentage of offspring with straight hairline = $1 \div 4 \times 100 = 25\%$

Autosomal codominance

Completing a Punnett square for **codominant** traits follows a similar process to complete dominance, however you need to ensure that you use the correct allelic notation (i.e superscripts). ABO blood grouping is an example of a codominant trait. Both the A and B blood group alleles are dominant (written as I^A and I^B, respectively) so they will both be expressed. Meanwhile, the O blood group is recessive and written as i.

codominance happens when two traits are independently and equally expressed

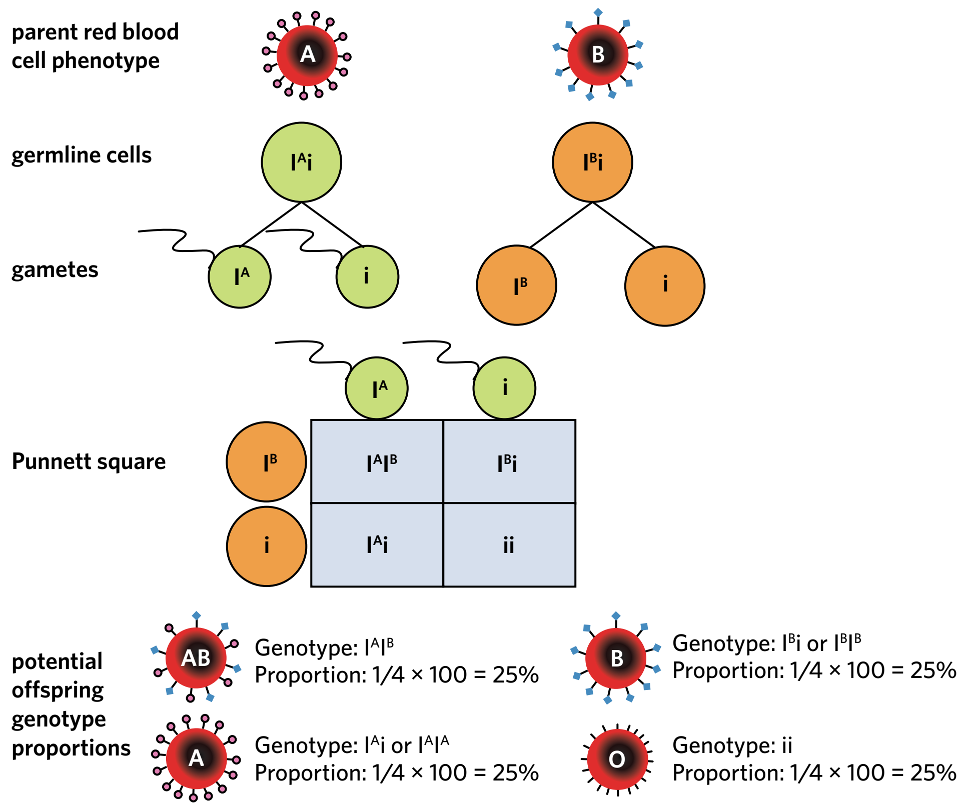


Figure 2 Diagram to summarise how to predict potential offspring genotypes and phenotypes for ABO blood types

Sex-linked alleles

As you learned in lesson 7C, sex-linked traits involve alleles on sex chromosomes. To complete Punnett squares for these traits, the method is the same, however, the way alleles are written and the genotypic and phenotypic proportions differ from that of an autosomal Punnett square. In Figure 3, a sex-linked cross for red-green colour blindness is shown. The colour blind allele is recessive (b) and the regular vision allele is dominant (B). However, it is sex-linked since it is only found on the X chromosome, not the Y chromosome.

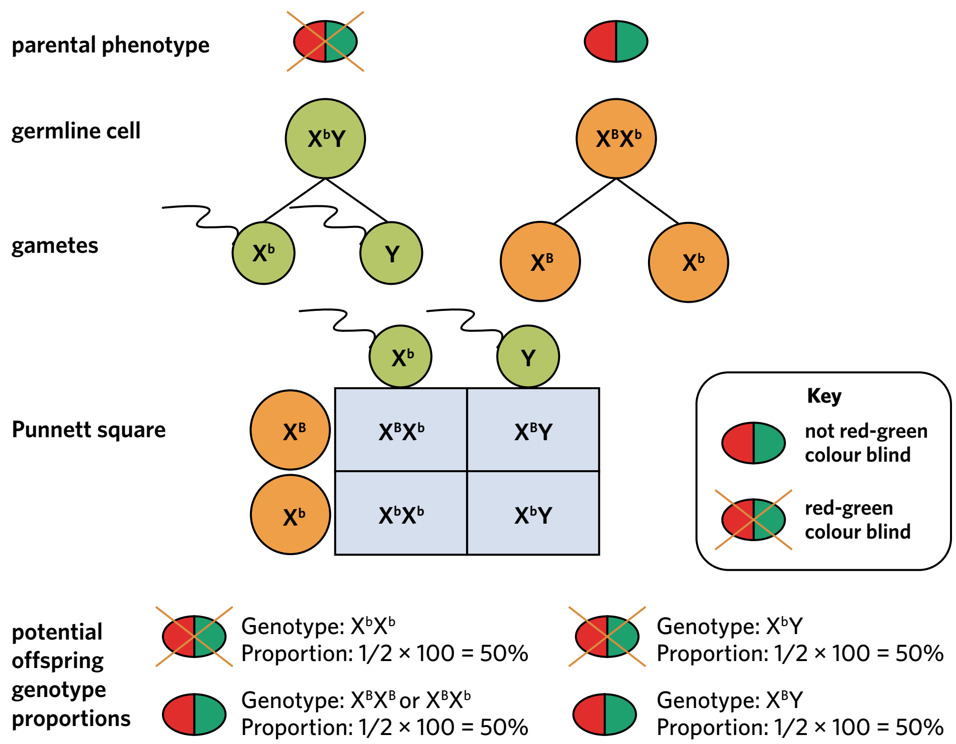


Figure 3 Diagram of how to predict potential offspring genotypes and proportions of phenotypes for red-green colour blind offspring

With sex-linked traits, it is important to notice for proportions are calculated with respect to sex. So, in the example shown, we would say 50% of female offspring will be red-green colour blind and 50% of male offspring will be red-green colour blind (Figure 3).

Monohybrid test crosses 2.1.10.2

OVERVIEW

For traits that operate via complete dominance, an individual that expresses the dominant phenotype could either be homozygous dominant and heterozygous. To determine the genotype of such an individual, we can use a monohybrid test cross.

THEORY DETAILS

A monohybrid **test cross** is performed by crossing an individual with an unknown genotype with a homozygous recessive individual. Then, by observing the phenotypes of all the offspring you can determine whether the unknown parent is homozygous dominant or heterozygous. In a sense, it is the reverse of a regular monohybrid cross as we are using the phenotypes of the offspring to determine a parent's genotype.

test cross when an individual expressing the dominant phenotype but with an unknown genotype is crossed with a homozygous recessive individual. The results indicate whether the individual with the dominant phenotype is homozygous dominant or heterozygous

In Figure 4, a black sheep (BB or Bb) and a white sheep (bb) are shown. If the two parental sheep were to have at least one white offspring you could instantly determine the genotype of the black sheep parent to be Bb, whereas if all offspring were black you could conclude the black sheep's genotype to be BB.

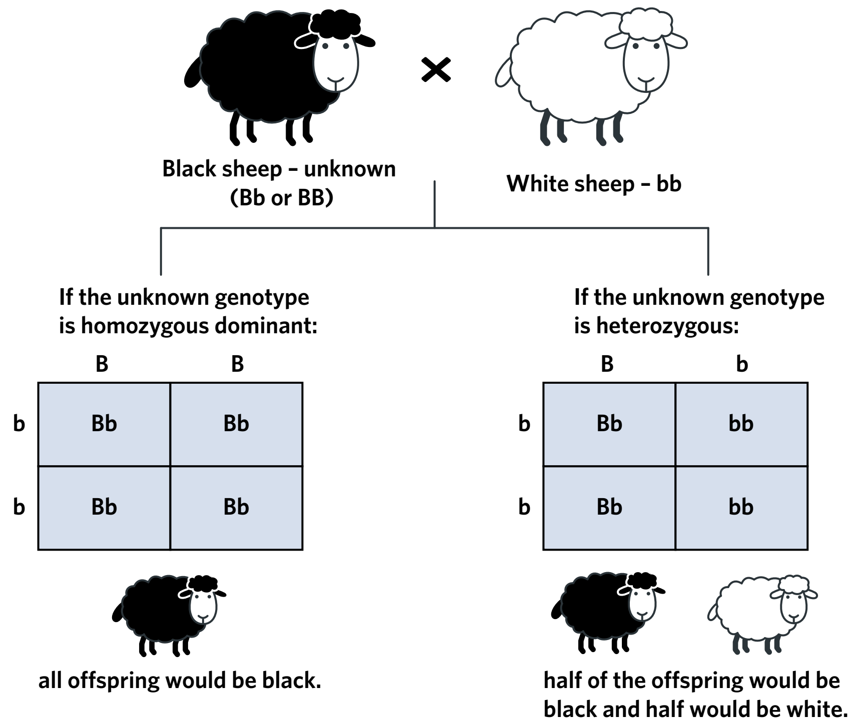


Figure 4 How a test cross can be used to determine the genotype of the black sheep

Theory summary

Monohybrid crosses are used to predict the genotypes of potential offspring and phenotypic proportions. A test cross is used to discover if an individual is homozygous or heterozygous dominant.

If your parent is diagnosed with Huntington's disease but is heterozygous for the disease-causing allele, there is a 50% chance that you don't also have the disease. Unfortunately, if both your parents are heterozygous then you have a 75% chance of developing Huntington's, and if either of your parents are homozygous dominant then you have a 100% chance of developing Huntington's disease.

One heterozygous parent

	H	h
h	Hh	hh
h	Hh	hh

Two heterozygous parents

	H	h
H	HH	Hh
h	Hh	hh

One homozygous dominant parent

	H	H
h	Hh	Hh
h	Hh	Hh

Luckily, modern medicine has plenty of genetic counsellors and tests that can help individuals to see if they possess the allele, and prospective parents can get tested to see how likely it is that their children will inherit the allele.

8A QUESTIONS

Theory review questions

Question 1

A monohybrid cross between two parents heterozygous for a complete dominance autosomal trait can produce

A three potential genotypes.

B four potential genotypes.

Question 2

Fill in the blanks in the following sentence.

In a __________, the parents' genotypes are placed along the __________ and __________.

Question 3

Order the steps to correctly describe how to complete a Punnett square.

I Execute the cross to determine the potential offspring genotypes. Ensure you write the dominant allele first in heterozygous offspring.

II Draw a 2 × 2 grid.

III Assign letters to each allele.

IV Calculate the ratio and percentage of each potential offspring phenotype by counting the number of each phenotype then dividing it by the total number of squares and multiplying by 100.

V Write each parent's alleles above or beside the grid.

Question 4

Complete the Punnett square.

	H	H
H	HH	
h		

Question 5

Complete the Punnett square.

	G	g
______	GG	Gg
______	Gg	gg

Question 6

Complete the Punnett square.

	I^A	I^B
I^A		
i		

Question 7

The following sex-linked Punnett square represents red-green colour blindness.
X^B = normal vision, X^b = colour blind.

	X^B	Y
X^b	X^BX^b	X^bY
X^b	X^BX^b	X^bY

What proportion of boys will be colour blind?

A 0%
B 25%
C 50%
D 100%

Question 8

Guinea pig fur colour can be determined by a single gene. Black fur is dominant (B) and white fur is recessive (b). How can you determine the genotype of a black guinea pig?

A It is impossible to determine the genotype of a black guinea pig.
B Perform a monohybrid test cross.
C Perform a monohybrid cross.
D All black guinea pigs are BB.

SAC skills questions

Data analysis

Use the following information to answer Questions 9–13.

Sickle cell anaemia is an example of an incompletely dominant trait that causes a deformity in red blood cells which makes red blood cells form a crescent-like shape. These sickled cells can get caught in small blood vessels creating blockages or clots and do not carry oxygen as efficiently as normal red blood cells. As red blood cells are responsible for transporting oxygen around the body, sickle cell anaemia can be a fatal disease.

The two alleles are normal red blood cells (Hb^A) and sickle cell anaemia (Hb^S). Individuals that are heterozygous show mild symptoms of sickle cell anaemia. However, a benefit of having an Hb^S allele is that it confers resistance to malaria.

	Hb^A	Hb^S
Hb^A	Hb^AHb^A	Hb^AHb^S
Hb^S	Hb^AHb^S	Hb^SHb^S

A Punnett square has been made up from a cross between two heterozygous individuals.

Around the world, sickle cell anaemia varies in prevalence in different regions. The map (adapted from Piel et al., 2013) shows the prevalence of newborns with sickle cell anaemia in different countries.

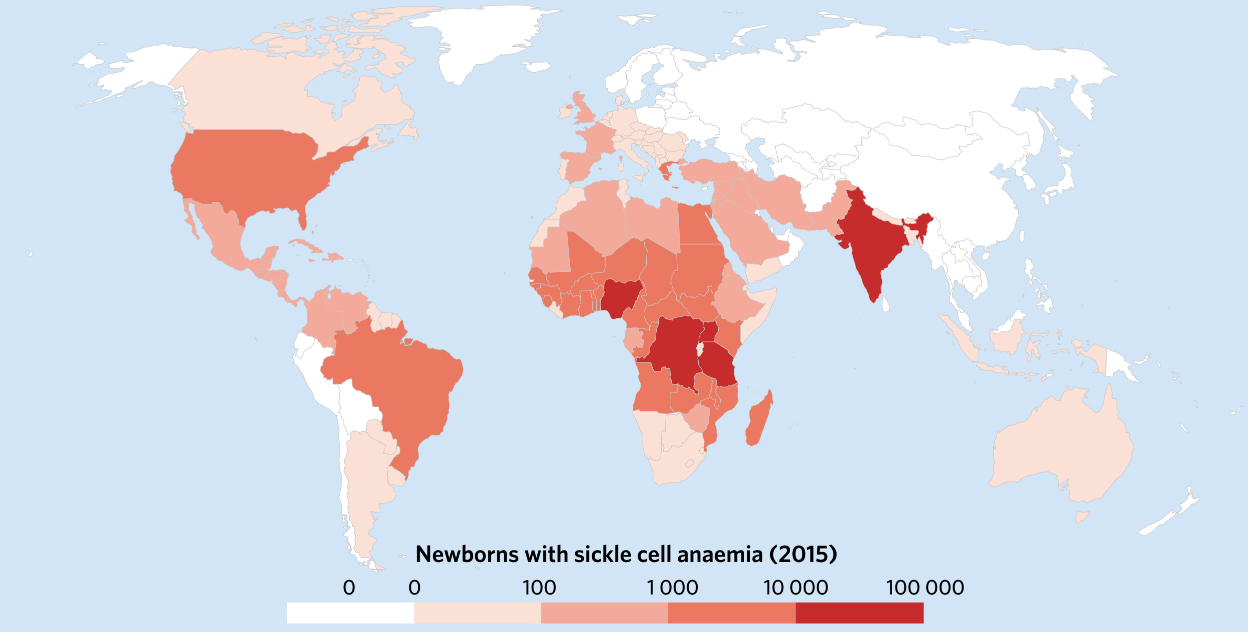


Image: infinetsoft/Shutterstock.com

Like sickle cell anaemia, malaria varies in prevalence around the world.

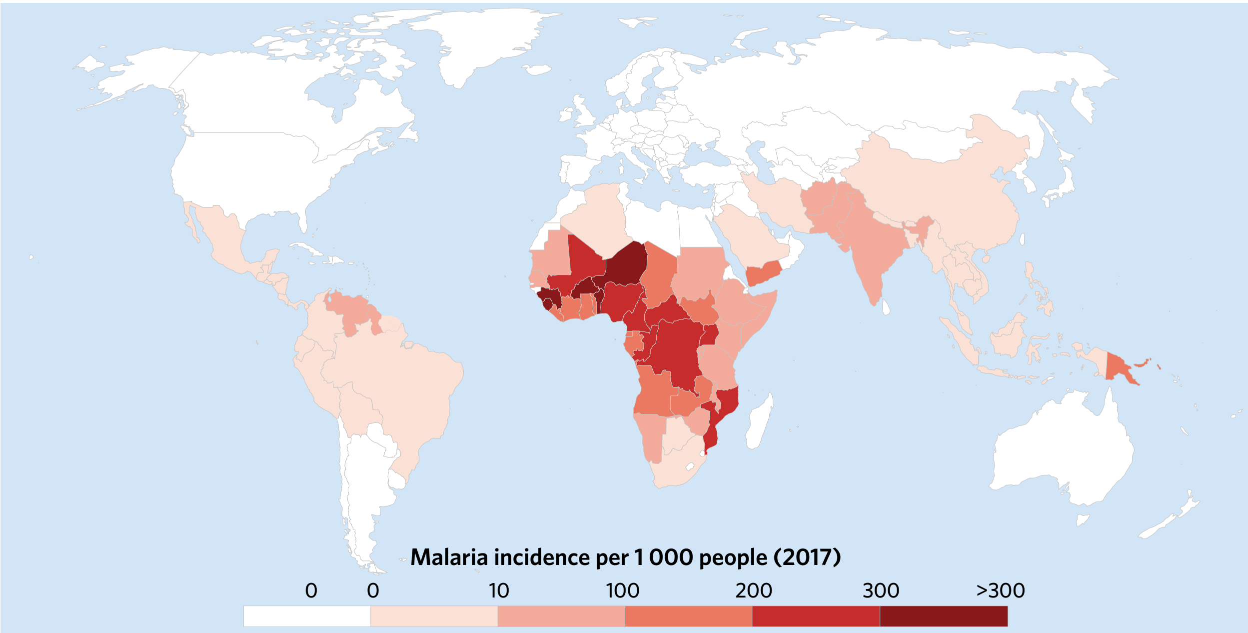


Image: infinetsoft/Shutterstock.com

Question 9

From the Punnett square, what is the percentage proportion of potential offspring that would have resistance to malaria?

A 25%
B 50%
C 75%
D 100%

Question 10

How many newborn cases of sickle cell anaemia were there in Australia in 2015?

A 0
B 1 to 100
C 101 to 1 000
D 1 001 to 10 000

Question 11

How many cases of malaria were there in China per 1 000 people in 2017?

A 0

B 1 to 10

C 11 to 100

D 101 to 200

Question 12

Where would being heterozygous for sickle cell anaemia be most beneficial for an individual?

A Europe

B Australia

C Central Africa

D North America

Question 13

Why was the data for the prevalence of sickle cell anaemia taken from newborns instead of adults?

A Taking tests from newborns does not require consent.

B As newborns are smaller in size, the blood test is easier to take.

C As it is a fatal disease, the data is more accurate with samples from newborns.

Exam-style questions

Within lesson

Use the following information to answer Questions 14 and 15.

Dimples are small indentations in the skin which can be located on the face when you smile. Dimples (D) is the dominant trait, and no dimples (d) is the recessive trait.

Consider the following Punnett square.

	D	d
d	Dd	dd
d	Dd	dd

Question 14 (1 MARK)

Referring to the information given and your knowledge of inheritance, which one of the following conclusions can be made?

A Dimples are an autosomal trait.

B Both the parents are heterozygous.

C All the potential offspring will have dimples.

D Only homozygous individuals will have dimples.

Question 15 (1 MARK)

What is the dimples to no dimples phenotypic ratio of the potential offspring?

A 1 : 1

B 1 : 3

C 2 : 2

D 0 : 2 : 2

Question 16 (1 MARK)

For a species of butterfly, wing colour can be determined by a single gene. Red (R) is the dominant trait over white (r). Scientists performed a test cross by mating a red butterfly with a white butterfly to determine the genotype of the red butterfly. Half of their offspring were red and the other half were white. Which of the following depicts the correct test cross in this situation?

A

	R	R
R	RR	RR
r	Rr	Rr

B

	R	r
R	RR	Rr
r	Rr	rr

C

	R	R
r	Rr	Rr
r	Rr	Rr

D

	R	r
r	Rr	rr
r	Rr	rr

Multiple lessons

Question 17 (8 MARKS)

A new species of beetle was discovered, leading geneticists to study the genome of this species. They concluded that beetle colour was determined by a single gene. The scientists determined that the dominant beetle phenotype was red and the recessive phenotype was black. They also noticed that in beetles, the X and Y chromosomes determine the sex of an individual, similar to the process in humans.

a Define the term 'genome'. (1 MARK)

b Assume the gene for beetle colour is found on autosomal chromosomes.

- **i** Complete a Punnett square between a homozygous red male and black female. (1 MARK)
- **ii** State the phenotypic percentage proportions. (1 MARK)

c A closely related species of beetle also contains a single gene that determines body colour. For this species, scientists noticed that males only tend to have one copy of the allele, whilst females have two. The scientists determined that for this gene, red beetle phenotype was dominant to the recessive black phenotype.

- **i** Explain what this means in terms of the location of the gene. (1 MARK)
- **ii** Complete a Punnett square for this new gene between a red male and a black female. (1 MARK)
- **iii** State the phenotypic percentage proportions. (1 MARK)

d Describe the difference in the number of black offspring between the two monohybrid crosses. Explain why this difference occurred. (2 MARKS)

Key science skills and ethical understanding

Question 18 (9 MARKS)

Sandra's sister, Payton, is pregnant and is wanting to predict the blood type of her baby. There are two factors that affect blood type, which indicates what antigens are present on the surface of red blood cells. First, she must look at ABO grouping, which is an example of codominance. A and B are codominant phenotypes, whilst O is recessive. Secondly, she must account for the Rhesus factor. Individuals have a phenotype that is either positive (dominant) or negative (recessive). Together, this will determine the baby's blood type (for example, O–).

a Sandra must first obtain a blood sample from both Payton and her husband, Martin. She verbally asks for their consent before taking their blood sample and testing it. What bioethical concept is Sandra following? (1 MARK)

b The blood test determines that Payton is B+ and Martin is O−. From this information and your knowledge of inheritance, explain whether Sandra can determine the genotypes of Payton and Martin for ABO and rhesus factors without any further testing. (2 MARKS)

c Sandra obtained consent to genetically screen Payton and Martin to determine their genotypes. The results are shown in the table.

	Payton	Martin
ABO group	I^Bi	ii
Rhesus factor	DD	dd

i Explain whether you would find the alleles on the autosomes or sex chromosomes for each trait. (1 MARK)

ii Complete a monohybrid cross between Payton and Martin for the Rhesus factor. (1 MARK)

iii What conclusion can be made about the Rhesus factor phenotype of the offspring? (1 MARK)

d Sandra completed a monohybrid cross and calculated the phenotypic percentage proportions for ABO groups.

	i	**i**
I^B	**ii**	**I^Bi**
i	**ii**	**ii**

Sandra suggests that 25% of potential offspring will be B blood type and 75% of potential offspring will be O blood type. Explain the error in Sandra's Punnett square. (2 MARKS)

e What percentage of potential offspring would share the same phenotype as Payton? (1 MARK)

8B DIHYBRID CROSSES

Have you ever wondered why most people with blue eyes tend to have light coloured hair, whilst darker haired people tend to have brown eyes?

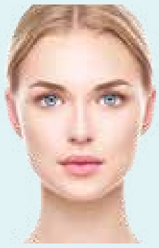


Image: Subbotina Anna/Shutterstock.com

Lesson 8B

In this lesson you will learn how to perform dihybrid crosses for linked and unlinked genes.

◀ *Prerequisite knowledge*

Future applications ▶

Chapter 7
The fundamental concepts of genetics and the process of meiosis are essential to understanding dihybrid crosses.

Lesson 8A
Dihybrid crosses follow a similar process to monohybrid crosses.

Lesson 8C
Pedigree charts show a trait's inheritance across many generations.

Year 12
The concept of linked genes and recombination is important for understanding natural selection.

Study design dot point

- predicted genetic outcomes for two genes that are either linked or assort independently

Key knowledge units

Unlinked dihybrid crosses	2.1.11.1
Linked dihybrid crosses	2.1.11.2

Unlinked dihybrid crosses 2.1.11.1

OVERVIEW

Punnett squares can be used to predict the genotypic and phenotypic ratios of two independently inherited genes.

THEORY DETAILS

In lesson 8A, you learned how to complete a monohybrid cross to predict the genetic outcomes for one trait. However, sometimes we may want to predict the genetic outcomes of two traits, and calculate the likelihood of different combinations of genes being expressed in offspring. To do this, we can use what are known as **dihybrid crosses**.

In this section, we will focus on **unlinked genes**, which are found on separate chromosomes or far apart on the same chromosome.

For example, assume we want to calculate the likelihood of an individual having both dimples and a cleft chin (Figure 1). For the gene responsible for dimples formation, D = dimples and d = no dimples, and for the gene responsible for cleft chin expression, C = cleft chin and c = no cleft chin. When writing the genotype of an individual for two separate genes, we write the genotype for one trait followed by the other, such that the genotype of a heterozygous individual for both traits is CcDd.

dihybrid cross a genetic cross used to observe the inheritance of alleles and phenotypes for two genes

unlinked genes genes located on different chromosomes, or far apart on the same chromosome. Unlinked genes have less chance of being inherited together

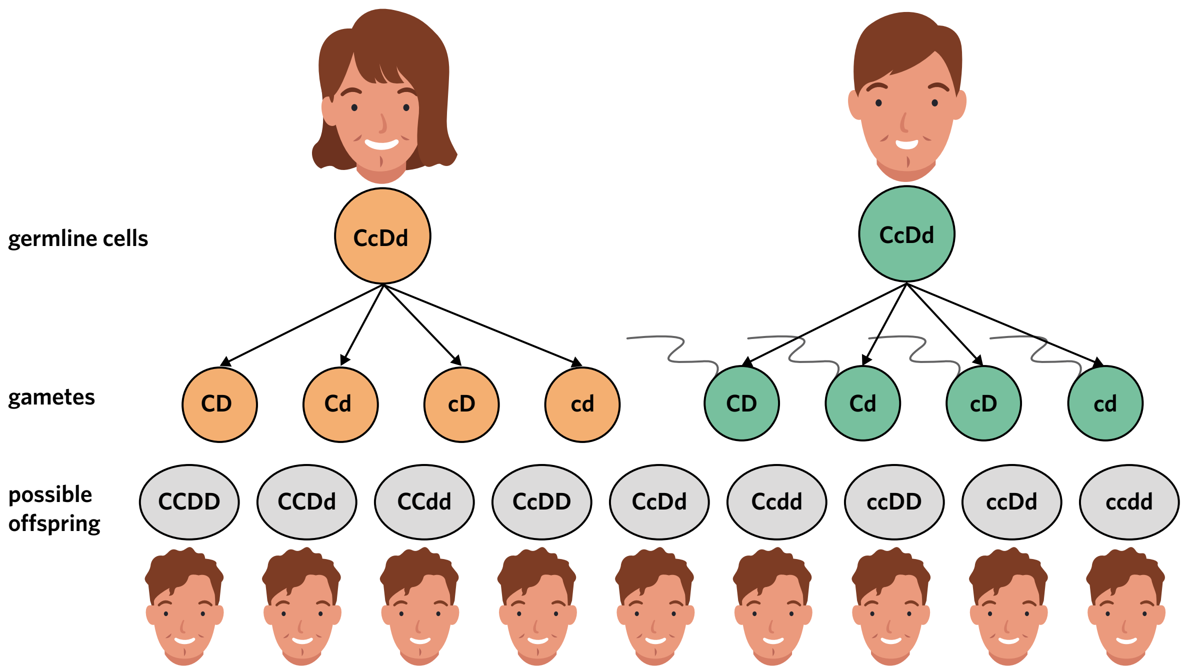


Image: Paranyu/Shutterstock.com

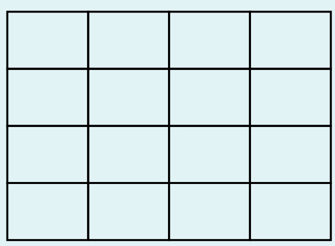
Figure 1 Possible offspring from two heterozygous parents for the expression of dimples and a cleft chin.

How to complete a dihybrid Punnett square

1 Assign letters to each allele
2 Draw a 4 × 4 grid
3 Write each of the father's allele combinations above one column
4 Write each of the mother's allele combinations beside one row
5 Complete the cross to determine the potential offspring genotypes. Ensure you write the dominant allele first in heterozygous offspring
6 Calculate the fractional proportions of each potential genotype by determining the frequency of each genotype then dividing it by the total number of squares. Multiply this fraction by 100 to determine the percentage of each genotype
7 Determine the phenotype of each offspring by looking at the genotypes. To calculate the fractional proportions of each phenotype, determine the frequency of each phenotype then divide it by the total number of squares. Multiply this fraction by 100 to determine the percentage of each phenotype.

(Note: steps 3 and 4 are interchangeable, and it doesn't matter which side the mother and father's alleles are placed.)

Table 1 Worked example of how to complete a Punnett square for cleft chin and dimples with two heterozygous parents

1 Assign letters to each allele	C = cleft chin c = no cleft chin D = dimples d = no dimples
2 Draw a 4 × 4 grid	

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Memory device

To determine the different gametes produced by an individual during meiosis, we can use what is known as the FOIL method.

F – First alleles

O – Outside alleles

I – Inside alleles

L – Last alleles

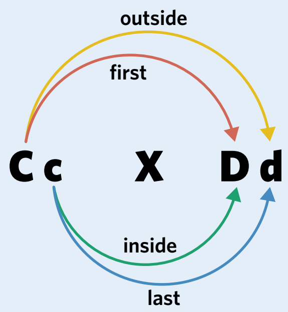

Figure 2 Combination method known as FOIL. Here, for an individual with the genotype CcDd, their possible gametes are CD, Cd, cD, and cd.

Table 1 Continued

3 Write each of the father's allele combinations above one column

CD	Cd	cD	cd

4 Write each of the mother's allele combinations beside one row

	CD	Cd	cD	cd
CD				
Cd				
cD				
cd				

5 Complete the cross to determine the potential offspring genotypes. Ensure you write the dominant allele first in heterozygous offspring

	CD	Cd	cD	cd
CD	CCDD	CCDd	CcDD	CcDd
Cd	CCDd	CCdd	CcDd	Ccdd
cD	CcDD	CcDd	ccDD	ccDd
cd	CcDd	Ccdd	ccDd	ccdd

6 Calculate the proportions of each potential genotype

Total squares = 16

Genotype	Number of offspring	Fractional proportion	Percentage proportion
CCDD	1	1/16	6.25%
CCDd	2	2/16	12.5%
CCdd	1	1/16	6.25%
CcDD	2	2/16	12.5%
CcDd	4	4/16	25%
Ccdd	2	2/16	12.5%
ccDD	1	1/16	6.25%
ccDd	2	2/16	12.5%
ccdd	1	1/16	6.25%

7 Determine the phenotype of each offspring by looking at the genotypes

Total squares = 16

Number of combinations with:

- cleft chin and dimples (CCDD, CCDd, CcDD, CcDd) = 9/16 = 56.25%
- cleft chin and no dimples (CCdd, Ccdd) = 3/16 = 18.75%
- dimples and no cleft chin (ccDD, ccDd) = 3/16 = 18.75%
- no cleft chin and no dimples (ccdd) = 1/16 = 6.25%

Ratio of phenotypes: 9 : 3 : 3 : 1

Whenever conducting a dihybrid cross with two heterozygous individuals, the phenotypic ratio will always be 9 : 3 : 3 : 1.

As Figure 1 and Table 1 both demonstrate, there can be up to four different possible combinations of alleles in any one gamete. From here, phenotypic and genotypic proportions can be calculated, which will be considered in closer detail later in this lesson. Out of the 16 combinations:

- nine potential offspring would have both a cleft chin and dimples
- three would have a cleft chin but no dimples
- three would have dimples but no cleft chin
- one would have neither a cleft chin or dimples.

This gives us a phenotypic ratio of 9 : 3 : 3 : 1. When considering the ratios from dihybrid crosses, an important tip to remember is that whenever you cross two heterozygous individuals, you will always finish with the same ratio of 9 : 3 : 3 : 1.

Linked dihybrid crosses 2.1.11.2

OVERVIEW

The distance between two genes determines whether or not they are linked. Linked genes require a different format for dihybrid crosses.

THEORY DETAILS

In the previous section, we learned how to complete dihybrid crosses with unlinked genes. Now we'll take things one step further and examine how inheritance of linked genes can be predicted.

Linked genes

Genes that are located more closely together on the same chromosome are known as **linked genes**. This means that during meiosis, because they are on the same chromosome, they are inherited together and are not separated during **independent assortment**. Linked genes, however, can occasionally be separated through **crossing over** (Figure 3).

linked genes genes that are found close together on the same chromosome and are likely to be inherited together

independent assortment the random orientation of homologous chromosomes along the metaphase plate during metaphase I

crossing over the exchange of genetic material between non-sister chromatids during prophase I of meiosis, resulting in new combinations of alleles in daughter cells

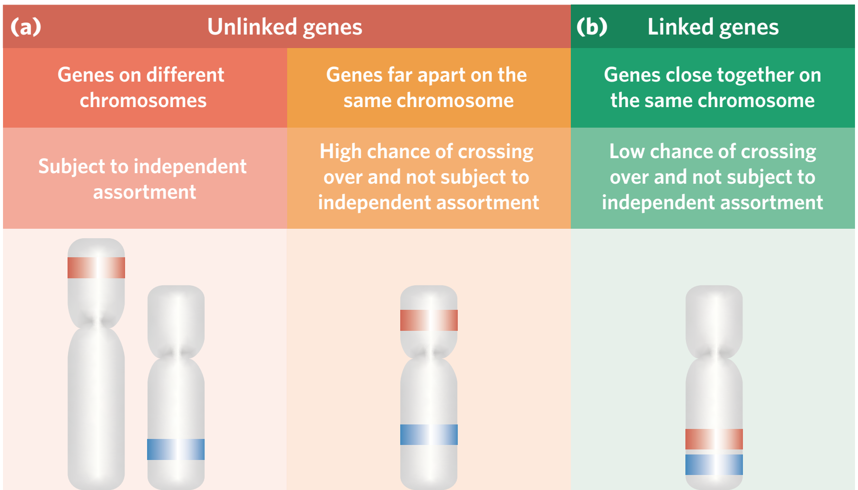

Figure 3 Summary diagram of **(a)** unlinked and **(b)** linked genes and examples of their respective locations on chromosomes.

Lesson link

In ***lesson 7B*** you learned about meiosis, which results in the production of haploid (*n*) gametes in an organism. When considering linked dihybrid crosses, it is important to understand the following:

- each gamete will contain only one copy of each gene on either a paternal or maternal chromosome. Which copy the gamete inherits is random, and depends on independent assortment.
- each chromosome that is inherited may also exhibit recombination as a result of crossing over.

Theory in context

LINKED GENES IN HUMANS

An example of two linked genes in humans is Rhesus blood type (*RHD*) and elliptocytosis (*EPB41*). Both genes are found on chromosome 1. The dominant allele for *RHD* results in a positive blood type, while the recessive allele results in a negative blood type – for example, O+ and O–, respectively. Elliptocytosis, on the other hand, is an inherited dominant blood disorder where an individual's red blood cells are more oval-shaped, rather than a biconcave disc (Figure 4). These two genes are linked, and are therefore commonly inherited together and are less likely to be separated during meiosis.

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Theory in context

LINKED GENES IN HUMANS – CONTINUED

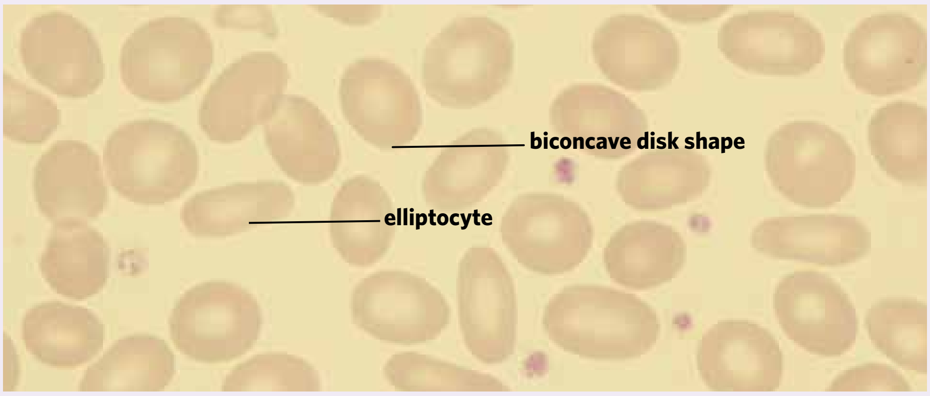


Image: LindseyRN/Shutterstock.com

Figure 4 A blood smear comparing elliptocytes from healthy blood cells

Linked genes can be found in fruit flies, *Drosophila melanogaster* (Figure 5). On their second chromosome are three linked genes that encode body colour, eye colour, and wing size. Their body colour can be grey (B) or black (b), their eye colour can be red (E) or brown (e), and their wing size can be normal (W) or vestigial (w).

Image: CG Narozi/Shutterstock.com

Figure 5 Photograph of *Drosophila melanogaster*

For unlinked genes, we can consistently predict offspring genotypes and phenotypes because all the genes sort independently. This means we get nice ratios like 1 : 1 : 1 : 1 when crossing a heterozygous individual with a homozygous recessive individual. For linked genes, however, we can't assume two alleles on the same chromosome will end up in the same gamete. Because of crossing over, the two alleles may occasionally end up on different chromosomes and in different gametes.

The chances of crossing over occurring are calculated by using **map units** (Figure 6). One map unit equates to a one per cent chance of crossing over and the offspring containing a **recombinant chromosome**. This means crosses with linked genes can result in strange ratios like 11.5 : 1 : 1 : 11.5 (Figure 7).

map units a measure of the distance between two genes on the same chromatid. Genes that are closer together are more likely to be linked genes

recombinant chromosome a chromosome which is not identical to one of the homologous chromosomes in a diploid cell

Memory device

Remember that map units cannot be calculated from DNA as they are an arbitrary value. Therefore, the only way to work them out is if you know the chance of recombination occurring.

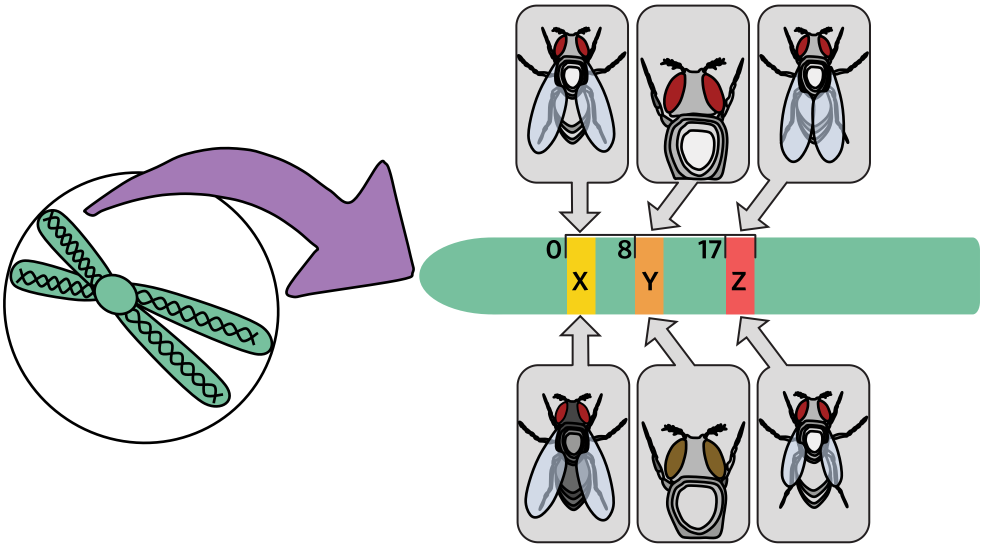
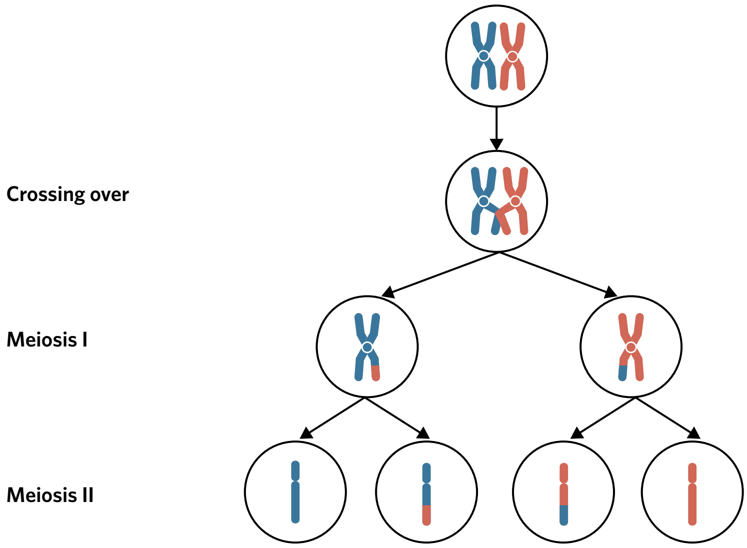


Figure 6 Map units between genes in *Drosophila melanogaster*. Crossing over is more likely to occur between allele X and allele Z than allele X and allele Y, as there is a greater distance between X and Z.

If we use the example of body colour and eye colour in *Drosophila melanogaster*, these genes are eight map units apart, meaning there is an eight per cent chance that crossing over will occur to create a recombinant chromosome. Alternatively, we can say 8 in 100 gametes will contain a recombinant chromosome. Thus, there is a 92 per cent chance that crossing over will not occur, resulting in a **parental chromosome**.

parental chromosome a chromosome which contains the same combination of alleles as one of the parents' chromosomes



Type of chromosome	Parental	Recombinant	Recombinant	Parental
Percentage of gametes	46%	4%	4%	46%

Figure 7 Diagram of meiosis with recombination showing the percentages of gametes with recombination. Red chromosomes are maternally inherited, and blue chromosomes are paternally inherited.

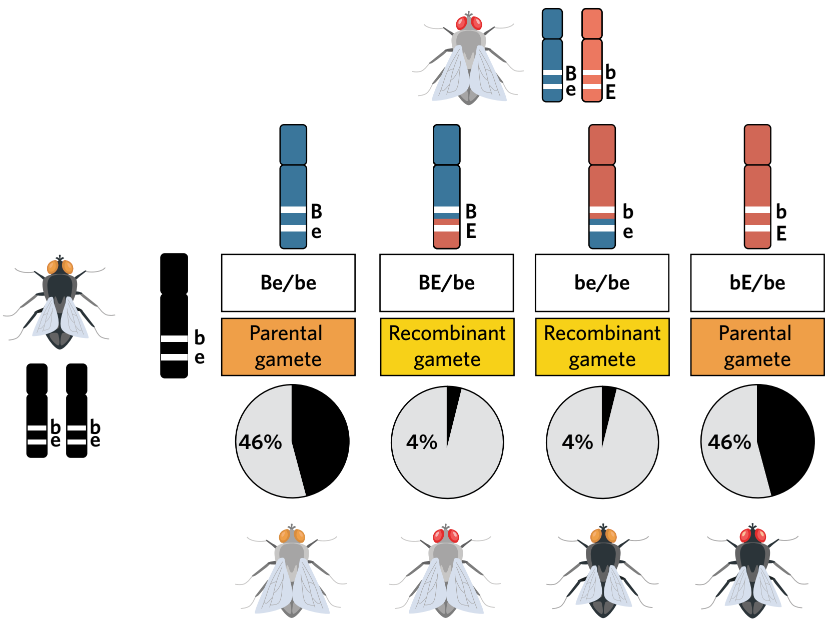


Image: adecvatman/Shutterstock.com

Figure 8 Linked dihybrid cross between a heterozygous and homozygous recessive individual. You can tell the recombinant offspring are individuals BE/be and be/be because they occur so rarely, and also because neither parent had these allele combinations on their chromosomes.

From this information, we can perform a linked dihybrid cross. For simplicity, usually these crosses are performed against a homozygous recessive individual (a test cross). Figure 8 shows a cross between a heterozygous male (Be/bE) and a homozygous recessive female (be/be). For the homozygous recessive female, only one gamete option is required for the cross, as even if crossing over occurs, the gametes will still have the parental allele combinations (be). There are four possible gametes (be, Be, bE, BE) for the heterozygous male as crossing over has created new combinations of alleles.

For linked genes, genotypes are written using a different convention. You write the alleles on one chromosome first, then add a forward slash (/), then write the alleles on the second chromosome. Using the example in Figure 8, the genotype for the individual in the left square would be Be/be.

Theory in action

Check out Scientific Investigations 8.1 and 8.2 to put this into action!

How to complete a linked dihybrid cross Punnett square

Note: these steps are for a cross with a homozygous recessive individual only.

1 Assign letters to each allele

2 Determine each of the possible alleles in each gamete for the parents and the chances of this happening. Be sure to account for crossing over

3 Draw a 1 × 4 grid

4 Write each of the non-homozygous recessive individual's allele combinations above one column and note which combinations are parental and which are recombinant

5 Write the homozygous recessive alleles next to the one row

6 Complete the cross to determine the potential offspring genotypes. Be sure to use the correct conventions for writing genotypes for linked genes

7 Write the percentage chance of this genotype occurring below each square

Table 2 Worked example of completing a linked dihybrid cross Punnett square

<table>
<tr><td>1 Assign letters to each allele</td><td colspan="5">B = grey body colour
b = black body colour
E = red eyes
e = brown eyes</td></tr>
<tr><td>2 Determine each of the possible alleles in each gamete for the parents and the chances of this happening. Be sure to account for crossing over</td><td colspan="5">Mother's genotype – be/be
All her gametes are – be
Father's genotype – Be/bE
Parental gametes – Be, bE
Recombinant gametes – BE, be
Map units – 8
Be chance – 46%
bE chance – 46%
BE chance – 4%
be chance – 4%</td></tr>
<tr><td rowspan="2">3 Draw a 1 × 4 grid</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">4 Write each of the non-homozygous recessive individual's allele combinations above one column and note which combinations are parental and which are recombinant</td><td></td><td>Be</td><td>BE</td><td>be</td><td>bE</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Parental gamete</td><td>Recombinant gamete</td><td>Recombinant gamete</td><td>Parental gamete</td></tr>
<tr><td rowspan="3">5 Write the homozygous recessive alleles next to the one row</td><td></td><td>Be</td><td>BE</td><td>be</td><td>bE</td></tr>
<tr><td>be</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Parental gamete</td><td>Recombinant gamete</td><td>Recombinant gamete</td><td>Parental gamete</td></tr>
<tr><td rowspan="3">6 Complete the cross to determine the potential offspring genotypes. Be sure to use the correct conventions for writing genotypes for linked genes</td><td></td><td>Be</td><td>BE</td><td>be</td><td>bE</td></tr>
<tr><td>be</td><td>Be/be</td><td>BE/be</td><td>be/be</td><td>bE/be</td></tr>
<tr><td></td><td>Parental gamete</td><td>Recombinant gamete</td><td>Recombinant gamete</td><td>Parental gamete</td></tr>
<tr><td rowspan="4">7 Write the percentage chance of this genotype occurring below each square</td><td></td><td>Be</td><td>BE</td><td>be</td><td>bE</td></tr>
<tr><td>be</td><td>Be/be</td><td>BE/be</td><td>be/be</td><td>bE/be</td></tr>
<tr><td></td><td>Parental gamete</td><td>Recombinant gamete</td><td>Recombinant gamete</td><td>Parental gamete</td></tr>
<tr><td></td><td>46%</td><td>4%</td><td>4%</td><td>46%</td></tr>
</table>

Theory summary

Dihybrid crosses allow us to predict the potential genotypes of offspring for two genes. There are two methods for this depending on how close together the genes are – linked and unlinked dihybrid crosses.

A common question you might come across is determining if a dihybrid cross involves linked or unlinked genes. A good clue for identifying linkage is seeing unusual genotypic ratios in offspring (i.e. a few genotypes that arise very rarely) or genotypes that were not present in the parents. Remember that if you did a dihybrid test cross between a heterozygote and a homozygous recessive individual, unlinked genes would result in a genotypic ratio of 1 : 1 : 1 : 1. This ratio would not occur if the genes were linked – it might be 1 : 1 : 0.1 : 0.1 or something unusual like that.

Blue eyes and light coloured hair are expressed by linked genes which means there is a lower chance of the two genes being separated by crossing over. This means there is a higher chance that individuals who possess one allele will also possess the other. So just like a meat pie and sauce, you can't have one without the other.

8B QUESTIONS

Theory review questions

Question 1

Linked genes are located

A close together on the same chromosome.

B far apart on the same chromosome.

C far apart on different chromosomes.

Question 2

Linked genes

A are not separated by independent assortment.

B have a high chance of recombination.

Question 3

The following diagram shows a Punnett square.

	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

What type of dihybrid cross is displayed?

A a linked gene dihybrid cross

B an unlinked gene dihybrid cross

Question 4

Complete the Punnett square.

	AB	Ab	AB	Ab
AB			AABB	AABb
Ab			AABb	AAbb
aB	AaBB	AaBb		
aB	AaBB	AaBb		

Question 5

Complete the Punnett square.

	______	______	______	______
ab	Ab/ab ______	AB/ab 2%	ab/ab ______	aB/ab 48%

Parental ______ Recombinant ______

Question 6

There are 7 map units between two linked genes.

What are the chances that a gamete will contain a parental chromosome?

A 7%

B 25%

C 75%

D 93%

SAC skills questions

Bioethical deep dive

Use the following information to answer Questions 7–11.

The human sex chromosomes are the X and Y chromosomes. Females will possess two X chromosomes, while a male will possess an X and a Y chromosome. This is determined during embryonic development due to the presence of the *SRY* (sex-determining region) gene on the Y chromosome, which activates a number of other genes to produce male features.

In very rare cases, the X and Y chromosome can undergo crossing over resulting in an X chromosome that possesses the *SRY* gene from the Y chromosome (*SRY* + X chromosome), and vice versa in males (*SRY* – Y chromosome). In these cases, individuals will appear phenotypically different from the sex suggested by their karyotype and will be infertile.

A controversial example of this condition occurred at the 2006 Asian Games, where Santhi Soundarajan was a female athlete competing in the 800 m. She was stripped of her silver medal as it was revealed that she was XY female. Whilst Santhi expressed female genitalia, she did not regularly menstruate.

Geneticists wish to perform a dihybrid cross to show the potential offspring's genotypes between the *SRY* and *DAX1* genes. *DAX1* is only found on X chromosomes. In this cross, genes are represented as present (+) or absent (–) from a chromosome.

		father			
		X chromosome		**Y chromosome**	
		***DAX1* + *SRY* –**	***DAX1* + *SRY* +**	***DAX1* – *SRY* –**	***DAX1* – *SRY* +**
mother	***DAX1* + *SRY* –**	*DAX1* + *SRY* – / *DAX1* + *SRY* –	*DAX1* + *SRY* + / *DAX1* + *SRY* –	*DAX1* – *SRY* – / *DAX1* + *SRY* –	*DAX1* – *SRY* + / *DAX1* + *SRY* –
		XX female	**XX male**	**XY female**	**XY male**
		49.9975%	0.0025%	0.0025%	49.9975%

Question 7

What phenotypic abnormality did Santhi exhibit?

A the presence of *SRY* on her X chromosome

B the inability to regularly menstruate

Question 8

What percentage of male gametes contain a recombinant sex chromosome?

A 0.0025%

B 0.0050%

C 49.9975%

D 99.9950%

Question 9

How might a duty/rule-based approach to bioethics have informed the committee's decision to strip Santhi of her silver medal?

A As an impartial adjudicator, the committee understands its responsibility to act in the interest of all competitors. It is only fair to remove any excessive athletic advantage from events, irrespective of whether the athlete has a choice.

B The adjudicator should consider how Santhi may react to losing her silver medal over something she had no knowledge of.

Question 10

How might the ethical concept of justice have informed the committee's decision to strip Santhi of her silver medal?

A The committee recognises the need to acknowledge Santhi as a female competitor, and show due consideration to her value as an athlete.

B The committee recognised their moral obligation to remove any unfair burden on other competitors and decided to disqualify Santhi because of the athletic advantage she held over other female runners.

Question 11

Santhi underwent testing with an endocrinologist to test her hormone levels. How might the actions of the endocrinologist be informed by the bioethical concept of non-maleficence?

A The endocrinologist accurately reported the correct results from Santhi's test to the committee so that they could make an informed decision.

B The endocrinologist undertook the correct safety precautions when completing the blood and urine tests to detect the presence of certain hormones.

Exam-style questions

Within lesson

Question 12 (1 MARK)

Which of the following conclusions can be made about linked genes?

A They act similarly to unlinked genes.

B They do not undergo crossing over during meiosis.

C Map units represent how frequently recombination occurs.

D They are susceptible to be separated by independent assortment.

Question 13 (7 MARKS)

In a particular insect species, sex is determined by a single gene. The male insect has the genotype Mm and the female insect is mm. This gene is linked to another gene that determines the eye colour of the insect. Black eye colour (E) is dominant over green eye colour (e). A heterozygous black-eyed male was crossed with a green-eyed female and the following offspring were produced.

Black-eyed male	Green-eyed male	Black-eyed female	Green-eyed female
44	6	6	44

a What is meant by the term 'linked genes'? (1 MARK)

b How many map units apart are the genes for eye colour and sex determination? (1 MARK)

c The same insect species has a gene on a different chromosome that determines body colour. Red body colour is dominant (B) and brown is recessive (b). Both the male and female insects are heterozygous for body colour.

- **i** What phenotype for body colour is expressed by the male and female insect? (1 MARK)
- **ii** Complete a dihybrid cross for body colour and eye colour. (2 MARKS)
- **iii** What proportion of offspring would have black eyes? (1 MARK)
- **iv** What proportion of offspring would have brown body colour? (1 MARK)

Adapted from VCAA 2002 Exam 2 Section B Q3

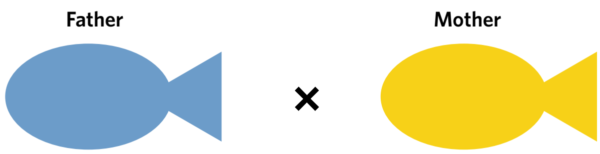
Multiple lessons

Use the following information to answer Questions 14–16.

An autosomal gene controls the body colour of fish. It has two codominant alternative alleles:

- Y = yellow
- B = blue

A blue male fish and a female yellow fish breed together.



Question 14 (1 MARK)

What is the genotype of the father?

A BB
B BY
C YY
D By

Adapted from VCAA 2004 Section A Q1

Question 15 (1 MARK)

All of the offspring of this cross would be

A blue.
B green.
C yellow.
D heterozygous.

Question 16 (1 MARK)

On a different autosomal chromosome, there is a gene that is responsible for the size of the tail fin. It has two alleles:

- F = large tail fin
- f = small tail fin

It would be expected that

A fin length and body colour are linked genes.
B the fin length gene is found on the X chromosome.
C fin size and body colour are subject to independent assortment.
D all fish with large tails would only give rise to offspring with large tails.

Key science skills and ethical understanding

Question 17 (3 MARKS)

Geneticists are analysing the offspring of a seahorse species to understand whether body colour and snout length are encoded by linked genes. The dominant body colour is yellow (B) and the recessive is grey (b). The dominant snout length is long (L) and the recessive length is short (l).

Male seahorses can give birth to thousands of offspring in one litter. The geneticists crossed two heterozygous individuals for both alleles together and looked at the offspring phenotypes to determine gene linkage. They used a sample size of 30 and the results collected were:

Yellow and long snout	Yellow and short snout	Grey and long snout	Grey and short snout
17	5	6	2

a Explain whether snout length and body colour are linked genes. (1 MARK)

b Explain any potential limitations of the experiment that could have affected the results. (1 MARK)

c Infant seahorses have a high mortality rate. In fact, only 1 in 20 will survive. In light of this, explain how the bioethical concept of beneficence might have informed this study. (1 MARK)

8C PEDIGREE ANALYSIS

Is your father going bald? Or do you know someone whose father is bald? Chances are you are worried that you are going to lose your hair, but that's actually not how it works. Male pattern baldness doesn't follow a typical inheritance pattern, as you cannot inherit the male baldness gene from your father. Unfortunately, if you are male and your maternal grandfather is bald, chances are you are going to lose your hair in your twenties (if you haven't already). But how do scientists work this out?


Image: Pathdoc/Shutterstock.com

Lesson 8C
In this lesson you will learn how the inheritance of a trait over many generations is visually represented through a pedigree chart.

◀ *Prerequisite knowledge* | *Future applications* ▶

Chapter 7
You can tell if an allele is dominant, recessive, sex-linked, or autosomal by reading the different indicators in a pedigree chart.

Lessons 8A & 8B
The two previous lessons focus on inheritance across two generations. Pedigree charts build upon this knowledge by looking at inheritance over multiple generations.

Year 12
Breeders can artificially select certain traits by tracking traits over multiple generations using pedigree charts.

Study design dot point

- pedigree charts and patterns of inheritance, including autosomal and sex-linked inheritance

Key knowledge units

Pedigrees	2.1.9.1
Patterns of inheritance	2.1.9.2

Pedigrees 2.1.9.1

OVERVIEW

Pedigrees are a visual representation of how a trait is passed down through multiple generations.

THEORY DETAILS

To analyse patterns of inheritance, geneticists use **pedigree charts** to characterise the inheritance of a trait over multiple generations. Figure 1 shows common symbols used in pedigree charts. While this is not an exhaustive list, for the purposes of VCE Biology, these are the symbols you need to know.

pedigree chart a diagram showing the expression of a trait over multiple generations

Important conventions of pedigree charts include:

- horizontal lines represent mating between two individuals
- vertical lines represent the link between two generations
- circles are females and squares are males
- coloured shapes are affected individuals
- uncoloured shapes are unaffected individuals.

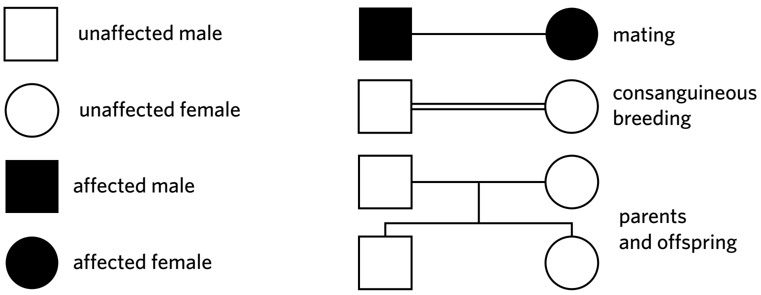


Figure 1 The common symbols used in pedigree charts

In a pedigree chart, each individual has a unique reference based on their generation and where they are located from left to right. The generation of an individual is noted with Roman numerals, ascending from oldest to youngest. The location of an individual in a generation is noted using numbers, ascending from left to right (Figure 2).

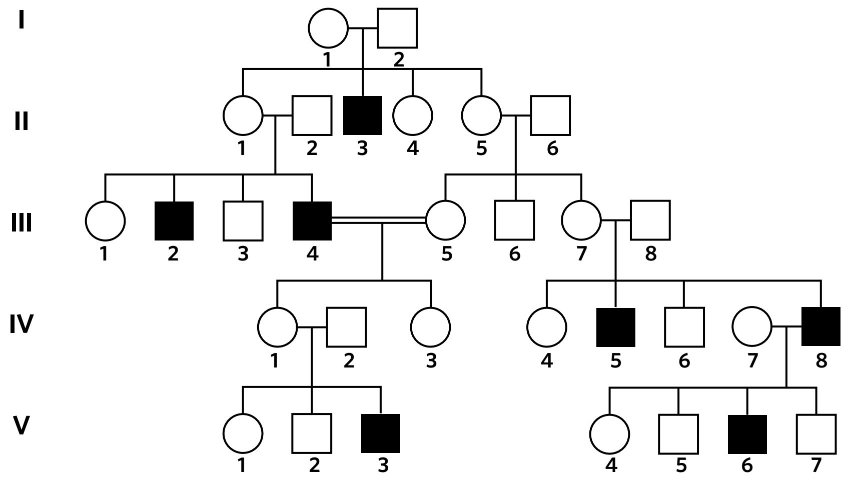


Figure 2 A pedigree chart showing the inheritance of an unknown trait and the unique codes for each individual. Note: the Roman numerals on the left-hand side of the pedigree chart denote generations.

By reading Figure 2, we can see that:

- individual II-3 is an affected male
- individual IV-1 is the unaffected mother of V-1, V-2, and V-3
- individuals III-4 and III-5 have engaged in **consanguineous breeding**
- individual III-8 is unrelated to all individuals from previous generations in this pedigree.

consanguineous breeding breeding of two individuals that are closely related. Also known as **inbreeding**

Theory in context

TRANSGENDER AND NON-BINARY REPRESENTATION IN PEDIGREES

Contemporary research has shown that gender is more nuanced and complex than a simple categorisation of 'male' or 'female'. As a result, scientists are increasingly moving towards an updated approach to pedigree symbols in order to reflect what is now frequently understood and labelled as the 'spectrum' of gender. At present, it's common to represent individuals who do not specify as male or female as diamonds (Figure 3).

Meanwhile, the National Comprehensive Cancer Network in the United States proposed integrating circles and squares to represent transgender individuals (Figure 4), although this convention is not yet widely used.

Read more about the science of gender at nationalgeographic.com/magazine/2017/01/how-science-helps-us-understand-gender-identity/

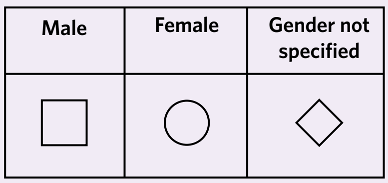


Figure 3 The current accepted conventions in pedigrees

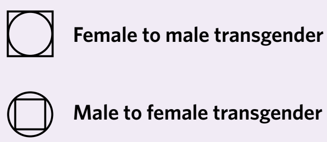


Figure 4 The NCCN proposed changes to represent transgender individuals

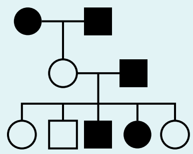
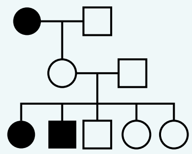
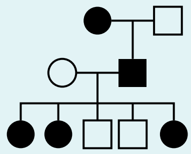
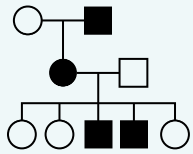
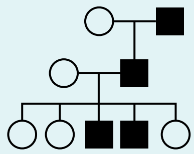
Patterns of inheritance 2.1.9.2

OVERVIEW

Where the allele is located and whether it is dominant or recessive will affect how that trait appears on a pedigree chart, and its inheritance pattern. The five inheritance patterns we will cover here are autosomal dominant, autosomal recessive, X-linked dominant, X-linked recessive, and Y-linked.

THEORY DETAILS

Table 1 Summary of the patterns of inheritance and their associated pedigrees

Inheritance pattern	Examples	Pedigree chart example
Autosomal dominant **1** If both parents are affected, the offspring may be unaffected. **2** If neither parent is affected, the offspring must be unaffected. **3** If an offspring is affected, there must be an affected parent. **4** The trait cannot skip a generation.	Huntington's disease, achondroplasia (dwarfism)	
Autosomal recessive **1** If both parents are affected, the offspring must be affected. **2** If neither parent is affected, the offspring may be unaffected. **3** If an offspring is affected, there may be an affected parent. **4** The trait can skip a generation.	Cystic fibrosis, Tay-Sachs disease, albinism, phenylketonuria (PKU)	
X-linked dominant **1** If a male is affected, his mother must be affected. **2** If a male is affected, his daughters must be affected. **3** If a female is unaffected, her father must be unaffected. **4** If a female is unaffected, her sons must be unaffected. **5** The trait cannot skip a generation. Sex-linked inheritance cannot be confirmed with certainty using just a pedigree.	Rett syndrome, fragile X syndrome	
X-linked recessive **1** If a female is affected, her father must be affected. **2** If a female is affected, her sons must be affected. **3** If a male is affected, his mother may be affected. **4** The trait can skip a generation. Sex-linked inheritance cannot be confirmed with certainty using just a pedigree.	Red-green colour blindness, haemophilia	
Y-linked **1** Only males can show the trait. **2** All males in a lineage will show the same phenotype. **3** The trait cannot skip a generation. Sex-linked inheritance cannot be confirmed with certainty using just a pedigree.	Hypertrichosis pinnae auris, Y chromosome infertility	

When identifying autosomal traits, we can rule out sex-linked traits if the pedigree does not satisfy all the criteria of sex-linked inheritance.

However, it is important to note that sex-linked inheritance cannot be confirmed from a pedigree as it is possible for autosomal traits to produce pedigree charts that suggest sex-linked inheritance. So, instead of saying that sex-linked inheritance is confirmed, we say that sex-linked inheritance is more likely, as the chances of autosomal traits producing a pedigree chart that looks like sex-linked inheritance are very low.
For instance, it is entirely possible that the pedigree chart for Y-linked inheritance is caused by an autosomal dominant trait that, by complete chance, only affected males.
More evidence, such as evidence obtained via gene sequencing and mapping, is required to conclusively identify sex-linked traits.

Steps to determine inheritance patterns

When approaching a new pedigree, the steps in Figure 5 can help breakdown what type of inheritance pattern it is showing. For more complex pedigrees, you may need to refer back to the criteria in Table 1 to identify the inheritance pattern. Remember, a trait is not necessarily sex-linked just because it is more prominent in one sex. It must satisfy the criteria in Figure 5 or Table 1.

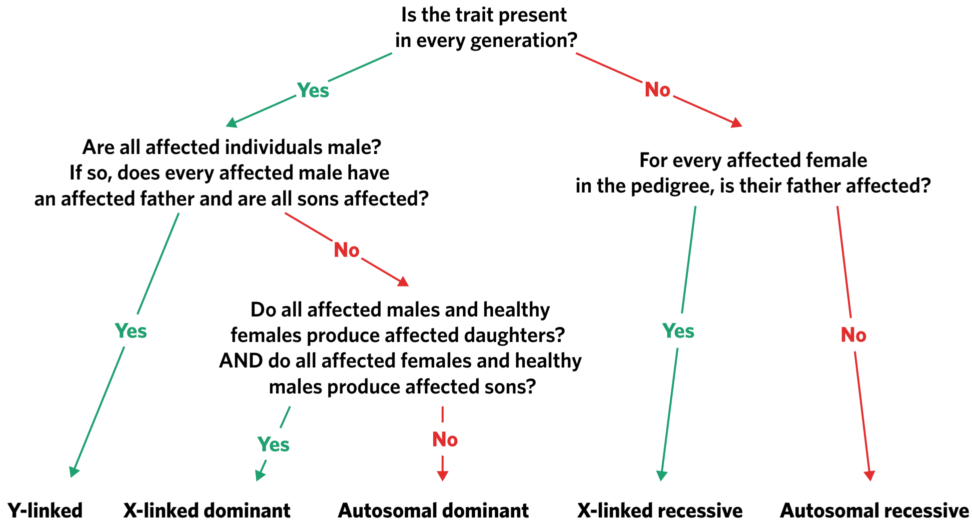


Figure 5 Flowchart for analysing pedigree charts

Theory in context

PHENYLKETONURIA

Phenylketonuria (PKU) is a metabolic disorder where an amino acid (the building blocks of proteins) known as phenylalanine is incorrectly produced. This can lead to malfunctioning proteins which cause seizures, intellectual disabilities, and mental disorders. Evaluate the pedigree to determine the inheritance pattern of this disease.

Analysis of the pedigree:

- Is this trait present in every generation? No.
- For every affected female in the pedigree, is their father affected? No.
- Therefore, this is an autosomal recessive disorder.

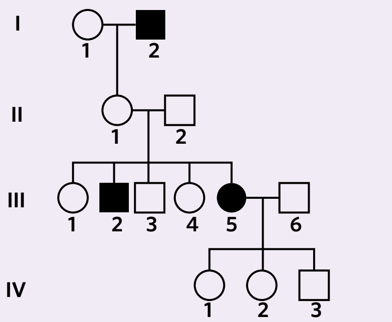


Figure 6 Sample pedigree of PKU across four generations

Theory in context

HAEMOPHILIA

Haemophilia is a blood disorder which affects an individual's ability to form blood clots. This can lead to prolonged, internal bleeding, and deep bruises. Evaluate the pedigree to determine the inheritance pattern of this disease.

Analysis of the pedigree:

- Is this trait present in every generation? No.
- For every affected female in the pedigree, is their father affected? Yes.
- Therefore, it is likely this is a X-linked recessive disorder. However sex-linked inheritance cannot be confirmed as it is possible that the trait is an autosomal recessive disorder.

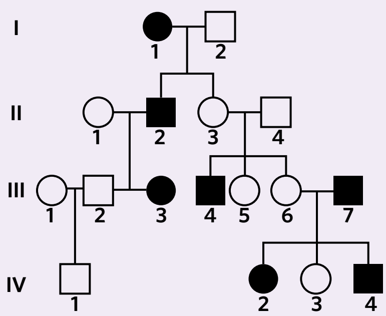


Figure 7 Sample pedigree of haemophilia across four generations

Theory in context

RETINITIS PIGMENTOSA

Retinitis pigmentosa (RP) is a rare disorder involving the breakdown and loss of cells in the retina. This can lead to decreased vision at night, vision disorders, and tunnel vision. Evaluate the pedigree to determine the inheritance pattern of this disease.

Analysis of the pedigree:

- Is this trait present in every generation? Yes.
- Are all affected individuals male? If so, does every affected male have an affected father and are all sons affected? Yes.
- Therefore, it is likely this is a Y-linked disorder. However sex-linked inheritance cannot be confirmed as it is possible that the trait is an autosomal dominant or recessive disorder.

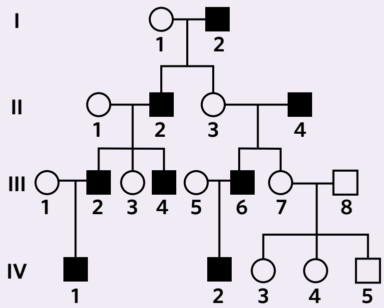


Figure 8 Sample pedigree of retinitis pigmentosa across four generations

Determining genotypes

From pedigree charts, you can determine the genotypes of certain individuals depending on the type of inheritance pattern the trait follows. In Figure 9, an autosomal dominant pedigree is shown.

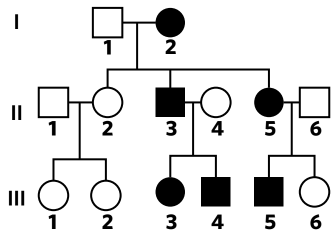


Figure 9 Autosomal dominant pedigree across three generations

Determining the genotype of I-1 and I-2:

- As it is an autosomal trait, all individuals will have two alleles.
- As it is a dominant trait, affected individuals may be homozygous or heterozygous. Therefore, they are not **carriers**.
- Therefore, if an affected individual produces an unaffected child (meaning a child who possesses two unaffected alleles), that individual must be heterozygous (having passed on an unaffected allele to their child).
- As I-1 is unaffected, he must be homozygous recessive.
- As I-2 has produced an offspring – II-2 – who is unaffected (homozygous recessive), that means that they must be heterozygous at this gene locus.

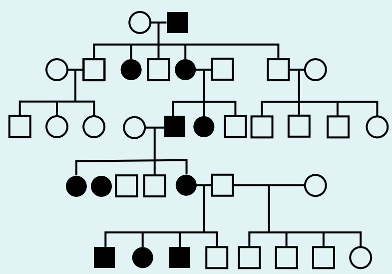
carrier an organism that has inherited a copy of a recessive allele for a genetic trait but does not display the trait due to it being masked by the presence of a dominant allele

To make it easier to track genotypes in the pedigree chart, you might find it helpful to write all of an individual's possible genotypes above their symbol.

Theory summary

Pedigree charts show the inheritance of a trait over many generations. We can analyse these charts to determine if a trait is dominant, recessive, sex-linked, or autosomal.

Pedigrees! By tracking male baldness over generations, scientists have worked out that the main gene for male baldness is dominant on the X chromosome. So if your maternal grandfather is bald, there is at least a 50% chance that you are going to inherit the X-linked male baldness gene. However, don't be too upset. While current science tells us there is no surefire way to regrow hair once it's lost, hair loss can be slowed down.



8C QUESTIONS

Theory review questions

Question 1

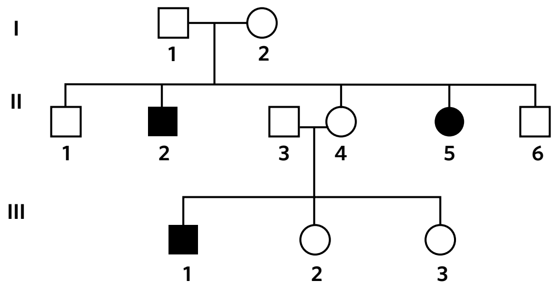
Pedigree charts primarily show the

A karyotypes of offspring based on their parents.

B inheritance of a trait over multiple generations.

Question 2

Consider the following pedigree chart.



Individual II-5 is

A an affected male.

B an affected female.

C an unaffected male.

D an unaffected female.

Question 3

Which of the following are examples of inheritance patterns? (*Select all that apply*)

I X-linked recessive

II Y-linked recessive

III X-linked dominant

IV autosomal recessive

Question 4

Fill in the blanks with the following terms. Terms may be used multiple times or not at all.

- may
- must

For an autosomal recessive trait, if both parents are affected the offspring __________ be affected. If neither parent is affected the offspring __________be unaffected. If an offspring is affected there __________ be an affected parent.

Question 5

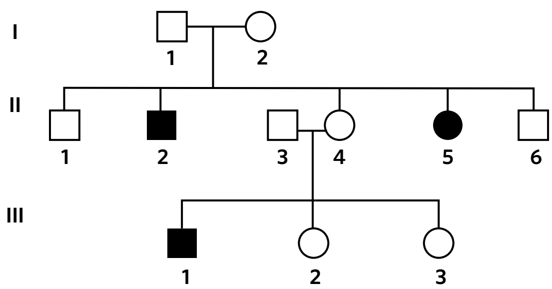
Fill in the blanks with the following terms. Terms may be used multiple times or not at all.

- must
- must not

For an X-linked dominant trait, if a male is affected, his mother __________ be affected and his daughters __________ be affected. If a female is unaffected, her father __________ be affected and her sons __________ be affected.

Question 6

Consider the following pedigree.



Which inheritance pattern is most likely shown in this pedigree?

A X-linked recessive

B X-linked dominant

C autosomal recessive

D autosomal dominant

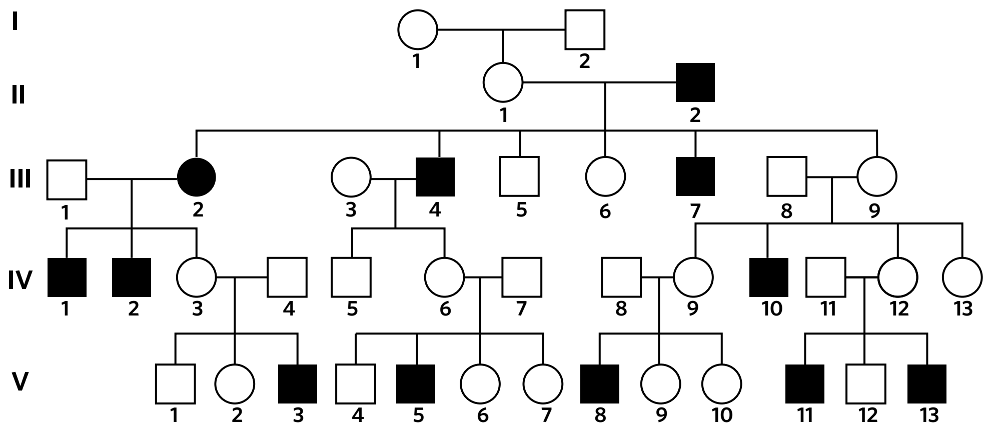
SAC skills questions

Scientific methodology comparison

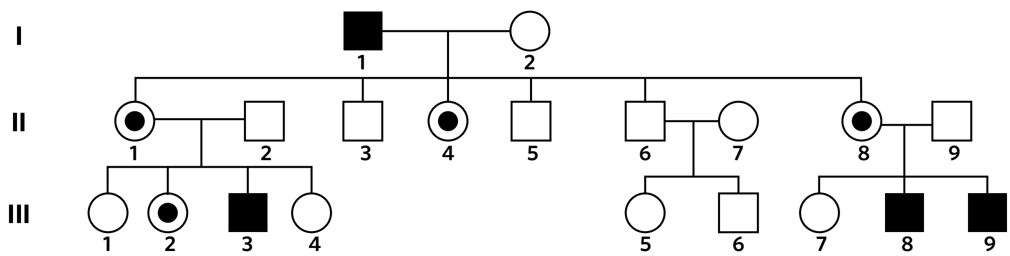
Use the following information to answer Questions 7–11.

Two teams of scientists were attempting to determine the inheritance pattern of Hunter syndrome. This syndrome causes abdominal hernias, an enlarged tongue, and joint stiffness. It can also cause developmental disorders such as autism. These symptoms are caused by a deficiency of the lysosomal enzyme iduronate-2-sulfatase, allowing the accumulation of products that cannot be broken down.

Team 1 recruited a 35-year-old woman to begin crafting a pedigree to show the inheritance of Hunter syndrome over multiple generations in her family. Luckily, the woman had great confidence in her memory of the three generations prior to her as well as the generation after her. This woman is seen in the pedigree table as individual IV-12.



Team 2 recruited an affected 2-year-old boy and conducted DNA testing on all living relatives on his mother's side to craft a pedigree showing the inheritance of Hunter syndrome. Each individual had their DNA sequenced and their alleles were determined. The subject of the study was individual III-3. Note: in this pedigree, carriers of the syndrome contain a black dot inside them.



Question 7

According to team 1's pedigree chart, which of the following individuals are not descendants of I-1 and I-2?

A V-3

B III-2

C IV-4

D V-13

Question 8

Hunter syndrome is

A dominant.

B recessive.

Question 9

What is a limitation of team 1's method?

A it is subject to memory errors

B the subject is 35 years old

Question 10

Which team has a more precise method?

A Team 1, as it has more generations in the pedigree for a clearer representation of how the syndrome is inherited.

B Team 2, as it relies on DNA sequencing to reliably identify who has the syndrome and who is a carrier for the syndrome.

Question 11

Which of the following conclusions can be made?

A this trait is not X-linked

B this trait is likely X-linked

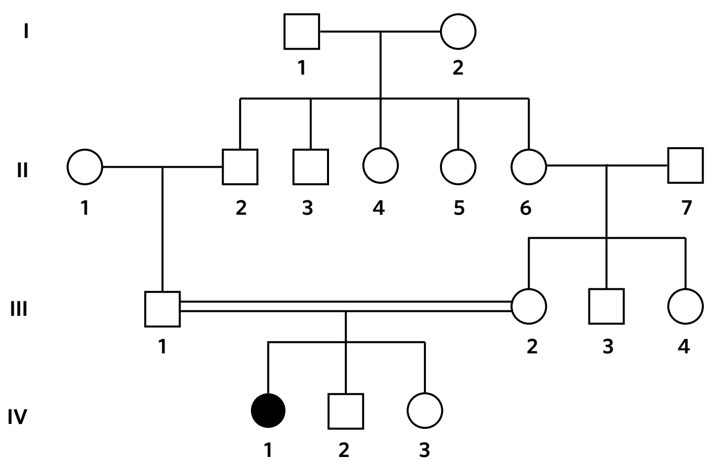
C the trait is definitely X-linked

Exam-style questions

Within lesson

Use the following information to answer Questions 12 and 13.

The pedigree shows the inheritance of Tay-Sachs disease, an autosomal recessive progressive neurological defect in humans.



Question 12 (1 MARK)

If individual I-1 is heterozygous and individual I-2 is homozygous recessive for Tay-Sachs disease, the chance that II-2 is a carrier of Tay-Sachs disease is

A 1/8.
B 1/4.
C 1/2.
D 3/4.

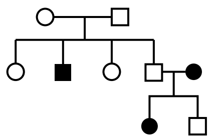
Question 13 (1 MARK)

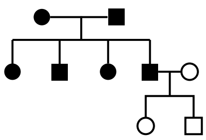
Which individuals engaged in consanguineous breeding?

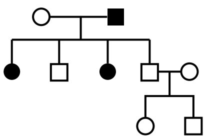
A I-1 and I-2
B II-1 and II-2
C III-1 and III-2
D IV-1 and IV-2

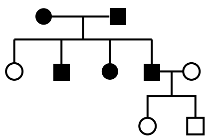
Question 14 (1 MARK)

In which one of the following pedigrees is an X-linked recessive pattern of inheritance portrayed?
(*Individuals showing a trait are shaded*)

A 

B 

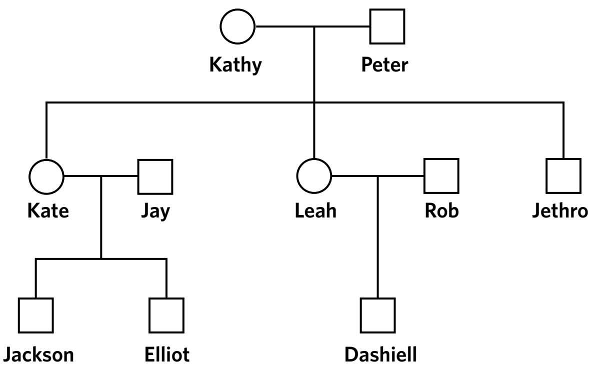
C 

D 

Adapted from VCAA 2016 Section A Q28

Question 15 (1 MARK)

Consider the following pedigree chart of Peter and Kathy's descendants.



They wanted to see if they could deduce the phenotypes of their children based on their own phenotypes.

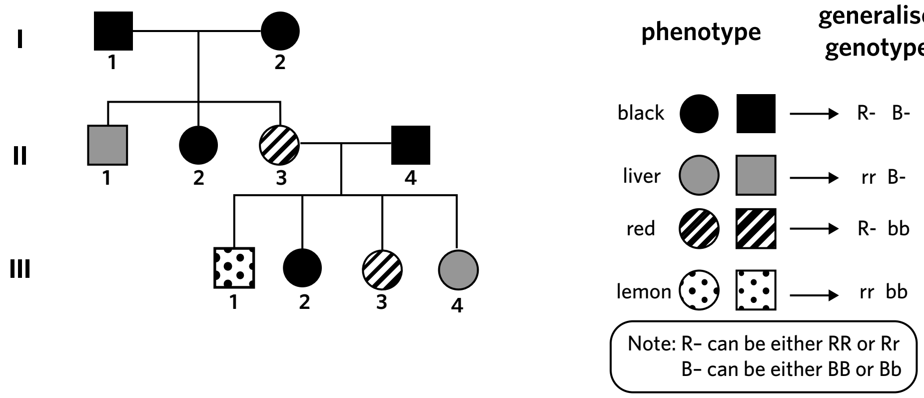
Peter is affected by an X-linked dominant trait. It is reasonable to expect that

A Elliot could be affected.
B Kate cannot be affected.
C Jethro would be affected.
D Dashiell cannot be affected.

Multiple lessons

Question 16 (6 MARKS)

Coat colour in Cocker Spaniel dogs varies. Four of these colours are black, liver, red, and lemon. These four colours result from the interaction of two unlinked autosomal genes. The pedigree shows the inheritance of coat colour in a group of Cocker Spaniels.



a Individuals II-3 and II-4 must be heterozygous at the R locus. What evidence from the pedigree supports this conclusion? (2 MARKS)

b If I-2 has a genotype of RrBb, what is the specific genotype of I-1? (1 MARK)

c III-3 has a genotype of Rrbb. Complete a dihybrid cross between individuals II-4 and III-3. (2 MARKS)

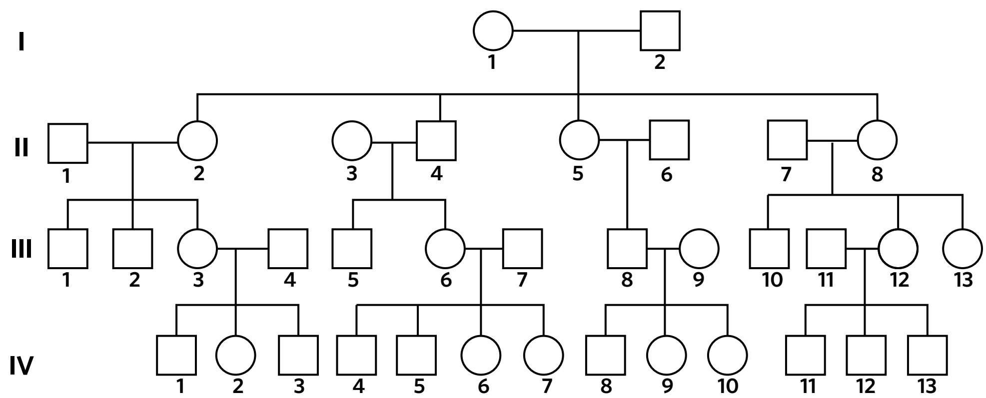
d State what fraction of offspring would share the same coat colour as their mother. (1 MARK)

Adapted from VCAA 2002 Exam 2 Section B Q2

Key science skills and ethical understanding

Question 17 (5 MARKS)

Triyan has noticed he has a widow's peak and wants to test to see which mode of inheritance the trait has. The following pedigree is incomplete but shows how each individual is related.



Triyan's data shows that the following individuals are affected:

I-1, II-2, II-4, II-5, II-8, III-3, III-4, III-5, III-10, III-12, IV-2, IV-3, IV-11, and IV-12.

a Complete the pedigree chart with affected individuals. (1 MARK)

b Using the pedigree chart, explain which inheritance pattern is displayed by widow's peak. (2 MARKS)

c I-2 is Triyan's great grandfather. Unfortunately, by the time Triyan was constructing his chart, his great grandfather had passed away. Noticing his distress over not being able to construct his chart, Triyan's mother provided a photograph of his great grandfather which showed his hairline. Explain whether this photograph is an example of primary or secondary data. (1 MARK)

d Triyan's Uncle Vernon (III-4) has begun losing his hair and his initial hairline is no longer visible. Triyan is cautious in the way he asks Uncle Vernon whether he has a widow's peak.

He is considering two different approaches.

Approach 1 – discard his uncle from the study out of respect for his feelings, as this is what a good person would do.

Approach 2 – explain the study to his uncle and attain the correct results to add to the validity of his study.

Suggest which approach best upholds a consequences-based approach to bioethics. (1 MARK)

CHAPTER 8 SUMMARY

Do I want to see an inheritance pattern over multiple generations?

Yes

Pedigree charts

Pedigree charts show how a trait is inherited over multiple generations. When reading pedigrees, remember that squares are males, circles are females, coloured is affected, and uncoloured is unaffected.

There are five inheritance patterns which can be determined from the flow chart. It is important to remember that pedigrees show patterns that we can interpret, but you typically need genetic testing to confirm if a gene is sex-linked.

Is the trait present in every generation?

Yes

Are all affected individuals male? If so, does every affected male have an affected father and all sons are affected?

Yes

Y-linked

No

Do all affected males and healthy females produce affected daughters? AND do all affected females and healthy males produce affected sons?

Yes

X-linked dominant

No

Autosomal dominant

No

For every affected female in the pedigree, is their father affected?

Yes

X-linked recessive

No

Autosomal recessive

No

Do I want to predict how two genes are inherited from parents to offspring?

No

Monohybrid crosses

Monohybrid crosses involve one gene and are used to predict the genotypes of potential offspring and phenotypic proportions. A test cross can be used to discover if an individual is homozygous dominant or heterozygous.

Father's gamete options

Mother's gamete options	W	w
W	WW	Ww
w	Ww	ww

75% of offspring will display the dominant trait
25% of offspring will display the recessive trait
This gives a phenotypic ratio of 3 dominant : 1 recessive

Yes

Are the two genes found close together on the same chromosome?

Yes

Linked dihybrid crosses

Linked genes are two or more genes that are found close together on the same chromosome and often are inherited together. They are not separated by independent assortment, but can still be separated by crossing over. Certain combinations of alleles have a higher chance of occurring than others. In VCE Biology, linked dihybrid crosses are usually only done with a homozygous recessive individual.

These two gametes options only occur when crossing over occurs between homologous chromosomes.

	Parental gametes: Be	Parental gametes: bE	Recombinant gametes: be	Recombinant gametes: BE
be	Be/be	bE/be	be/be	BE/be
	46%	46%	4%	4%

Chance of genotype occurring in offspring

Only homozygous recessive alleles possible, whether crossing over occurs or not, as parent is homozygous recessive.

Should get this information in the question. E.g. if genes are 8 map units away, recombinant offspring occur 8% of the time (4% + 4% = 8%)

No

Unlinked dihybrid crosses

Unlinked genes are found on different chromosomes, or very occasionally they are located far apart on the same chromosome. They can be separated by independent assortment and/or crossing over. All combinations each have an equal chance of occurring.

Father's gamete options

Mother's gamete options	CD	Cd	cD	cd
CD	CCDD	CCDd	CcDD	CcDd
Cd	CCDd	CCdd	CcDd	Ccdd
cD	CcDD	CcDd	ccDD	ccDd
cd	CcDd	Ccdd	ccDd	ccdd

56.25% of offspring will be dominant for traits C and D
18.75% of offspring will be dominantfor trait C and recessive for trait D
18.75% of offspring will be dominantfor trait D and recessive for trait C
6.25% of offspring will be recessive for traits C and D
This gives a 9 : 3 : 3 : 1 ratio of phenotypes

CHAPTER 8 SAC PRACTICE

SAC skills covered in this section:

✓ Case study analysis ✓ Data analysis

GENETIC DISEASES (21 MARKS)

Haemophilia

Haemophilia is a genetic disease that reduces the blood's ability to clot due to a lack of clotting factors. Currently in Australia approximately 3 000 people have been diagnosed with haemophilia. The severity of haemophilia varies, with mild cases only being noticeable during surgery or after large impact incidents, whilst severe cases can potentially be fatal from injuries as small as papercuts.

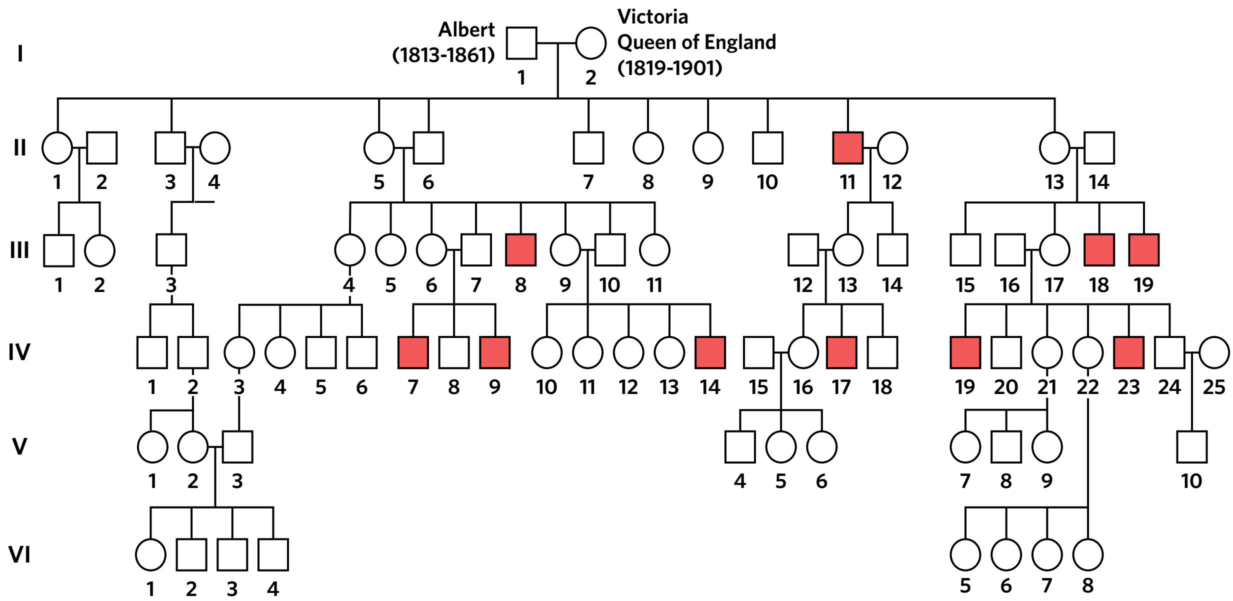
1 Explain whether or not haemophilia is contagious. (1 MARK)

2 Evaluate the statement, 'haemophilia is always a life-threatening condition.' (2 MARKS)

3 Identify how someone could be diagnosed with mild haemophilia if they had never had surgery or a major accident. (1 MARK)

The royal family

Queen Victoria of England introduced haemophilia to the British royal family. The pedigree illustrates how the trait was passed on from generation to generation. Queen Victoria is represented by I–2.



4 Explain how it is possible that neither I–1 or I–2 were affected by haemophilia, yet their offspring, II–11 is affected. (2 MARKS)

5 It is suggested that haemophilia is Y-linked as only males are affected by the trait in this pedigree. Explain why this is incorrect. (1 MARK)

6 The trait is X-linked. Explain why males are more likely to be affected by it. (1 MARK)

7 State the genotypes of I–1 and I–2 where X^H encodes the healthy allele, X^h encodes the haemophilic allele, and Y represents the Y chromosome. (2 MARKS)

8 Complete a monohybrid cross between a heterozygous female and an affected male. (2 MARKS)

9 State the phenotypic percentages that occur as a result of the monohybrid cross completed in Question 8. (1 MARK)

Cystic fibrosis

Cystic fibrosis is another genetic disease, and the genes responsible for the disease are found on chromosome 7. All sufferers must contain two matching alleles for the disease to occur. Cystic fibrosis causes the production of thick mucus in the respiratory tract that creates blockages and restricts the passage of air.

10 Complete a monohybrid cross between a heterozygous male and an affected female. (2 MARKS)

11 State the phenotypic percentages that occur as a result of the monohybrid cross completed in Question 10. (1 MARK)

12 Explain whether or not the genes encoding haemophilia and cystic fibrosis would be linked. (1 MARK)

13 Complete a dihybrid cross between a heterozygous female for both cystic fibrosis and haemophilia and a male that is heterozygous for cystic fibrosis but is affected by haemophilia. (2 MARKS)

14 Complete the table with the fractional proportions of offspring occurring from the dihybrid cross in Question 13. (2 MARKS)

	Females	**Males**
Neither cystic fibrosis nor haemophilia		
Cystic fibrosis but not haemophilia		
Haemophilia but not cystic fibrosis		
Both cystic fibrosis and haemophilia		

CHAPTER 8 EXAM PRACTICE

30 min

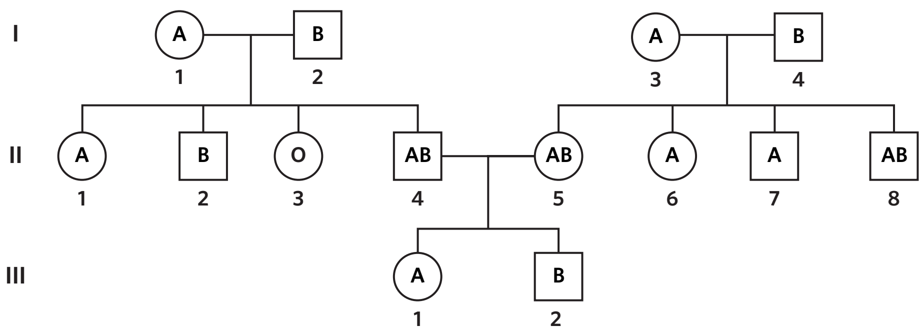
Section A (5 MARKS)

Use the following information to answer Questions 1–3.

In humans, the ABO blood group has a single autosomal gene locus with three possible alleles. There are four different blood types. The different blood types and their underlying genotypes are shown in the table.

Blood types	Possible alleles
Group O	ii
Group A	I^AI^A or I^Ai
Group B	I^BI^B or I^Bi
Group AB	I^AI^B

The following pedigree chart shows the phenotype with respect to the ABO gene locus of each individual.



Question 1 (1 MARK)

A man of blood type B, whose genotype is unknown, and a woman of blood type O have a child. Genetically, this is an example of a

A test cross.

B sex-linked cross.

C linked dihybrid cross.

D unlinked dihybrid cross.

Adapted from VCAA 2012 Exam 2 Section A Q10

Question 2 (1 MARK)

Which of the following individuals would most likely be homozygous at the ABO gene locus?

A I–1

B I–2

C I–3

D I–4

Adapted from VCAA 2012 Exam 2 Section A Q11

Question 3 (1 MARK)

If Individual II–1 and II–8 mated, which of the following conclusions could be made?

A All offspring would have at least one allele coding for A type blood.

B It is not possible for any offspring to have O type blood.

C All offspring will express a codominant phenotype.

D This is an example of consanguineous breeding.

Question 4 (1 MARK)

Rett syndrome is inherited as an X-linked dominant condition. It is reasonable to conclude that an

A affected female must have an affected daughter.
B affected female must have an affected mother.
C affected male must have an affected mother.
D affected male must have an affected father.

Adapted from VCAA 2002 Exam 2 Section A Q5

Question 5 (1 MARK)

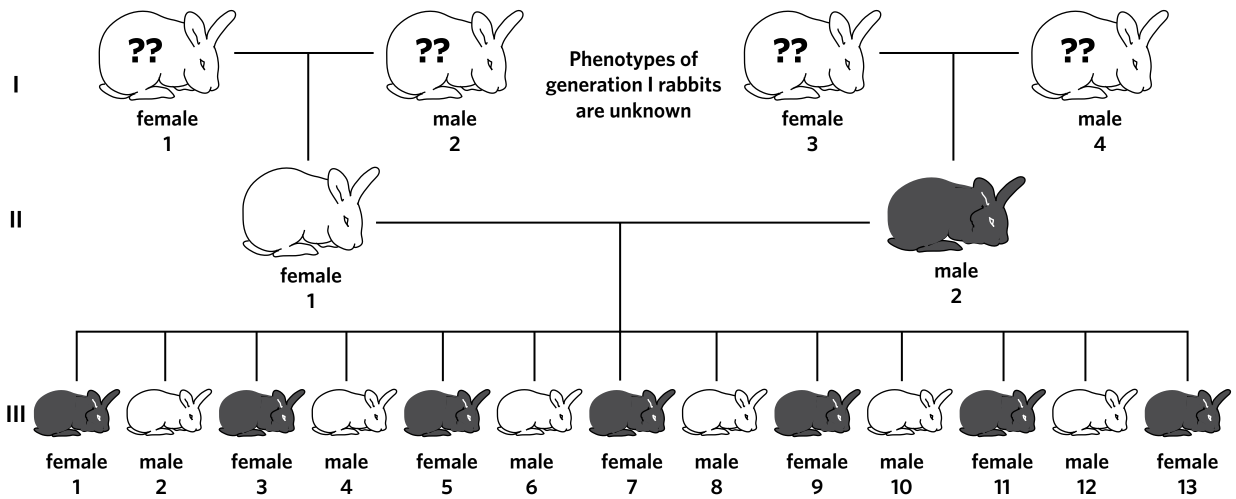
Linked genes must be

A inherited together.
B related to a similar trait.
C on the same chromosome.
D less than 10 map units apart.

Section B (14 MARKS)

Question 6 (7 MARKS)

The pedigree chart shown represents a family of rabbits. The shaded rabbits have an inherited disease. The phenotypes of rabbits I-1, I-2, I-3, and I-4 are not known.



a Suggest which mode of inheritance likely explains how the disease is passed onto offspring using evidence from generation II and III. (2 MARKS)
b Explain which individuals in generation I can be confirmed to be affected by the disease. (2 MARKS)
c Using the alleles X^D, X^d, and Y, complete a monohybrid cross between III-1 and III-2. (2 MARKS)
d Using the monohybrid cross completed in part c, what is the percentage frequency of each phenotype? (1 MARK)

Adapted from VCAA 2007 Exam 2 Section B Q4

Question 7 (7 MARKS)

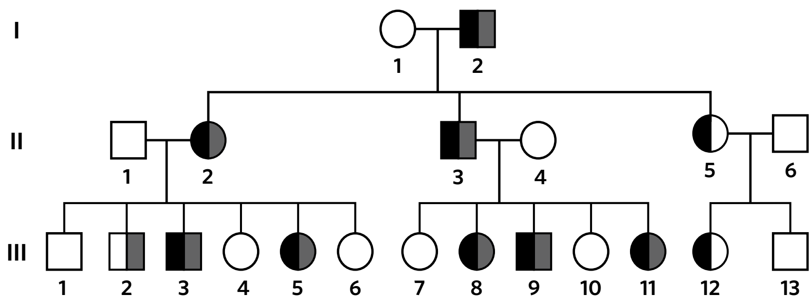
Two linked genes in humans have the following alleles:

Gene 1	Gene 2
A : secretor a : non-secretor	B : production of protein X b : no protein X produced

These genes are eight map units apart. Information regarding these traits in a family was collected and the chromosome composition of each member for these two genes was established. It was found that there were four different chromosome compositions in the family. The four types are shown in the table.

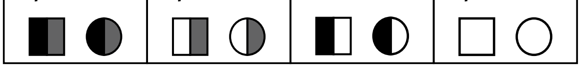
	Type one	Type two	Type three	Type four
Genotype	A B / a b	A b / a b	a B / a b	a b / a b

The pedigree shows the inheritance over three generations.



The code for interpreting the pedigree symbols is:

secretors and produce protein X	non-secretors and produce protein X	secretors and no protein X	non-secretors and no protein X



a What is meant by the term 'linked genes'? (1 MARK)

b State the genotype of individuals who are non-secretors and who do not produce protein X. (1 MARK)

c Explain whether these genes are autosomal or sex-linked. (1 MARK)

d An individual with a type one genotype crosses with a type four genotype. Complete the appropriate dihybrid cross between these individuals. (2 MARKS)

e Using the dihybrid cross completed in part d, what is the percentage frequency for each phenotype? (2 MARKS)

Adapted from VCAA 2004 Exam 2 Section A Q6

UNIT 2

AOS2

How do inherited adaptations impact on diversity?

In this area of study students analyse the advantages and disadvantages of asexual and sexual reproduction and investigate the use and application of reproductive cloning technologies. Students explore the biological importance of genetic diversity and the structural, physiological, and behavioural adaptations that enable species to survive in an ecosystem.

Students explore the interdependencies between species, including the importance and impact of keystone species and top predators. They consider the contributions of Aboriginal and Torres Strait Islander knowledge and perspectives to the understanding of the adaptations of, and interdependencies between, species in Australian ecosystems.

Outcome 2

On completion of this unit the student should be able to analyse advantages and disadvantages of reproductive strategies, and evaluate how adaptations and interdependencies enhance survival of species within an ecosystem.

Reproduced from VCAA VCE Biology Study Design 2022-2026

CHAPTER

9

Reproduction

Key knowledge

- biological advantages and disadvantages of asexual reproduction
- biological advantages of sexual reproduction in terms of genetic diversity of offspring
- the biological importance of genetic diversity within a species or population

Image: nevodka/Shutterstock.com

9A SEXUAL VS ASEXUAL REPRODUCTION

The Antechinus *is a small marsupial found in Australia that exhibits very interesting (and rather destructive) mating patterns. The male* Antechinus *will enter a hormone-fueled mating frenzy that lasts for 2–3 weeks straight, seeking out females day and night to breed with (sometimes for up to 14 hours at a time). During this time, males often suffer from significant internal bleeding, hair loss, and a weakened immune system that leaves them vulnerable to infections and gangrene until they eventually die. Few male* Antechinuses *live to be older than one year old due to this intense mating behaviour.*

The strangest animal of all, adult humans, also have some pretty interesting breeding behaviours. They spend crazy amounts of money on metals and stones to give as presents, they take each other to fancy feeding grounds called 'restaurants', and – perhaps most bizarrely of all – they chop the heads off flowering plants and give them to each other only to watch them slowly wilt and die in a vase on the kitchen bench. Why do animals go to such extreme lengths in order to reproduce? What makes it worth the effort?

Image: Pete Evans, Kunturlte/Shutterstock.com

Lesson 9A

In this lesson you will learn about the importance of genetic diversity to a population, as well as how asexual and sexual reproductive strategies influence the genetic diversity of a species.

◀ *Prerequisite knowledge*

Lesson 4A
Prokaryotes replicate through a process known as binary fission, which is a form of asexual reproduction.

Lesson 7B
Sexual reproduction depends on the production of haploid gametes via a specific type of cell division known as meiosis.

Future applications ▶

Lesson 9B
Similar to asexual reproduction, reproductive cloning techniques produce two or more genetically identical copies of an organism.

Year 12
Changes to a species' gene pool over time are heavily influenced by reproductive patterns.

Study design dot points

- biological advantages and disadvantages of asexual reproduction
- biological advantages of sexual reproduction in terms of genetic diversity of offspring
- the biological importance of genetic diversity within a species or population

Key knowledge units

Genetic diversity	2.2.4.1
Sexual reproduction	2.2.2.1
Asexual reproduction	2.2.1.1

Genetic diversity 2.2.4.1

OVERVIEW

The gene pool is a measure of all of the alleles within a population. The larger or more diverse a population's gene pool, the greater that population's resilience to environmental change.

THEORY DETAILS

What is genetic diversity?

The genetic diversity of a **population** refers to the amount of genetic variation that exists between individuals. This is measured by reference to the population's **gene pool**, which is the sum of all of the different **genes** and **alleles** that are present in a population and, by extension, a species. A larger, or more diverse, gene pool contains a greater variety of different genes and alleles, meaning that the population will have a greater variety of genotypes and phenotypes.

The gene pool of a population is influenced and maintained by a number of naturally occurring mechanisms, including mutations, genetic drift, gene flow, and natural selection. You will learn more about each of these in more detail in Year 12. For now, it is enough to understand what genetic diversity is, and the effect genetic diversity has on a population's wellbeing.

population a group of individuals of the same species living in the same location

gene pool the total number of individual alleles within a particular population

gene a section of DNA that carries the code to make a protein

allele alternate forms of a gene

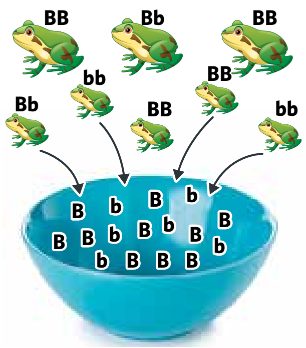


Image: nortongo, SGV_Arts/Shutterstock.com

Figure 1 Visual representation of a 'gene pool'

Why is genetic diversity important?

Genetic diversity is vitally important in protecting the longevity of a species by guarding against disadvantageous environmental changes, like new diseases or predators. The larger the gene pool, the greater that population's resilience to environmental change. This is because populations with a greater number of alleles are more likely to contain alleles that are already well adapted to survive the new environmental challenges.

For example, in Figure 2, assume that one population (A) of flowering plant contained only one allele for petal colour – bright red – whilst another population (B) contained five alleles for petal colour. In this case, population B has a larger gene pool than population A. If a new species of predator was introduced that was attracted to red flowers, population A would suffer much more than population B (Figure 2).

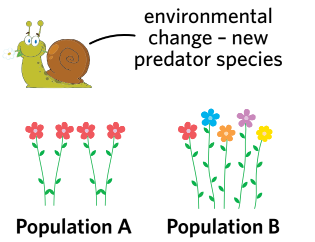


Image: Vovanlanovich, HitToon/Shutterstock.com

Figure 2 The importance of genetic diversity in guarding against drastic environmental changes

Memory device

Think of genetic diversity as a game of roulette. If one population decides to bet all of their money on a single number, say number four, while another population decides to spread its money out and bet on twenty different numbers – the second population has a much higher chance of winning (shall we say, surviving) the fall of the ball.

In the same way, if a given population has a higher number of different alleles present in its gene pool, then that population is more likely to survive a new environmental threat than other populations with much less genetic diversity.

Image: nazarovsergey/Shutterstock.com

Figure 3 Roulette is analogous to genetic diversity

Theory in context

WILD CHEETAHS

Cheetahs (*Acinonyx jubatus*) are well known for their lack of genetic diversity, which resulted from a large population collapse around 12 000 years ago at the end of the last ice age.

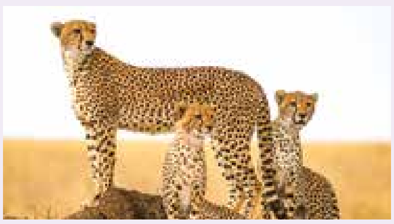


Image: Vaganundo_Che/Shutterstock.com

Figure 4 Wild cheetah populations are vulnerable due to low genetic diversity.

The reduced genetic diversity of the cheetah population makes it vulnerable to environmental changes. Due to increasing habitat encroachment and poaching, the vulnerable cheetah population, and its genetic diversity, is beginning to shrink even further. Low genetic diversity in the population has resulted in increased inbreeding between closely related individuals, which increases the likelihood of birth defects occurring in offspring. Currently, only around five per cent of cheetahs survive to adulthood.

Sexual reproduction 2.2.2.1

OVERVIEW

Sexual reproduction involves the fusion of male and female haploid gametes and occurs in almost all eukaryotes, including animals and plants. The specific reproductive strategies employed by different species depends on the environment in which they live.

THEORY DETAILS

What is sexual reproduction?

Sexual reproduction is a specific **reproductive strategy** that involves the fusion of two haploid gametes, a process known as **fertilisation**, to form a single, genetically unique, diploid **zygote**.

sexual reproduction the fusion of two distinct haploid gametes to produce a single diploid zygote composed of two sets of chromosomes

reproductive strategies adaptations to reproduction that improve the success of survival of a species

fertilisation the process by which two gametes (such as sperm and egg cells) fuse and form a zygote

zygote the diploid cell formed by the combination of two haploid gamete cells

Types of sexual reproduction

Up to 99 per cent of eukaryotic organisms can reproduce sexually, including most plants and animals. There are many different methods of sexual reproduction, each of which have evolved over time due to the environmental pressures facing the species, such as resource availability and predation.

It is helpful to think of these methods as differences in reproductive strategies rather than in animal categories, as organisms within the same broad category, such as insects or fish, can show huge variation in how they reproduce. This includes factors such as the location of embryonic development, the number of offspring produced per reproductive cycle, and the amount of parental care invested in each offspring.

Theory in context

OVIPARITY VS VIVIPARITY – HOW DOES THE EMBRYO DEVELOP?

Sexually reproducing animals can be classed as either oviparous or viviparous, which are distinguished by their mode of embryonic development.

Oviparity – eggs are released into the external environment and the embryo develops from nutrients inside the yolk. The organism grows with little development inside the mother. For most birds and insects, fertilisation occurs inside the mother, while most fish will release unfertilised eggs into the water to be fertilised externally by free-flowing sperm (ovuliparity).

Viviparity – the embryo develops inside the mother's body and is born after a period of gestation. Fertilisation occurs inside the mother, and the organism grows and receives nutrients inside the mother during gestation. For many sharks and snakes, the embryo will develop inside an egg that is retained in the mother's uterus (ovoviviparity), while for most mammals, the embryo will develop inside a fluid-filled sac inside the mother's uterus.

Image: grayjay/Shutterstock.com

Figure 5 In oviparous species, the embryo receives nutrients from the yolk.

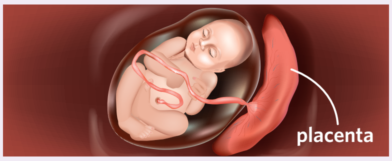


Image: Sakurra/Shutterstock.com

Figure 6 In viviparous species, the embryo receives nutrients inside the mother.

Both oviparous and viviparous species invest significant amounts of resources into reproduction. In oviparous species, the mother must allocate resources to produce eggs containing nutrient-rich yolk, and in viviparous species the mother must support the developing embryo inside her body from fertilisation until birth. Often, parental investment in offspring will extend well beyond birth in both oviparous and viviparous species. For example, well over three-quarters of bird species receive extended care from both parents after hatching, and in many human cultures around the world parental investment often extends well into 20 years.

Lesson link

In ***lesson 7B***, we covered meiosis, which is used to produce gametes in sexually reproducing organisms. Meiosis involves crossing over and independent assortment, two important processes which are essential to maintain a high degree of genetic diversity in a population.

Lesson link

Another important point of difference between reproductive strategies is the number of offspring produced per reproductive cycle, and the amount of time and energy invested into each individual offspring. This is considered in detail in ***lesson 10C***, which explains the difference between r-selection (quick and many) and K-selection (slow and few).

Theory in context

SEXUAL REPRODUCTION IN PLANTS – ANGIOSPERMS

It is estimated that there are roughly 400 000 different species of plants currently known to science. Around 90% of these are flowering plants (**angiosperms**), which reproduce via **pollination**. Pollination occurs when pollen (male gamete) is collected by the stigma of the flower and fuses with the ovule (female gamete). From here, the embryo that develops will become a seed, which contains nutrients from which an immature plant can begin to grow into a new plant under the right conditions.

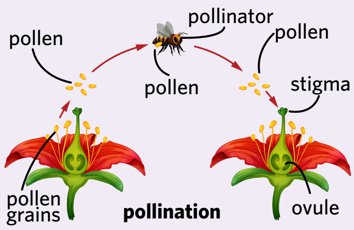


Image: BlueRingMedia/Shutterstock.com

Figure 8 Pollination in sexually-reproducing plants

Pollen transfer in plants typically relies on a pollinator to move the pollen from one plant to another. These pollinators can be:

- biotic – living organisms such as insects or birds which are often attracted to the brightly coloured petals, inviting smell, and nutrient-rich nectar.
- abiotic – non-living methods such as wind or water. This method allows the plant to focus on maximising pollen dispersion rather than attracting pollinators. Such plants will often lack colourful petals and smells and will hang downwards to enable wind dispersion (Figure 9).

Image: Jack Hong/Shutterstock.com

Figure 7 Bees are attracted to flowers and act as biotic pollinators.

angiosperms flowering plants with stems, roots, and leaves

pollination a form of sexual reproduction in plants that involves the fusion of pollen (male gamete) and ovule (female gamete) and leads to the production of seeds

Image: torikell/Shutterstock.com

Figure 9 The common catkin has evolved to maximise wind dispersion.

Advantages and disadvantages of sexual reproduction

Sexual reproduction is a complex and risky process for an organism. Despite this, sexual reproduction is the main reproductive method for almost all eukaryotic organisms, predominantly because of the immense benefits it has for ensuring genetic diversity. Some of the typical advantages and disadvantages of sexual reproduction are summarised in Table 1.

Table 1 Advantages and disadvantages of sexual reproduction

Advantages	Disadvantages
• increases genetic diversity of a population by allowing for recombinant offspring • improving disease resistance by promoting the presence of different alleles • combining the genetic material from two gametes reduces the chances of an offspring inheriting a genetic disorder that might be carried by one parent.	• the cost of male progeny (Figure 15) • the time, energy, and resources it takes to attract and find a mate • the risk of transferable diseases associated with sexual intercourse • the risk of losing offspring to outside influences such as embryo damage.

Asexual reproduction 2.2.1.1

OVERVIEW

Asexual reproduction is a type of reproduction that does not require the fusion of gametes, and usually only occurs in unicellular and simple multicellular organisms.

asexual reproduction producing offspring without the fusion of gametes

clone a genetically identical organism or section of DNA

binary fission a type of asexual reproduction where one organism divides into two identical organisms

THEORY DETAILS

What is asexual reproduction?

In the previous section you learned that most species of animals and plants reproduce sexually. However, some organisms can reproduce without the fusion of gametes, and therefore do not require a mate. This method of reproduction is called **asexual reproduction**, where the offspring or daughter cells are **clones** of each other and of the parent.

The most common form of asexual reproduction is known as **binary fission**, which was covered in lesson 4A. This occurs most commonly in simple prokaryotic organisms such as bacteria, though a similar form of binary fission also occurs in more complex multicellular organisms such as polyps, where the organism splits into two equally sized clones (Figure 10).

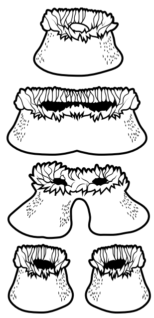


Figure 10 Though most common in unicellular prokaryotes, binary fission can also occur in some multicellular organisms.

There are, however, many other methods of asexual reproduction, including **budding**, **fragmentation, vegetative propagation, sporogenesis**, and **parthenogenesis**.

budding a type of asexual reproduction where a group of cells form a bud and break away from the original organism to form a clone

fragmentation a type of asexual reproduction where a parent organism breaks into fragments, each of which may develop into individual clones

vegetative propagation a type of asexual reproduction where a plant grows from fragments, such as stem or root cuttings, of its parents

sporogenesis a type of asexual reproduction where spores form on the surface of the organism and are dispersed into the surroundings where they may develop into individual clones of the original

parthenogenesis a type of asexual reproduction where an embryo can develop from a single unfertilised gamete

Types of asexual reproduction

Budding

Budding typically occurs in simple eukaryotes such as yeast, sponges, jellyfish, coral, and worms. It involves the formation of a bud, which forms due to increased cell growth and then breaks away from the main organism where it can then develop into an entirely separate organism. This new organism will have identical DNA to the original organism.

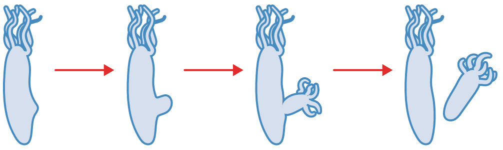


Figure 11 Budding – notice the formation and separation of the bud

Fragmentation

Fragmentation typically occurs in simple eukaryotes such as worms and sea stars, as well as many species of plants. It involves a parent organism breaking into separate fragments, each of which is capable of independently developing into a new, separate organism that is identical to the original. The breaking away of fragments may or may not be intentional, and will involve the regrowth of the parent organism to account for the lost fragments.

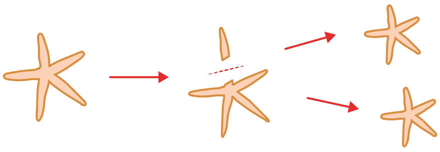


Figure 12 Fragmentation – both fragment and original organism grow separately

Vegetative propagation

Vegetative propagation is a type of asexual reproduction that allows a plant to reproduce without the need for seeds. It involves a vegetative section of the plant, such as the roots or the leaves, breaking away from the original plant and then independently growing into a new plant. This breakaway section is called a 'cutting'.

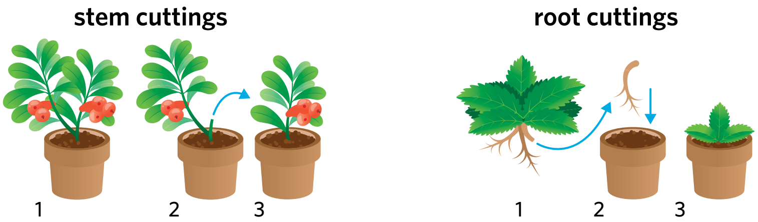


Image: VectorMine/Shutterstock.com

Figure 13 Plant propagation involves a vegetative cutting from the plant regrowing into a new plant.

Sporogenesis

Sporogenesis typically occurs in many plants, as well as fungi, algae, and moulds. It involves the formation of **spores**, which are small haploid units that form on the surface of the organism and are dispersed into the surroundings (often via water or air) where they may then grow into a larger, multicellular, haploid organism (known as a sporeling).

spores small haploid units used as a means of asexual reproduction in sporogenesis

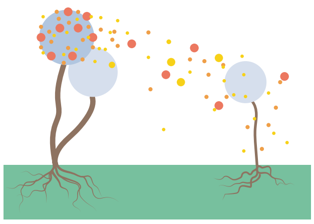


Figure 14 Sporogenesis – notice the dispersing of spores

Parthenogenesis

Parthenogenesis is a rarer form of asexual reproduction where an embryo can develop from a female gamete alone, without the need for a male gamete to fertilise it. This process is sometimes referred to as 'virgin birth', and results in eggs that are produced via mitosis and develop into a new organism that is identical to the female parent. This is extremely rare, and occurs in less than 0.1% of all vertebrate species.

Advantages and disadvantages of asexual reproduction

As you have learned, the vast majority of eukaryotic organisms reproduce sexually. However, all prokaryotes and a small percentage of eukaryotes reproduce asexually without the fusion of gametes. Some of the typical advantages and disadvantages of asexual reproduction are summarised in Table 2.

Table 2 Advantages and disadvantages of asexual reproduction

Advantages	Disadvantages
• asexually reproducing populations grow faster than sexually reproducing populations (Figure 15) • offspring are identical clones of the parent. This is especially important for organisms that have adapted a phenotype that is fine-tuned to survive in a particular environment • does not require an organism to find a mate to reproduce, meaning that the organism does not have to be mobile • requires very little parental investment and removes the need to protect fragile offspring.	• genetic diversity is low and asexually reproducing populations may suffer during rapid environmental change.

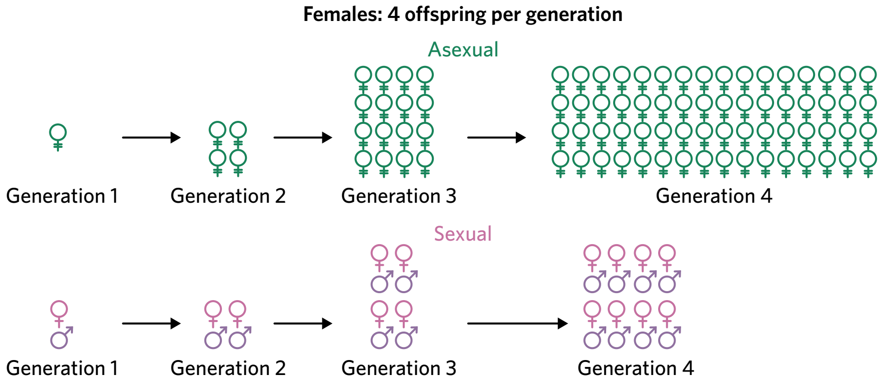


Figure 15 Sexually reproducing populations reproduce slower than asexually reproducing ones. This is because of the cost of male offspring. Assume each female has four offspring in both populations – sexually reproducing females will also give birth to male progeny, who can't have offspring themselves.

Theory in context

VIRGIN BIRTH IN ASIAN WATER DRAGONS

Sometimes an organism may flexibly adapt their reproductive strategy based on the circumstances of their environment. For example, many species, such as the Asian water dragon (*Physignathus cocincinus*), may be forced to reproduce asexually in the absence of a mate.

An example of this occurred at the Smithsonian National Zoo, where a female Asian water dragon, who had lived alone for more than four years and hadn't come into contact with a male of her species since well before sexual maturity, laid a number of fertile eggs and produced at least nine offspring without the presence of a mate. The female produced the offspring by parthenogenesis, resulting in identical offspring that developed via mitosis from unfertilised eggs.
While parthenogenesis does occur in nature, it is more commonly observed in captivity, where otherwise sexually-reproducing organisms switch from sexual to parthenogenetic reproduction in the absence of a mate.

Image: reptiles4all/Shutterstock.com

Figure 16 Asian water dragon (*Physignathus cocincinus*)

Theory summary

Genetic diversity is very important for maintaining the health and longevity of a species. It is maintained in a variety of ways, including sexual reproduction and asexual reproduction. The characteristics of sexual and asexual reproduction are as follows:

- Sexual reproduction is the fusion of haploid gametes to form a new organism. It involves a range of reproductive strategies, each of which has been fine-tuned for success based on an organism's environment.

- Asexual reproduction does not involve the fusion of gametes, and produces identical clones. This is typical of many simpler life forms, and can involve budding, fragmentation, vegetative propagation, sporogenesis, and parthenogenesis.

Table 3 Summary of the strengths and weaknesses of sexual and asexual reproduction

	Sexual reproduction	Asexual reproduction
Strengths	• increases genetic diversity of a population • reduces the risk of birth defects and genetic diseases	• more frequent and energy-sparing • fine-tuned to thrive in a steady environment, as offspring are clones
Weaknesses	• more time-consuming and energetically expensive	• hinders genetic diversity

Just like the Antechinus, *humans reproduce sexually. This is because, unlike asexual reproduction, the fusion of separate gametes from two parents helps maintain the genetic diversity of our species. Therefore, the benefits of having a genetically diverse population must outweigh the downside of seasonal death by sexual reproduction – or indeed, the trials and tribulations of the human dating scene. So for reference: whenever your date tells you they don't want fries... make sure to get a large!*

9A QUESTIONS

Theory review questions

Question 1

Genetic diversity refers to

A the number of different phenotypes in a given population.

B the number of different alleles present in a given population.

Question 2

Genetic diversity is important for a population because it

A helps an organism hide from and escape predators.

B helps a species adapt to and survive environmental changes.

Question 3

Which of the following most accurately summarises sexual reproduction?

A fertilisation followed by the formation of a diploid zygote

B evolved behavioural adaptations to help an organism pass on their genetic material

Question 4

Categorise the following as possible features of **oviparity**, **viviparity**, or **both**.

I live birth __________

II lack of development inside the mother __________

III a fertilised egg retained inside the mother __________

IV a reproductive strategy that results in recombinant offspring __________

Question 5

Which of the following describes an advantage of sexual reproduction? (*Select all that apply*)

I rapid population growth

II increased protection against inherited genetic disorders

III reduced resource investment by the reproducing organism

IV the clonal nature of offspring fine-tuned for success in their environment

Question 6

Which of the following best describes the difference between biotic and abiotic pollinators?

A Biotic pollinators are living organisms, while abiotic pollinators are non-living mechanisms of pollen transfer.

B Biotic pollinators are living organisms that depend on the pollen created by the plant for survival, while abiotic pollinators are living organisms that are attracted to the bright colours of the flower.

Question 7

Which of the following descriptions best distinguishes budding from fragmentation?

A Budding is a type of asexual reproduction, whereas fragmentation is a type of sexual reproduction.

B Budding occurs more readily in simple aquatic animals such as sponges and jellyfish, while fragmentation occurs exclusively in plant species.

C Budding involves a small bud forming and breaking away from the parent organism, while fragmentation involves a parent organism physically breaking into fragments.

Question 8

Which of the following is the main advantage of sexual reproduction over asexual reproduction?

A Sexual reproduction increases genetic diversity in a population by allowing for recombinant offspring.

B Sexual reproduction is much safer than asexual reproduction, which often causes an organism to split itself into fragments.

C Sexual reproduction better maintains genetic diversity in a population as it ensures that strong alleles are selected for and reproduced in a population.

SAC skills questions

Data analysis

Use the following information to answer Questions 9–14.

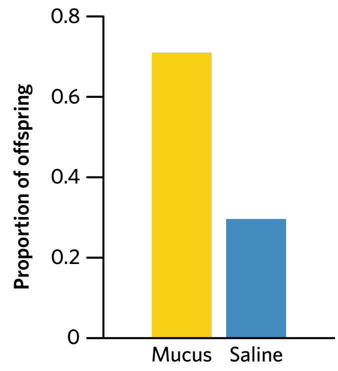
Many animal species mate promiscuously, meaning they mate with multiple different partners. This often leads to sexual competition amongst a population, where individuals adopt behaviours to help ensure their own reproductive success. Basheer wanted to examine sexual competition in garden snails (*Cornu aspersum*) and took the following notes during a lecture he attended:

- *C. aspersum* are hermaphrodites, meaning that they function as both male and female during sexual reproduction. They are also promiscuous, and will mate multiple times with different partners to try and fertilise as many snails as possible.
- While mating, each snail will attempt to stab their partner with a sharp calcium dart covered in mucus. These darts are not involved in sperm transfer, but are used instead to increase the reproductive chances of the snail.
- Typically, only one of the snails will land a significant blow with their dart (the other missing). Once one snail successfully stabs their partner, that snail can then insert their sperm and fertilise the other snail's eggs.
- Successful dart shooting has been shown to double the amount of sperm stored by the recipient snail for potential fertilisation, and significantly increases the likelihood of paternity (being a father) for the shooting snail.

Basheer hypothesised that the presence of mucus on the darts, rather than the darts themselves, increases a snail's chance of impregnating another snail. To test this, he collected a group of adult *C. aspersum* snails from his garden and isolated them for 50 days. From there, Basheer:

- dipped the snails in 5% ethanol to anaesthetise them before removing their darts and mucus glands
- extracted the mucus from the glands of each snail and froze until use

- arranged matings so that each future mother was mated with two donor snails. When a snail adopted the dart-shooting posture, Basheer stabbed the future mother with one of two needles:
  - in the first pairing, an injection containing mucus
  - in the second pairing, an injection containing saline solution
- the future mother and the donor snail were then given the opportunity to mate before being separated.



Basheer then collected the offspring of the mother to measure whether mucus injections aided the reproductive success of the first donor. This was estimated by examining the proportions of offspring in each clutch that were sired by each of the two sperm donors, as determined by genetic analysis (mucus or saline). He summarised his findings using the bar graph shown.

Question 9

Based on the information, which of the following is an example of an adaptation to sexual competition in *C. aspersum*?

A their hermaphroditic nature

B the firing of sharp, calcium darts into a sexual partner

Question 10

The firing of sharp, calcium darts into a sexual partner serves to

A increase sperm count in paternal *C. aspersum.*

B increase the probability of finding a mate for *C. aspersum.*

C increase levels of donated sperm storage in maternal *C. aspersum.*

Question 11

In Basheer's experiment, reproductive success was measured by

A the success of dart firing shown by a particular *C. aspersum.*

B the proportion of offspring fathered by a particular *C. aspersum.*

C the level of mucus concentration found on each dart from a particular *C. aspersum.*

Question 12

The findings of the study suggest that

A mucus aids paternity.

B promiscuity increases levels of reproduction.

Question 13

The presence of saline solution serves which of the following purposes for the experiment?

A control

B dependent variable

C independent variable

Question 14

Which of the following bioethical concepts best explains why Basheer decided to anaesthetise the snails in 5% ethanol prior to removing their mucus glands?

A Justice – Basheer recognised his moral obligation to consider competing claims.

B Beneficence – Basheer recognised his responsibility to maximise the benefits of his experiment.

C Respect – Basheer recognised his moral obligation to protect his research subjects where possible.

Exam-style questions

Within lesson

Use the following information to answer Questions 15 and 16.

Cryptasterina pentagona and *Cryptasterina hystera* are two species of sea star that live in the coastal waters of Queensland. Despite being closely related, the two species exhibit vastly different reproductive strategies. *C. pentagona* reproduces by releasing unfertilised eggs into the water where they interact with male sperm, while *C. hystera* reproduces by self-fertilising their own eggs and retaining those eggs until they are ready to hatch.

Question 15 (1 MARK)

Which of the following modes of embryonic development is shown by *C. pentagona*?

A ovuliparity
B sporogenesis
C egg-yolk viviparity
D placental viviparity

Question 16 (1 MARK)

Based on the information provided, which of the following is true in regards to the two species of *Cryptasterina*?

A both species are oviparous
B both species exhibit sexual reproductive strategies
C *C. hystera* would have a higher diversity of alleles in its gene pool
D *C. pentagona* reproduces sexually, while *C. hystera* reproduces asexually

Question 17 (4 MARKS)

Schistosoma mansoni is a type of parasitic blood fluke (*Schistosoma*) that lives in the blood vessels of humans. Inside these vessels, a mature fluke will reproduce sexually and will lay the equivalent of its own body weight in eggs each day, which will then move into the intestine of the human host and be excreted via the faeces into water. Once in water, the fertilised eggs will hatch into larvae and search for a new host.

a Based on the information provided, suggest which mode of embryonic development *S. mansoni* displays. (1 MARK)

b Typically, the new host will be a freshwater snail (*Biomphalaria*). Inside the snail, the larvae will lose their cilia (used for locomotion) and will multiply rapidly via asexual reproduction before leaving the snail and continuing their development in water.

- **i** What type of cell division would the *S. mansoni* exhibit during asexual reproduction inside the snail? (1 MARK)
- **ii** Explain one advantage of asexual reproduction with respect to the larvae inside the *Biomphalaria*. (2 MARKS)

Adapted from VCAA 2016 Exam Section B Q8

Multiple lessons

Question 18 (1 MARK)

It is expected that an offspring produced via asexual reproduction will

A receive half of its DNA from the female parent.
B have equal numbers of guanine and thymine nucleotides.
C have the same combination of alleles as other offspring from the same parent.
D show linear growth, where the population grows by the same number each reproductive cycle.

Adapted from VCAA 2012 Exam 2 Section A Q3

Question 19 (7 MARKS)

Giardia intestinalis is a type of single-celled parasitic microorganism that reproduces asexually in the small intestine of humans and causes a type of diarrhoea known as giardiasis. It possesses flagella for locomotion, a sucker used for attaching to its host, and an outer shell that protects the organism once it leaves the host. Scientists have found that *G. intestinalis* multiplies rapidly by dividing longitudinally and segregating into identical organisms.

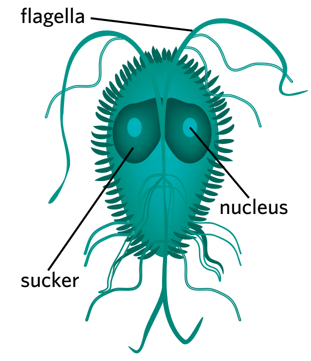


Image: Timonina/Shutterstock.com

a Identify which method of asexual reproduction is used by *G. intestinalis.* (1 MARK)

b Is *G. intestinalis* eukaryotic or prokaryotic? Use evidence to support your answer. (2 MARKS)

c It has been shown that *G. intestinalis* populations have low genetic diversity. Explain why this is an advantage for *G. intestinalis.* (2 MARKS)

d Recent research has called into question whether *G. intestinalis* reproduces exclusively via asexual reproduction. Some researchers argue that *G. intestinalis* once was able to reproduce sexually but has since lost the ability. For example, some researchers have found the presence of particular genes involved in meiotic cell division.

Outline one difference between meiosis and mitosis that might influence the genetic diversity of the resulting populations. (2 MARKS)

Key science skills and ethical understanding

Question 20 (8 MARKS)

Biologists at Edrolo Labs hope to use a simulation to study the growth pattern of a particular pathogenic bacteria called *Legionella.* The simulation has been designed to imitate natural water flow and bacterial population growth under different parameters.

The biologists conduct two separate simulations to test the reproductive process of *Legionella* in pools of different temperatures whilst exposed to different wavelengths of UV radiation. The physical parameters of the pool (Figure A) were entered into the simulation along with the flow patterns of the water. Separate simulations were then conducted based on the following parameters:

Simulation A

- Temperature – 35 °C
- UV wavelength – 250 nm
- Reproductive cycle – 20 minutes

Simulation B

- Temperature – 43 °C
- UV wavelength – 150 nm
- Reproductive cycle – 20 minutes

Simulation C

- Temperature – 35 °C
- UV wavelength – 150 nm
- Reproductive cycle – 20 minutes

Simulation D

- Temperature – 60 °C
- UV wavelength – 150 nm
- Reproductive cycle – 20 minutes

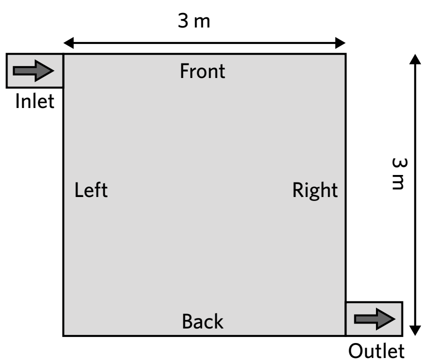


Figure A The computational diameters of the pool – water enters the pool at the inlet at a constant rate and is drained via the outlet

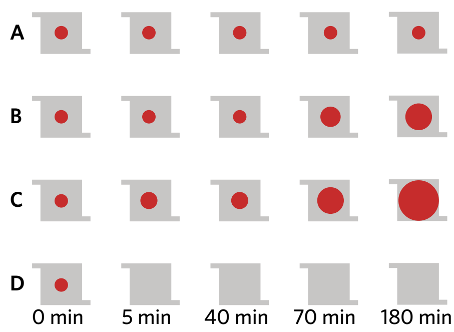


Figure B The results of each simulation

Results from each simulation were summarised and presented (Figure B). The size of the red circle illustrates the concentration of *Legionella.*

a Based on the results of the simulation, identify the optimal temperature for *Legionella* replication. (1 MARK)

b *Legionella* are unable to reproduce when exposed to certain wavelengths of ultraviolet light. Based on the results of the simulation, which UV wavelength is likely to cause inactivation of *Legionella*? (1 MARK)

c *Legionella* reproduce rapidly via binary fission and will grow exponentially under the right conditions. After 200 minutes of growth, *Legionella* in simulation C reached pool capacity and began to spill out from the outlet.

i Provide an explanation for the result shown in simulation D. (1 MARK)

ii Outline what is likely to occur if the reproductive cycle was reduced to 10 minutes in simulation C. (1 MARK)

d Identify one advantage of using a simulation as opposed to a controlled experiment. (1 MARK)

e The accuracy of a simulation often depends on the accuracy of its mathematical models and inputs. When publishing their findings, the team at Edrolo Labs decided to include their equations in their report.

i How might including these numerical models aid in the reproducibility of their investigation? (1 MARK)

ii Justify how the inclusion of numerical models might satisfy the bioethical concept of integrity. (2 MARKS)

9B CLONING

The gastric-brooding frog is a native Australian genus famously known for incubating pre-juvenile offspring within its stomach and later giving birth through its mouth. Interested in watching a video of this amazing phenomenon? Unfortunately, because the gastric-brooding frog became extinct in the mid-1980s there are no recorded videos. But don't worry, scientists from the Lazarus Project at the University of Newcastle are hoping to bring it back to life. Is this pure science fiction or could scientists actually bring a species back from beyond the brink of extinction?

Lesson 9B

In this lesson you will learn about animal and plant reproductive cloning techniques and their real-world applications.

◀ *Prerequisite knowledge*

Lesson 4D
Stem cells can be grown in a lab using reproductive cloning technologies, and later harvested and repurposed for therapeutic cloning.

Lesson 9A
When organisms reproduce asexually, they produce genetically identical copies of themselves, which is a form of natural cloning.

Future applications ▶

Year 12
Cloning produces genetically identical copies of a plant or animal, affecting the species' genetic diversity and overall fitness.

Year 12
Individual genes can be cloned, inserted into other organisms, and expressed to produce large quantities of medication such as insulin.

Study design dot point

- the process and application of reproductive cloning technologies

Key knowledge units

Reproductive cloning technologies in animals	2.2.3.1
Reproductive cloning technologies in plants	2.2.3.2

Reproductive cloning technologies in animals 2.2.3.1

OVERVIEW

Reproductive cloning technologies in animals include somatic cell nuclear transfer and embryo splitting.

THEORY DETAILS

In lesson 9A, you learned how asexual reproduction is the natural process of producing genetically identical **clones** of an organism. In this lesson, you will explore **reproductive cloning technologies** in animals and plants. While asexual reproduction and reproductive cloning technologies are similar in that they produce genetically identical offspring, reproductive cloning is an artificially induced human intervention where the processes involved are completely different. Therefore, the ethical implications of their use must be considered.

clone a genetically identical organism or section of DNA

reproductive cloning technologies artificially induced human interventions to produce genetically identical clones

somatic cell nuclear transfer (SCNT) the transference of a somatic cell nucleus into an enucleated egg cell

Somatic cell nuclear transfer

Somatic cell nuclear transfer (SCNT) involves two different cells: a donated egg cell and a donated somatic cell from another animal. The stages of SCNT include:

1 Enucleation – the removal or destruction of the nucleus from the donated egg cell to produce an **enucleated** egg cell.
2 Extraction – the donated somatic cell's nucleus is extracted.
3 Insertion – the somatic cell's nucleus is inserted into the enucleated egg cell.
4 Development – following insertion, the cell begins to divide and develop into an embryo, which is then implanted into a surrogate mother. The pregnancy then continues as normal.

enucleated a cell that has had its nucleus removed or destroyed

In this process, the offspring produced is genetically identical to the donated somatic cell as they both contain the same nucleus and genetic material.

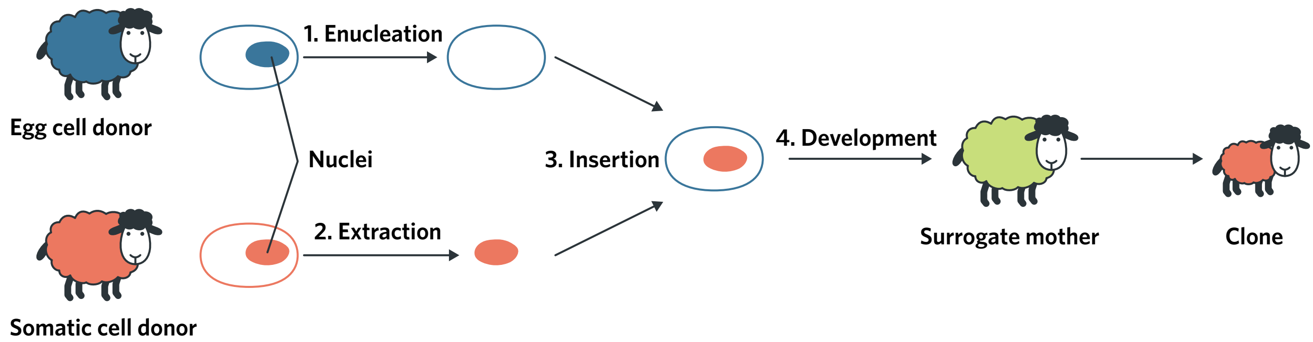


Figure 1 The process of somatic cell nuclear transfer

Applications of somatic cell nuclear transfer

To date, SCNT has been primarily used to clone a variety of living and recently deceased animals including sheep, dogs, and monkeys. Of these, the most famous is Dolly the sheep, who was the first mammal cloned using SCNT in 1997. Despite the success of Dolly, SCNT is relatively new and still has much room for improvement. A few unsolved issues surrounding the use and application of SCNT are discussed in Table 1.

Table 1 Complications surrounding the use of SCNT

Complication	Description
Animal suffering	SCNT attempts are often unsuccessful, producing non-viable embryos or resulting in miscarriage during pregnancy. Even animals that survive to birth often suffer from severe developmental abnormalities, and the life expectancy of cloned animals is far shorter than non-cloned offspring. This is because the somatic cell nucleus must be converted back into an embryonic state. However, as the somatic cell is fully differentiated, there would be varying degrees of epigenetic alterations and DNA damage, which must be cleared/reversed to match that of an embryonic state. Unfortunately, correct reprogramming rarely occurs, leading to the inefficient nature of SCNT and the potential for developmental abnormalities to arise. For example, researchers took over 250 attempts to successfully clone Dolly. Therefore, some have argued against the use of SCNT due to its potential to inflict suffering on the offspring produced.
Human cloning	Currently, the application of SCNT in humans is illegal in many countries, including Australia. Arguments against SCNT in humans include opposition to the mass destruction of egg cells and embryos from failed attempts, as well as issues surrounding the unethical sourcing of eggs.
Premature ageing	Although sheep from the same species as Dolly typically survive for up to 12 years, Dolly was euthanised after only 6 years when she developed a severe lung infection. During her lifetime, she also developed arthritis, a disease that becomes more common with old age, causing many scientists to proclaim that clones age at a greater rate due to the shortening of telomeres. While cloned animals do often appear to suffer from age-linked diseases, recent science questions whether cloned animals actually do age at a greater rate than non-cloned animals.

In addition to living and recently deceased animals, researchers are also investigating ways to revive extinct species through SCNT. For example, scientists attempted to revive the Pyrenean ibex (*Capra pyrenaica pyrenaica*), which became extinct in 2000. Unfortunately the clone only survived a few minutes after birth due to defects in its lungs. This attempt, and others like it, continue to spark debate over which extinct species should be cloned, and whether they should be cloned at all.

Theory in context

THERAPEUTIC CLONING

Animal cloning is not the only application of SCNT. Therapeutic cloning involves the cloning of particular tissues for some medical benefit in humans, and is quickly showing promise as a replacement for conventional medical treatments such as organ transplants and skin grafts, and some applications could even involve the treatment of previously untreatable diseases. The main benefits of therapeutic cloning over conventional techniques are that as the tissues are genetic clones of a patient, there is little to no risk of rejection, and tissues or organs may be manufactured quicker than the current waitlist for many organ transplants.

Instead of implanting the developing embryo into a surrogate mother, embryonic stem cells can be harvested from the developing embryo. From lesson 4D, we should remember that stem cells are undifferentiated cells that can differentiate into specialised cells. Therefore, embryonic stem cells, which are pluripotent stem cells, can develop into many different cell types. For example, when embryonic stem cells are treated with a derivative of vitamin A, they can differentiate into nerve cells.

Embryo splitting

Typically, after the successful fertilisation of an egg cell, the cell begins to divide, forming an embryo and then an entire organism. However, if an embryo is split during the early stages of embryonic development, each individual section will develop as an independent embryo, making it possible to produce two or more genetically identical offspring. While this process naturally occurs in the production of identical twins in humans, embryos are often artificially split for agricultural applications. The split embryos are implanted into surrogate mothers where embryonic development is completed, where each individual is genetically identical to the original embryo. Ideally, the splitting of the early embryo occurs when the cluster of cells is between 6–8 cells. During this stage, because cells are still totipotent, they are capable of developing into viable embryos.

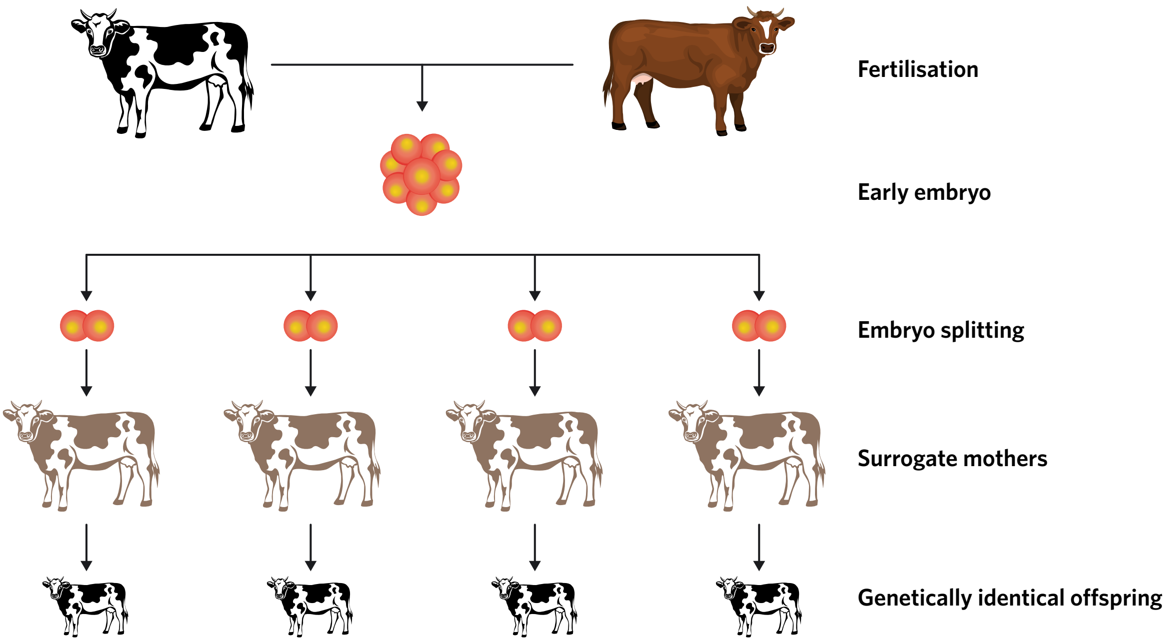


Image: SunshineVector/Shutterstock.com

Figure 2 The process of embryo splitting

Applications of embryo splitting

In agriculture, **embryo splitting** is often conducted in combination with ***in-vitro* fertilisation** (IVF) where scientists can selectively choose eggs and sperm from parents with desirable traits and fertilise them in a laboratory. For example, farmers may selectively choose cows (female) and bulls (male) based upon desirable traits, such as high milk production or increased muscle mass, and split the resulting embryo to produce genetically identical offspring, all of which would have the desirable traits. However, the use of embryo splitting is contentious – some complications are outlined in Table 2.

embryo splitting the division of an early embryo into several individual embryos

***in-vitro* fertilisation (IVF)** the fertilisation of an egg outside of the body

Table 2 Complications surrounding the use of embryo splitting

Complication	Description
Alteration of embryos	Some believe that embryo alteration is acceptable, and others argue that embryos are sacred and should never be altered.
Genetic diversity	By producing genetically identical offspring, the genetic diversity of a population is decreased. This decrease can potentially leave the population more susceptible to disease and environmental changes.
Research animals	The ability to produce large numbers of cloned animals could lead to the commercialisation and objectification of research animals, where animals are treated more as objects than living beings. These animals may then be subjected to increased levels of abuse and mistreatment. Additionally, research animals with a higher level of cognitive functioning may be used, which are more conscious of the actions of researchers, causing them to experience more stress than an animal with less cognitive awareness.

Reproductive cloning technologies in plants 2.2.3.2

OVERVIEW

Reproductive cloning technologies in plants include plant tissue culturing, cutting, and grafting.

THEORY DETAILS

Plant tissue culturing

Plant tissue culturing, or micropropagation, involves the cloning of plant cells in a controlled environment. Plant cells, which can be obtained from a leaf, shoot, or stem, are grown on a nutrient culture medium in sterile conditions, where lighting, temperature, and hormone and nutrient availability are closely regulated. As the tissue culture develops, a **callus** begins to form. The callus can then be separated into several cultures and stimulated to grow into clones of the original plant.

plant tissue culturing the cloning of plant cells on a nutrient culture medium in a controlled environment

callus a mass of plant cells

Figure 3 Plant tissue cultures

Applications of plant tissue culturing

Instead of growing in the wild, the environment of plants produced from plant tissue cultures is closely monitored and regulated. Therefore, plant tissue cultures can be used to produce plants all year round in a disease-free environment. Applications of plant tissue culturing include the production of clones for agricultural research, and may allow conservation groups to clone rare and endangered plants to save them from extinction.

Plant cuttings

A **plant cutting** is obtained by cutting off a fragment of a plant such as a leaf, stem, or root. This plant cutting can be planted in soil or water and then, under the correct conditions, the cutting of the plant will grow, producing a clone of the original plant.

plant cutting the growth of plants using a fragment of the original

Image: Garanga/Shutterstock.com

Figure 4 The process of cloning plants using plant cuttings

Plant grafting

Plant grafting involves attaching the stem of one plant (the **scion**) to the stem of another plant with an already developed root system (the **rootstock**). Eventually, the two sections of the individual plants will grow and fuse together, producing a clone of the plant from which the scion was taken from.

plant grafting the attachment of two individual plant stems together

scion the upper stem of a plant used in grafting

rootstock the lower stem of a plant with a well-developed root system

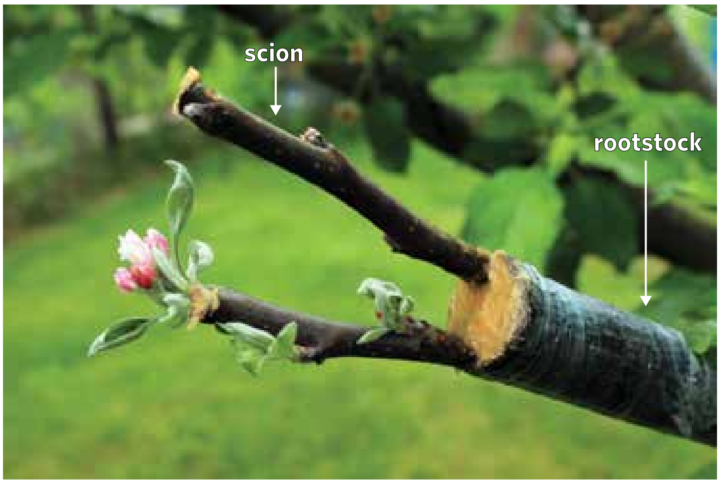


Image: Syndy1/Shutterstock.com

Figure 5 The attachment of a scion to a rootstock in plant grafting

Applications of cutting and grafting

Compared with other plant cloning technologies, cutting and grafting are relatively old plant cloning techniques. While both of these techniques allow for the rapid growth of a desired plant, grafting can often help provide plants with cold tolerance, resistance to disease, and increased productivity.

Theory in action

Check out Scientific Investigation 9.1 to put this into action!

Biological implications of plant cloning

Just like reproductive cloning technologies in animals, unrestrained cloning in plants could lead to a reduction in genetic diversity. Subsequently, a cloned population of plants is more susceptible to disease, pests, and environmental change than a natural population with high genetic diversity.

Theory in context

BANANAS

Panama disease is a lethal fungal disease caused by *Fusarium oxysporum* which affects banana trees by interfering with the movement of water within the xylem, leading to the wilting and death of entire banana plantations. The two races of *F. oxysporum* which are known to affect banana trees are 'Race 1' and 'Tropical Race 4' (TR4).

Up until the 1950s, the main commercial banana sold was known as the Gros Michel banana. However, the appearance of 'Race 1' completely devastated banana plantations, prompting farmers to cultivate another species of banana known as Cavendish bananas, which can be found on every supermarket shelf today. However, recently, the emergence of 'Tropical Race 4' has begun to worry researchers who fear that history will repeat itself once again. Currently, there are no effective pesticides or antifungals which can combat the infection. In 2015, TR4 reached Australia, affecting one of the largest banana plantations in Queensland's Tully Valley, leading to the closure of the farm and destruction of all infected banana plants to prevent further transmission. Since then, TR4 has reappeared multiple times.

Figure 6 A banana tree affected by Panama disease

But why are bananas so susceptible to disease? Because commercial bananas are seedless, they cannot sexually reproduce and must instead be produced through reproductive cloning techniques. Banana trees can either be produced through tissue culturing or by dividing an existing banana tree into many separate segments for planting. Therefore, virtually all Cavendish bananas grown today are genetically identical, leaving them exceptionally vulnerable to disease.

Theory summary

Reproductive cloning technologies are human interventions that artificially produce genetically identical clones of an organism. When clones are produced naturally, the process is instead known as asexual reproduction.

There are two main reproductive cloning technologies in animals: somatic cell nuclear transfer and embryo splitting. Somatic cell nuclear transfer involves the transfer of a somatic cell nucleus into an enucleated egg cell, which is subsequently implanted into a surrogate mother to produce a cloned offspring. Embryo splitting involves the fertilisation of egg cells and the splitting of early embryonic cells to produce multiple cloned offspring.

In plants, there are three main reproductive cloning technologies: plant tissue culturing, plant cuttings, and plant grafting. Plant tissue culturing involves the growth of plant cells in a controlled environment, plant cutting involves the replanting of a leaf, stem or root, and plant grafting involves the attachment of a scion to a rootstock.

Despite the success of animal reproductive cloning techniques, they are still complicated by ethical issues such as the suffering of animals, premature ageing, and the controversy surrounding the potential for human cloning. Furthermore, animal and plant cloning may lead to a decrease in genetic diversity, leaving species and populations more susceptible to disease, pests, and environmental change.

Researchers working on the Lazarus Project are using somatic cell nuclear transfer in an attempt to resurrect the gastric-brooding frog. In doing so, they are transferring the genetic material from preserved gastric-brooding frogs into an enucleated egg cell obtained from a closely related species. Unfortunately, researchers are yet to produce an embryo that has survived more than a couple of days, so you might have to wait a bit longer till you get to see a frog giving birth through its mouth!

9B QUESTIONS

Theory review questions

Question 1

Reproductive cloning technologies are

A naturally occurring.

B artificially induced.

Question 2

Match the stage of somatic cell nuclear transfer to its description.

Stage	Description
• development	**I** __________ removal of the nucleus from the egg cell
• enucleation	**II** __________ the procurement of a somatic cell nucleus
• extraction	**III** __________ transference of the nucleus from the somatic cell into the egg cell
• insertion	**IV** __________ continued embryonic growth and implantation into the surrogate mother

Question 3

Following somatic cell nuclear transfer, the clone is genetically identical to the

A somatic cell donor.

B egg cell donor.

Question 4

The creation of multiple genetically identical offspring can be produced through

A embryo splitting, which increases genetic diversity.

B embryo splitting, which decreases genetic diversity.

C somatic cell nuclear transfer, which increases genetic diversity.

D somatic cell nuclear transfer, which decreases genetic diversity.

Question 5

Fill in the blanks with the following terms.

- plant tissue culturing
- plant grafting
- plant cutting

__________ involves the joining of two plants. __________ involves the cloning of plant cells on a nutrient culture medium. __________ involves cloning by replanting a fragment of a plant in soil or water.

Question 6

During plant tissue culturing,

A light, temperature, and hormone and nutrient availability are controlled.

B the environment contains many microorganisms.

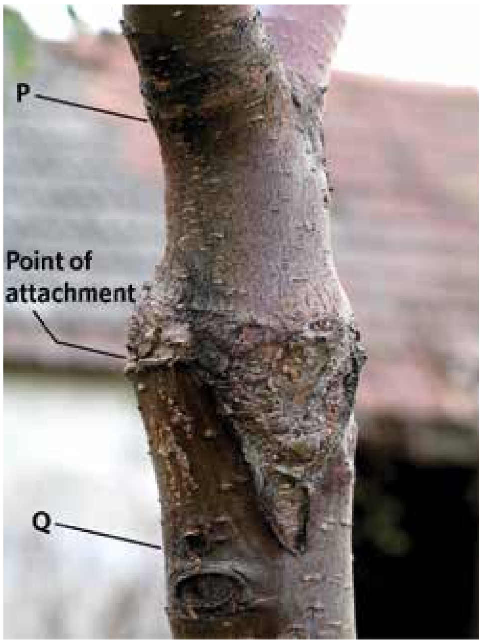
C only one culture of plants can be made.

D the environment is not regulated.

Question 7

Label the parts of the plant graft from the list of terms.

- scion
- rootstock



SAC skills questions

Bioethical deep dive

Use the following information to answer Questions 8–13.

In 2019, researchers at the Institute of Neuroscience in Shanghai produced five gene-edited and cloned macaque monkeys (Liu et al., 2019). These monkeys, which had a gene related to their circadian rhythm removed, exhibited increased levels of anxiety and depression (Qiu et al., 2019). While experiments on genetically identical macaque monkeys could be beneficial to the testing of drugs and research into how different human diseases develop, a debate has sparked regarding the ethics of cloned animals.

Firstly, such cloning of monkeys has raised concerns over which animals should be used in research. To be able to extract clinically relevant information, the more closely related an animal is to humans the better. However, the more closely related the animal is to humans, the greater chance they will have a higher order of reasoning and cognition, which would result in them experiencing greater stress in a laboratory environment.

Additionally, as scientists refine their technique to clone animals such as monkeys, they will be able to mass-produce cloned animals. This mass production of cloned animals could lead to their commodification, where they are treated more as objects than real 'beings'. In doing so, researchers might be able to justify abuse and mistreatment of cloned animals, as commodities by definition have no ethical standing.

Question 8

Based on the passage, the commodification of cloned monkeys could lead to

A widespread abuse and mistreatment of monkeys.

B increased affection and adoption of monkeys.

Question 9

If an animal is more closely related to humans, they will more likely have a

A lower order of reasoning.

B higher order of reasoning.

Question 10

The five cloned macaque monkeys were produced from an enucleated egg cell and a somatic cell. The technique used to produce these monkeys is known as

A grafting.

B tissue culturing.

C embryo splitting.

D somatic cell nuclear transfer.

Question 11

If monkeys are consciously aware of the actions of researchers, then based upon the ethical principle of

A justice, experiments should continue to maximise benefits for humans.

B respect, experiments should be restricted as the welfare of monkeys should be protected and because they are unable to provide consent.

Question 12

Based on the ethical principle of non-maleficence, researchers should

A reduce the number of experiments using animals with a high order of reasoning and use animals with lower cognitive abilities where possible.

B always conduct experiments on animals with a high order of reasoning, since they are more clinically relevant to humans than other animals.

Question 13

Some scientists argue that by experimenting with animals more closely related to humans, they can obtain more accurate information. Which of the following ethical approaches could opponents use to justify the prohibition of experiments on animals irrespective of the potential benefits or damages?

A a consequences-based approach

B a utilitarianism-based approach

C a duty/rule-based approach

Exam-style questions

Within lesson

Question 14 (1 MARK)

All reproductive cloning techniques

A can be used to preserve endangered organisms.

B involve the manipulation of embryos.

C involve human intervention.

D occur naturally.

Question 15 (1 MARK)

Which of the following techniques is best suited to growing seasonal plants during any time of the year?

A plant tissue culturing

B embryo splitting

C plant cuttings

D plant grafting

Question 16 (1 MARK)

Plant grafting involves

A the fusion of two scions together.

B the fusion of two rootstocks together.

C a scion that contains well-developed roots.

D a rootstock that contains well-developed roots.

Multiple lessons

Question 17 (5 MARKS)

'CC', or 'Carbon Copy', is the name given to the first cloned kitten born in 2001. The nucleus of a cat's egg cell was removed. It was replaced by a nucleus from a somatic cell of a donor male cat. Once development commenced the egg cell was transferred into a surrogate female. The diploid number of a cat is 38.

a What is a clone? (1 MARK)

b Identify the name of the technique used to create CC. (1 MARK)

c How many chromosomes would have been in the egg cell before enucleation? Explain. (2 MARKS)

d Two friends, Josh and Isaac, were having a debate over the gender of the cat CC. While Josh believed the cat was male, Isaac believed the cat was female. Which of the two is correct? Justify your answer. (1 MARK)

Adapted from VCAA 2006 Exam 2 Section B Q5

Question 18 (7 MARKS)

Traditionally, farmers would naturally breed cows and bulls with desirable traits such as high levels of muscle mass, in the hopes of producing offspring with the same desirable trait, a practice known as selective breeding. However, this process generally only produces one offspring at a time. An alternative technique farmers could use is called embryo splitting.

a Describe the process of embryo splitting. (4 MARKS)

b Suggest an advantage of embryo splitting over traditional selective breeding techniques. (1 MARK)

c Embryo splitting and selective breeding techniques lead to a decrease in genetic diversity, which can leave species more susceptible to disease. Describe the mechanisms in meiosis that help to increase genetic diversity. (2 MARKS)

Key science skills and ethical understanding

Question 19 (6 MARKS)

When investigating the effect of a newly invented chemical on the fruit productivity of a specific species of apple tree, scientists must ensure that the apple trees are all genetically identical. During any experiment, this ensures that differences in fruit productivity are explained by the effects of the chemical and not differences in genetics between apple trees. One method of ensuring that all the apple trees are genetically identical is to grow them with the reproductive cloning method of plant tissue culturing.

a Suggest a possible hypothesis for the experiment. (1 MARK)

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

c Apart from genetically identical apple trees, identify another variable which should be controlled in the experimental design. (1 MARK)

d Other methods of producing genetically identical apple trees include plant cuttings and grafting.

 i Suggest why scientists might prefer plant cuttings and grafting compared to plant tissue culturing. (1 MARK)

 ii Describe a biological implication of producing genetically identical plants. (1 MARK)

CHAPTER 9 SUMMARY

Genetic diversity

Genetic diversity refers to the amount of genetic variation that exists between individuals within a population. This is important in protecting the longevity of a species by reducing their susceptibility to sudden environmental changes. Populations with greater genetic diversity have a higher chance of containing alleles that are better suited to survive new environmental challenges.

Sexual reproduction

Advantages	Disadvantages
• increases the genetic diversity of a population by allowing for recombinant offspring • improves disease resistance by promoting the presence of different alleles • combining the genetic material from two gametes reduces the chances of an offspring inheriting a genetic disorder that might be carried by one parent.	• the cost of male progeny • the time, energy, and resources it takes to attract and find a mate • the risk of transferable diseases associated with sexual intercourse • the risk of losing offspring to outside influences such as embryo damage.

Oviparity vs viviparity

- Oviparity – eggs are released into the external environment and the embryo develops from nutrients inside the yolk.
- Viviparity – the embryo develops inside the mother's body and is born after a period of gestation.

Sexual reproduction in angiosperms (flowering plants)

Flowering plants produce and release pollen (the male gamete). Pollen is carried by a pollinator to the flower of another plant, collected by the stigma of the flower, and fertilises the ovule (the female gamete). Pollinators can either be biotic (living organisms such as insects) or abiotic (non-living methods such as wind and water).

Asexual reproduction

Asexual reproduction involves the production of offspring without the fusion of gametes. While this form of reproduction is advantageous due to its speed and relative simplicity when compared with sexual reproduction, it does not increase genetic diversity.

Advantages	Disadvantages
• grows faster than sexually reproducing populations • offspring are identical clones of the parent. This is especially important for organisms that have adapted a phenotype that is fine-tuned to survive in a particular environment • does not require an organism to find a mate to reproduce, meaning that the organism does not have to be mobile • requires very little parental investment and removes the need to protect fragile offspring.	• genetic diversity is low and asexually reproducing populations may suffer during rapid environmental change.

Types of asexual reproduction

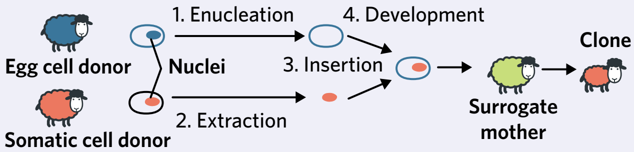
- Binary fission – asexual reproduction in prokaryotes and certain species of eukaryotes, which results in the generation of two identical cells.
- Budding – formation of buds which grow and split away from the main organism to develop into another separate organism.
- Fragmentation – breaking of fragments from an organism which can regrow back into a whole organism.
- Vegetative propagation – reproduction of plants with roots or leaves breaking away from the original plant and independently growing into a new plant.
- Sporogenesis – formation of spores which are dispersed into the environment where they can grow into an organism.
- Parthenogenesis – formation of an embryo from a female gamete alone, without the need for a male gamete to fertilise it.

Reproductive cloning technologies

Reproductive cloning technologies are human interventions which artificially produce genetically identical clones of an organism.

Reproductive cloning technologies: animals

Somatic cell nuclear transfer



1. Enucleation – removal or destruction of the nucleus from the donated egg cell
2. Extraction – the donated somatic cell's nucleus is extracted
3. Insertion – the donated somatic cell's nucleus is inserted into the enucleated egg cell
4. Development – the developing embryo is implanted into a surrogate mother

Embryo splitting

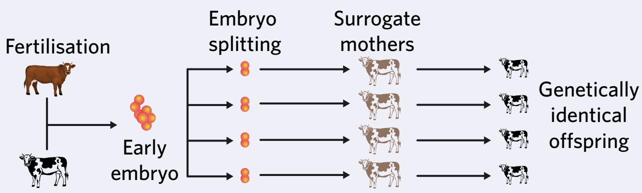


Image: SunshineVector/Shutterstock.com

Reproductive cloning technologies: plants

- Tissue culturing – growth of plant cells on a growth medium in sterile conditions.
- Plant cuttings – production of new plants from fragments such as the stem or root from the original plant.
- Plant grafting – attachment of a rootstock and scion together to produce a clone.

CHAPTER 9 SAC PRACTICE

SAC skills covered in this section:

✓ Case study analysis ✓ Data analysis ✓ Bioethical deep dive

REPRODUCTION (23 MARKS)

Infertility

Infertility describes the inability to conceive a pregnancy. In Australia, infertility affects 15 in 100 couples, with 40% of cases being attributed to problems with the male reproductive system, another 40% being attributed to problems with the female reproductive system, and the remaining 20% either attributed to a combination of factors, or some unknown cause (Healthdirect, 2020).

The major components of the female reproductive system include the Fallopian tubes, the ovaries, and the uterus.
Egg cells are produced in the ovaries, and are released into the Fallopian tubes. The egg cell travels down the tube, where it may come into contact with a sperm cell and be fertilised. The fertilised egg continues travelling down the Fallopian tube, eventually arriving in the uterus, where it implants into the lining of the uterus and continues developing into an embryo. In women, common causes of infertility include Fallopian tube damage or blockage, which can prevent the transportation of the egg. This can cause ovulation disorders where the release of eggs from the ovaries is abnormal, and primary ovarian insufficiency in which the ovaries cease to function normally, resulting in the decreased production of egg cells and hormones.

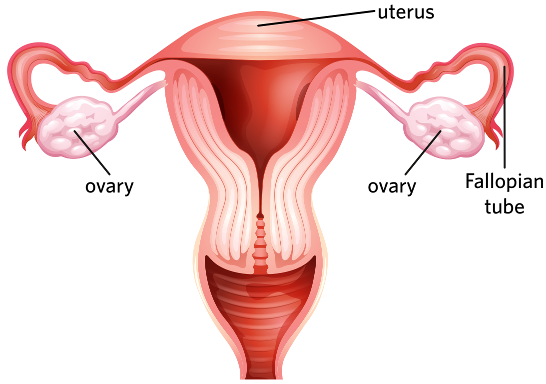


Image: BlueRingMedia/Shutterstock.com

In men, sperm are produced in the testes. Common causes of male infertility include the abnormal production of sperm due to genetic defects, low sperm count, or poor sperm motility.

1 Based on the information provided, identify the purpose of the ovaries and testes. (1 MARK)

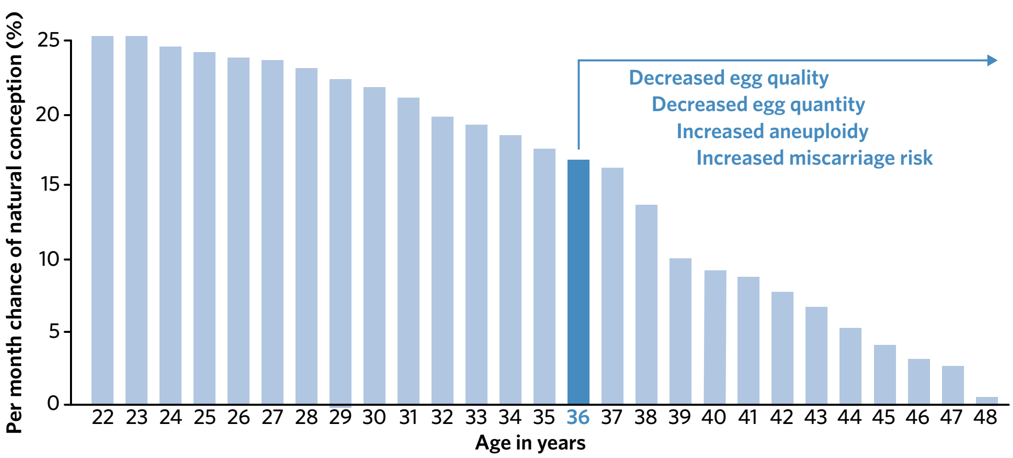
2 Explain how a damaged Fallopian tube leads to infertility. (2 MARKS)

3 Identify and describe the mode of embryonic development in humans. (2 MARKS)

4 Describe an advantage and disadvantage of sexual reproduction. (2 MARKS)

5 The graph depicts the monthly chance of natural conception in women as age increases. Using data from the graph, describe the general trend. (1 MARK)

Chance of natural conception by age



In-vitro fertilisation (IVF)

In-vitro fertilisation is a technique used to increase an individual's chances of conceiving. During IVF, egg cells are fertilised with sperm outside of the body, before being introduced into the mother's uterus to develop. As part of IVF, parents can often select against deleterious traits with genetic screening techniques. However, access to IVF can often be limited to certain individuals due to both economic and judicial constraints.

For example, in Victoria, couples previously had to submit a police check and pass child welfare checks in order to be eligible for IVF treatment, so as to ensure that the parents of the child can provide a physically and emotionally safe environment.

Victoria used to be the only jurisdiction in the world which had such requirements in place. In a 2019 inquiry into these checks, patients described these checks as humiliating and unfair. While the state harboured good intentions, attempting to make sure that the child was raised in a suitable environment, opponents argued that couples were being discriminated against based on their fertility status as natural conception is largely unrestricted. Therefore, in 2020, the Victorian government announced that they would be easing these requirements for IVF therapy.

6 Describe a difference between *in-vitro* fertilisation and somatic cell nuclear transfer. (1 MARK)

7 Describe a similarity between *in-vitro* fertilisation and embryo splitting. (1 MARK)

8 With reference to the bioethical concept of respect, discuss whether people seeking IVF therapy should have been subjected to police checks and child welfare testing. (2 MARKS)

9 Genetic disorders often have severe or life-threatening implications. Explain why *in-vitro* fertilisation could be beneficial for parents with genetic disorders. (1 MARK)

Plant sterility

While human infertility can often be devastating, sterile – or seedless – fruit are typically preferred over their seeded counterparts due to their convenience to eat. Examples of common seedless fruit include watermelons and grapes. These seedless variants can be produced through a phenomenon known as parthenocarpy, where fruit develops without the fertilisation of the ovule. Stenospermocarpy is similar to parthenocarpy, but instead involves the abortion of the embryo as they develop in fruit, thereby disrupting the production of seeds.

Seedless watermelons are produced by artificially breeding diploid and tetraploid watermelon together to produce triploid watermelon. Because there are three sets of chromosomes, they won't pair correctly during meiosis. This prevents the formation of functional gametes, causing seedlessness. Conversely, some varieties of seedless grapes naturally arose from a random change in the gene responsible for seed development, inhibiting seed formation.

10 Identify the male reproductive gamete in flowering plants. (1 MARK)

11 Describe the reproductive process in flowering plants. (2 MARKS)

12 Explain whether seedless watermelons produced by crossing diploid and tetraploid watermelon is a form of stenospermocarpy. (2 MARKS)

13 Explain why seedless grapevines must be propagated through reproductive cloning techniques. (1 MARK)

14 Describe how plant tissue cultures could be used to produce seedless grapevines. (3 MARKS)

15 Some plants can develop from spores released into the environment. Name this reproductive technique. (1 MARK)

CHAPTER 9 EXAM PRACTICE

30 min

Section A (7 MARKS)

Question 1 (1 MARK)

Which of the following groups of reproductive and cloning techniques could decrease genetic diversity?

A pollination, plant tissue culturing, and somatic cell nuclear transfer
B somatic cell nuclear transfer, parthenogenesis, and binary fission
C fragmentation, oviparity, and embryo splitting
D plant grafting, viviparity, and sporogenesis

Use the following information to answer Questions 2 and 3.

Cornu aspersum is commonly known as the garden snail. *C. aspersum* has two methods of reproduction. It can either reproduce sexually with other snails or it can self-fertilise its own eggs. Two weeks after fertilisation, *C. aspersum* lay its eggs in the soil.

Question 2 (1 MARK)

Which of the following statements about *C. aspersum* is correct?

A *C. aspersum* reproduces both sexually and asexually.
B The reproductive method of *C. aspersum* is known as parthenogenesis.
C Mating with other snails yields greater genetic diversity than self-fertilisation.
D *C. aspersum* is more likely to survive sudden environmental changes if self-fertilisation increases.

Question 3 (1 MARK)

The embryonic development of *C. aspersum* is known as

A viviparity because the egg is released into the external environment.
B oviparity because the egg is released into the external environment.
C viviparity because the organism develops inside the mother's body.
D oviparity because the organism develops inside the mother's body.

Question 4 (1 MARK)

Which of the following statements about pollinators is correct?

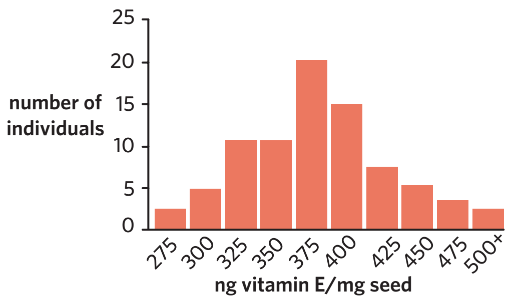
A Examples of biotic pollinators include wind and water.
B Examples of abiotic pollinators include insects and birds.
C Plants with abiotic pollinators often lack colourful petals and smells.
D Biotic pollinators produce greater increases in genetic diversity compared to abiotic pollinators.

Question 5 (1 MARK)

Scientists have been studying the amount of vitamin E in the corn plant *Zea mays*. The amount of vitamin E in hundreds of different plant seeds in the wild was tested and is summarised in the graph.

The variation in vitamin E in *Z. mays* is most likely due to

A plant tissue culturing.
B sexual reproduction.
C plant grafting.
D budding.



Adapted from VCAA 2010 Exam 2 Section A Q7

Question 6 (1 MARK)

Gene therapy can be used to introduce normal genes into cells to replace missing or defective genes in order to treat or prevent disease. Recently, scientists have taken a number of different approaches to using gene therapy. One of these approaches uses the reproductive cloning technology of somatic cell nuclear transfer which

A involves the insertion of a somatic cell nucleus into an enucleated egg cell.

B involves the splitting of embryos to produce multiple viable embryos.

C involves the complete development of an embryo in a Petri dish.

D produces genetically identical cells to the egg donor.

Question 7 (1 MARK)

A rare form of asexual reproduction involves the development of an embryo from the female gamete without fertilisation from the male gamete. This form of asexual reproduction is called

A parthenogenesis.

B sporogenesis.

C binary fission.

D budding.

Section B (13 MARKS)

Question 8 (5 MARKS)

The garden nasturtium, *Tropaeolum majus*, can have flowers which are either single, double, or superdouble. The three flower types differ in their number of petals; single flowers have the least number of petals, and superdouble flowers have the largest number of petals. These plants may be made to reproduce via several methods.

a These plants can be produced through plant tissue culturing. Describe the conditions necessary for plant tissue culturing. (1 MARK)

b Another technique that could be used is plant grafting. Outline the process of plant grafting. (2 MARKS)

c Explain why pollination is a form of sexual reproduction. (2 MARKS)

Adapted from VCAA 1998 Q3

Question 9 (5 MARKS)

Lucilia cuprina, the sheep blowfly, lays its eggs in wounds and the wet fleece of sheep. The larvae hatch and burrow into the sheep's skin, reducing wool production, causing distress, and sometimes result in the death of the sheep. Particular chemicals were used in the past to control the sheep blowfly but these became less effective as *L. cuprina* developed resistance to the chemicals. Therefore, scientists are considering finding and breeding sheep with a natural resistance to *L. cuprina*.

a Identify and describe a reproductive technology which could be used to rapidly produce sheep with the favourable genotype. (4 MARKS)

b Describe a biological implication of mass-producing sheep with a natural resistance to *L. cuprina*. (1 MARK)

Adapted from VCAA 2008 Exam 2 Section A Q23

Question 10 (3 MARKS)

There are many advantages and disadvantages to sexual and asexual reproduction. However, depending on whether an organism is prokaryotic or eukaryotic and their environment, one form of reproduction can be more advantageous than the other.

a Describe how genetic diversity can be measured. (1 MARK)

b Describe two advantages of asexual reproduction. (2 MARKS)

CHAPTER

10

Adaptations and survival

Key knowledge

- structural, physiological, and behavioural adaptations that enhance an organism's survival and enable life to exist in a wide range of environments
- survival through interdependencies between species, including the impact of changes to keystone species and predators and their ecological roles in structuring and maintaining the distribution, density, and size of a population in an ecosystem
- contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of, and interdependencies between, species in Australian ecosystems

10A ADAPTATIONS FOR HOT ENVIRONMENTS

It's the middle of summer and it's 42 °C. You are sweating like a pig, and you have a hot flush. You look outside and you notice your dog is lying down in the shade with its tongue lolling out of its mouth. You think this means your dog is happy. You are wrong. Your dog is trying its absolute best to cool down. How do you know when your dog is too hot, and when should you invite it into the air-conditioned house?

Image: Reddogs/Shutterstock.com

Lesson 10A

In this lesson you will learn about how some organisms have developed a set of structural, physiological, and behavioural adaptations to help them survive in hot and dry environments.

◀ *Prerequisite knowledge*

Years 7–10
Natural selection acts on the phenotype of an organism so that individuals with beneficial adaptations are fitter and have more offspring.

Chapter 6
Organisms have evolved a variety of thermo- and osmoregulatory mechanisms to maintain homeostasis in hot and dry environments.

Future applications ▶

Year 12
Behavioural, structural, and physiological adaptations can help an organism thermoregulate, ensuring that their proteins do not denature and that cellular processes can progress.

Year 12
Hot environments can act as a selection pressure that leads to changes in allele frequencies of a population.

Study design dot point

- structural, physiological, and behavioural adaptations that enhance an organism's survival and enable life to exist in a wide range of environments

Key knowledge units

The challenges of hot and dry environments	2.2.5.1
Adapting to the desert: animals	2.2.5.2
Adapting to the desert: plants	2.2.5.3

The challenges of hot and dry environments 2.2.5.1

OVERVIEW

An environment is made up of abiotic and biotic factors, and for each factor an organism will have a tolerance range within which it can survive. To help survive in their environment, animals have evolved a set of structural, physiological, and behavioural adaptations, whereas plants have only evolved a set of structural and physiological adaptations.

THEORY DETAILS

Environments are characterised by their **abiotic** and **biotic** factors. Abiotic factors are properties of the environment that are non-living and include temperature, water, nutrient availability, and acidity. On the flipside, biotic factors are properties of the environment that are alive and include predator-prey interactions, plant-herbivore interactions, competition for resources, and symbiotic relationships. For example, coral reefs are characterised by tropical temperatures (abiotic) and the presence of corals, a type of animal (biotic).

Organisms evolve adaptations to deal with the abiotic and biotic factors in their environment. For each factor, an organism will have a range of conditions within which it will thrive, survive, or not-stay-alive (Figure 1). The zone in which an organism can survive is the **tolerance range**.

abiotic factor a property of the environment relating to non-living things. Examples include temperature, nutrient availability, and water availability

biotic factor a property of the environment relating to living things. Examples include predator-prey relationships, competition, and symbiotic relationships

tolerance range the range of environmental conditions in which an organism can survive

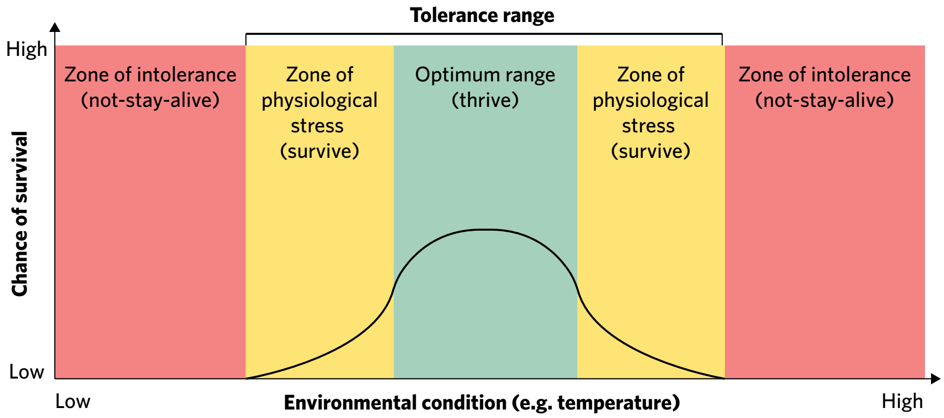


Figure 1 Every organism has a tolerance range for each environmental condition. Staying within this tolerance range means the organism survives, and straying outside of this range will result in the organism's death.

Deserts are extremely complex ecosystems, and generally are either hot (such as the Simpson desert in Australia) or cold (such as the Patagonian desert in Argentina). In this lesson, we will only consider hot desert environments, typically characterised by high temperatures and low water availability. Here, we will explore the set of evolved adaptations in plants and animals to these two abiotic factors. When considering these adaptations, notice that most fall into one of two categories: **structural** or **physiological adaptations**. Additionally, animals often modify their **behaviours** to better suit their environment.

desert a geographic area receiving on average less than 250 mm of rain per year

structural adaptation evolved modifications to an organism's physical structure

physiological adaptation evolved modifications to an organism's internal functioning or metabolic processes

behavioural adaptation evolved modifications to an organism's actions

Theory in action

Don't think two abiotic factors are enough? Discuss with the person next to you and see if you can identify two other abiotic and two biotic factors in the desert.

Adapting to the desert: animals 2.2.5.2

OVERVIEW

Animals have evolved specialised structures, modifications to internal physiological processes, and can alter behaviours to survive in the desert.

THEORY DETAILS

You'll remember from chapter 6 that an organism's survival depends on **thermoregulation** and maintaining water balance. Organisms exchange heat with their environment through radiation, conduction, and convection. They also produce their own metabolic heat and release heat via evaporation. Organisms obtain water by drinking, eating food, and metabolic water production. They lose water through excretion and evaporative water loss (sweating).

thermoregulation the homeostatic process of maintaining a constant internal body temperature

In hot deserts, organisms have generally adapted to maximise heat loss, minimise heat gain, maximise water uptake, and minimise water loss.

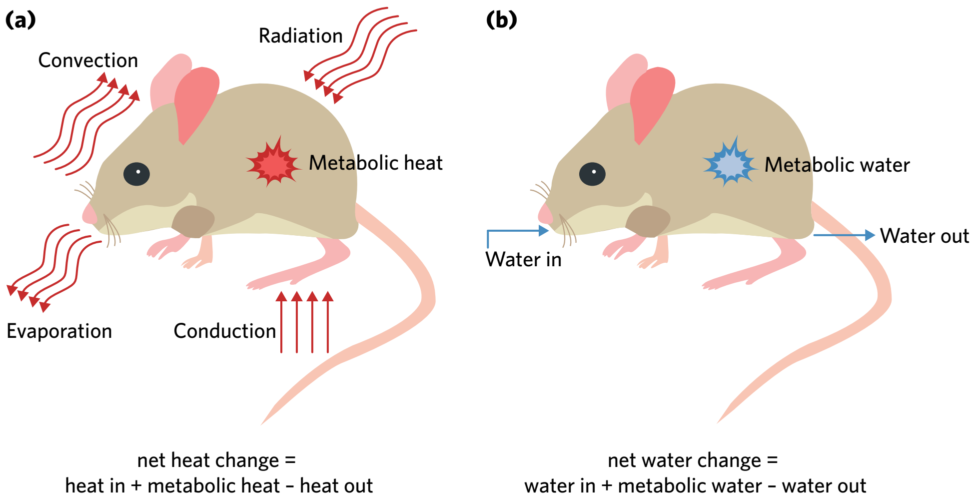


Figure 2 To survive in the desert, animals must maintain **(a)** a temperature balance and **(b)** a water balance.

Structural adaptations

Many animals have evolved elegant structural solutions to maintaining a heat (or temperature) balance. Maintaining a temperature balance prevents the animal from overheating. If the animal does overheat, many biochemical processes within the body cannot continue and the animal may die.

Insulation

The more insulated an animal is, the harder it is for the animal to release heat into the environment. By the same logic, we can say that the less insulated an animal is, the easier it is to release heat into the environment. It should come as no surprise that many animals have evolved the optimal thickness of fur and fat to regulate temperature. As many desert animals release heat into the environment, a thin insulating layer is often preferable.

Theory in context

THE INSULATION TECHNIQUES OF CAMELS

Camels are one of the best adapted and most widespread large desert animals on earth. They have developed a simple yet effective insulating system to help them maintain a temperature balance. The top of the camel has a thick layer of fur and fat, which reduces the total amount of heat absorbed by the sun. The underside of a camel consists of a very thin layer of fur and fat, such that they can effectively release large amounts of heat into the environment.

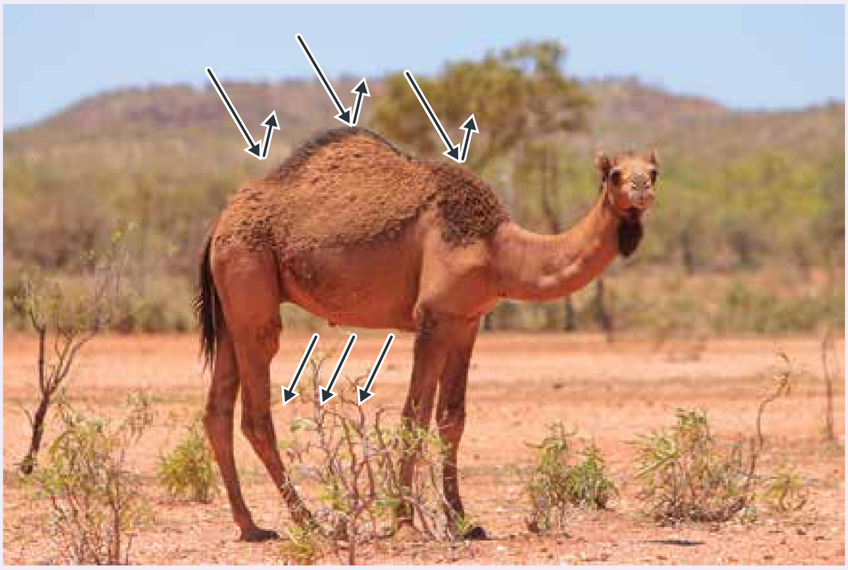


Figure 3 A feral camel found in the Australian outback

Surface area to volume ratio

An animal can only release or absorb heat at the border between its body and the environment at a rate determined by the environmental temperature compared to the body temperature of the animal and its **surface area (SA) to volume (V) ratio**. When considering the adaptations of animals in the desert, there are advantages and disadvantages to both a high and low SA:V ratio.

An animal with a high SA:V ratio releases or absorbs a proportionally large amount of heat in little time, allowing their body temperature to quickly change. In the desert a high SA:V ratio may be beneficial if you release heat into a cold microclimate, but exposure to direct sunlight may quickly increase body temperature. For instance, the fennec fox of Northern Africa, which has large ears to increase its SA:V ratio, releases heat into cold microclimates (such as those found in burrows) and avoids direct sunlight.

Conversely, an animal with a low SA:V ratio releases or absorbs a proportionally low amount of heat and their internal body temperature is resistant to change. In the desert a low SA:V ratio may be beneficial for an animal if it is exposed to direct sunlight or cannot avoid heat. However, animals with low SA:V ratios must still release waste heat. For instance, the SA:V ratio of the African elephant's body is relatively low, allowing it to survive in direct sunlight with ease. However, the highly vascularised ears of the African elephant have a high SA:V ratio. When hot, an elephant will often extend and fan its ears, promoting heat loss via convection.

surface area : volume ratio (SA:V) a comparison of the amount of surface area per unit of volume. In Biology, SA:V influences temperature regulation, and a high SA:V leads to more effective transport into and out of cells

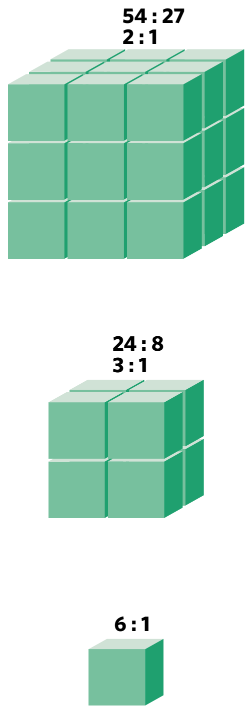


Figure 4 The surface area to volume ratio (SA:V) increases as the total volume decreases.

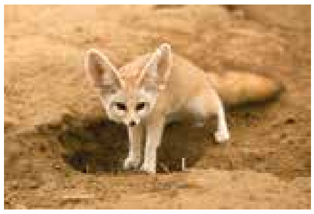


Image: hagit berkovich/Shutterstock.com

Figure 5 The fennec fox's large ears help increase its overall surface area.

Image: Carolyn Z Cheney/Shutterstock.com

Figure 6 The African elephant uses its ears as fans to promote heat loss via convection.

Theory in action

DOES INCREASING THE SURFACE AREA INCREASE HEAT DISSIPATION?

Materials

- 1 × bowl
- 1 × cup
- 2 × thermometers
- 1 × kettle
- Water

Method

1 Boil the water in your kettle.
2 Fill the cup with hot water.
3 Fill the bowl with an identical amount of hot water.
4 Place a thermometer in the cup and the bowl.
5 Record the temperature in each after five minutes.

Questions

1 Which water-holding device has a greater surface area to volume ratio?
2 How quickly does the temperature drop in the cup compared to the bowl? Why?
3 How can desert animals use this to regulate temperature?

Theory in action

DOES DECREASING THE VOLUME INCREASE HEAT DISSIPATION?

Materials

- 2 × identical cups
- 2 × thermometers
- 1 × kettle
- Water

Method

1 Boil the water in your kettle.
2 Fill one cup with hot water.
3 Fill the other cup one-quarter full of hot water.
4 Place a thermometer in the full cup and in the quarter-full cup.
5 Record the temperature in each cup after five minutes.

Questions

1 Which cup has a greater surface area to volume ratio?
2 How quickly does the temperature drop in the full cup compared to the quarter-filled cup? Why?
3 How can desert animals use this to regulate temperature?

Physiological adaptations

Metabolic heat

There are two strategies for generating heat: an animal can either be an **endotherm** or an **ectotherm**. Endotherms include mammals, birds, and some fish whereas ectotherms include reptiles, amphibians, fish, and invertebrates.

endotherm an animal that produces the majority of its own heat via metabolic processes

ectotherm an animal that obtains heat primarily from the environment, rather than its own metabolic heat

Endotherms spend a lot of energy producing metabolic heat, but in the desert they must evolve effective strategies to release excess heat. As ectotherms obtain heat from their environment, they can use the energy they don't spend generating metabolic heat on other processes, such as foraging for food or finding a mate. This is why we tend to find many ectotherms in hot environments as permanently cold environments typically provide too little environmental heat for ectotherm survival.

Theory in context

TORPOR AND THE AUSTRALIAN WATER-HOLDING FROG

Torpor is a physiological and behavioural adaptation for survival in which an animal's metabolic rate is severely reduced. It appears to be triggered by changes in the environment. Torpor has two major benefits for an animal: little energy is required to fuel this state and prolonged torpor helps animals avoid extreme environmental conditions for extended periods of time.

torpor a physiological state in which the metabolism of an animal is reduced to conserve energy

aestivation prolonged torpor in response to hot and dry conditions

The Australian water-holding frog uses a particular state of torpor, called **aestivation**, to survive the hot and dry periods during the scorching summer months. It stores water in its body and creates a sealed burrow, where it begins aestivation. The Australian water-holding frog can live up to three years in this state, only surfacing for brief periods following rain to reproduce.

The Australian water-holding frog's importance is not solely due to its interesting ability to survive droughts. During times of water scarcity, the Aboriginal people of Australia would traditionally dig up these frogs as a valuable source of food and water.

Figure 7 The Australian water-holding frog

Surface blood flow

The circulatory system plays a huge role in the maintenance of temperature balance in the desert. When internal temperature rises after activity, blood vessels near the skin dilate and total surface blood flow increases. This hot blood releases heat into the environment, cooling the animal down.

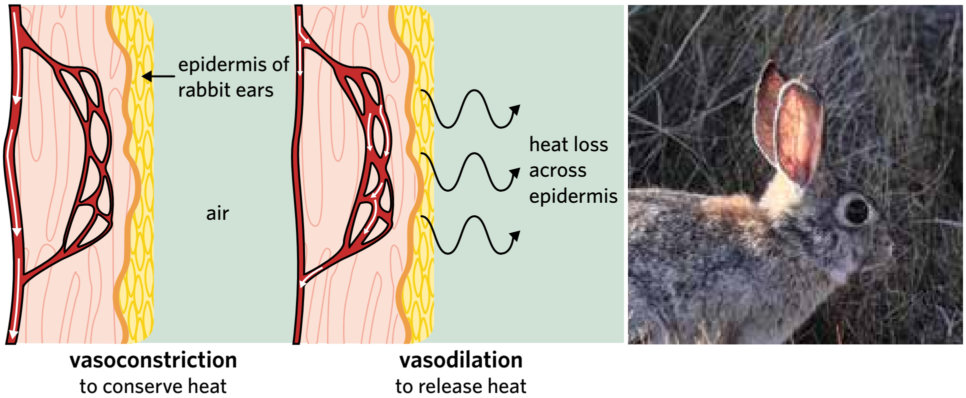


Image: Ingrid Curry/Shutterstock.com

Figure 8 Animals can release heat by the **vasodilation** of superficial blood vessels. When hot, the cottontail rabbit manipulates the vessels in its ears to do just this.

vasodilation the widening of blood vessels

Increase water input

Due to the low availability of surface water, most desert animals obtain their water from other sources, including the food that they eat. Other sources of water include drinking the dewfall that occurs at night, and the metabolic production of water during aerobic cellular respiration.

Theory in context

'MOISTURE-HARVESTING' LIZARDS

The thorny devil belongs to a group of phenotypically similar, although genetically unrelated, 'moisture-harvesting' lizards. These lizards have evolved highly specialised and complex structures to passively collect water.

How is this possible? The skin of the thorny devil is covered in tiny capillary-like channels that direct water to the mouth of the lizard. If standing in an open water puddle or rain (an admittedly rare occurrence in the desert), water will travel up the legs and down the back into the mouth via capillary action. Thorny devils have been also observed drinking water from wet sand that they shovel onto their own back, and some scientists suggest that other moisture-harvesting lizards (such as *Phrynocephalus helioscopus*) may even be able to drink condensation from the air.

Imge: Kristian Bell/Shutterstock.com

Figure 9 The thorny devil (*Moloch horridus*)

Want to read the study this is based on? Find the free article by searching:

"Comanns, P., Withers, P. C., Esser, F. J., & Baumgartner, W. (2016). Cutaneous water collection by a moisture-harvesting lizard, the thorny devil (*Moloch horridus*). *Journal of Experimental Biology, 219*(21), 3473–3479"

If you think back to lesson 2B, you should remember that six water molecules are produced when one glucose molecule is broken down to produce ATP. Many desert animals have adapted to survive entirely on the water they consume from food and the water produced during aerobic cellular respiration – they never have to drink at all!

Decrease water output

As you learned in lesson 5D, human urine contains urea, other waste products, and water. Desert mammals also urinate, but most excrete concentrated urine which contains very little water. Typically, this is achieved with an extremely long loop of Henle in the nephron. Reptiles and birds use even less water by excreting uric acid with other wastes in a semi-solid state. By excreting highly concentrated wastes, animals conserve water.

Human faeces are approximately 60% water. Unlike humans, desert animals cannot afford to lose water in their faeces. To compensate, desert animals have evolved highly complex digestive systems which absorb the maximum amount of water and nutrients from the food they ingest and the faeces they excrete. Consequently, the faeces of most desert animals have low water content.

Evaporative cooling

Animals release huge amounts of heat via the **evaporation** of water, commonly known as evaporative cooling. Sweating and panting are both examples of evaporative cooling methods. While the evaporation of water is an effective heat loss mechanism, it requires water and may cause dehydration in arid environments.

evaporation the loss of heat via the conversion of water from liquid to gas

Evaporative cooling works because water has a high specific heat capacity and latent heat of vaporisation, which means that it takes a lot of energy to raise the temperature of water and to convert water into water vapour. Evaporative cooling cools you down because the heat from your body is removed when water evaporates.

In environments where the surface air and ground temperature is greater than an animal's skin temperature, the animal will always absorb heat via conduction, convection, and radiation. In this situation, evaporative cooling methods are the most effective method of heat loss. Alternatively, the animal could always move to an area with lower air and ground temperatures and release heat via conduction, convection, radiation, and evaporative cooling methods.

Image: horsemen/Shutterstock.com

Figure 10 Horses and humans both sweat to lose heat via evaporative cooling.

Behavioural adaptations

In the desert there are two general behavioural strategies demonstrated by animals: 1) **evading** or 2) **enduring**. Evaders avoid extreme temperatures and endurers simply endure the harsh conditions. Evaders tend to consist of small to medium-sized animals, whilst endurers are often larger animals like emus or camels.

evaders generally smaller animals that modify their behaviours to avoid extreme temperatures and high internal body temperatures

endurers generally larger animals that do not avoid extreme temperatures

Evading extreme conditions

To avoid extreme temperatures many desert animals seek out shade or retreat to a burrow system. While the air temperature in and out of shade is nearly identical, in the shade you do not absorb heat from solar radiation. Temperatures in burrow systems are less than the temperature outside, and temperatures in the burrow rarely change during the hottest few hours of the day.

Hot and dry deserts have the largest percentage of nocturnal activity of any environment. This behavioural adaptation is beneficial, as temperatures during the night are much lower on average than during the day and water availability is higher.

Enduring extreme conditions

While endurers display greater resistance to environmental warming in high-temperature conditions, they still must release metabolic waste and absorbed heat into the environment in order to survive.

For instance, endurers tend towards inactivity during the hottest periods of the day, reducing detrimental metabolic heat production, and many dig small pits in which they sit down, releasing heat into the cooler soil via conduction. Additionally, while larger endurers are too large to retreat to burrow systems, often they will seek out shade underneath larger trees.

Some animals have evolved behaviours to promote heat loss by the evaporation of water. During the heat of the day, kangaroos lick their arms (Figure 11), and many larger mammals (pigs, buffalo, elephants) wallow in mud or water baths. When the water evaporates from the skin, heat is removed from the body. Furthermore, as wallowing animals use an external source of water for evaporative cooling their water balance remains largely unaffected.

Figure 11 Kangaroos have thick blood vessels below the skin in their forearms. To cool down, they will saturate their arms with saliva, which then evaporates and removes heat.

Theory in context

THE BEHAVIOURS OF THE GREAT DESERT SKINK

The evolution of structural or physiological traits occurs slowly over multiple generations. Therefore, such adaptations rarely help organisms respond to rapidly changing environmental conditions. Behavioural adaptations are less rigid, as an animal may adapt these daily to suit their changing environment.

Moore, Stow, and Kearney (2018) wanted to find out if rapid climate change would threaten the critically endangered great desert skink of central Australia. In their study, they looked at skink behaviour in response to surface temperature. Their results suggested that skinks would increase their activity at dusk, dawn, and night, and retreat to burrow systems whilst reducing their metabolic activity during peak temperatures. The researchers concluded that while the effects of climate change would likely impact species survival indirectly, altering their burrowing, aversion, and foraging behaviours would help the great desert skinks survive.

Image: Inavanhateren/Shutterstock.com

Figure 12 The great desert skink of central Australia adapts to changing temperatures by modifying its behaviours.

Theory in context

DESERT ENDURERS, *CATAGLYPHIS BOMBYCINA*

The general rule of the desert is that small animals avoid the heat, whilst larger animals endure. But every rule has an exception, as shown by the *Cataglyphis bombycina* (Saharan silver ant) of southern Morocco.

These ants brave the biting sun and scorching sands reaching temperatures of over 70 °C during the peak of peak summer. Where most ants would immediately 'cook' upon leaving their nest, *C. bombycina* have evolved a specific set of structural, physiological, and behavioural adaptations enabling them to endure the extreme temperatures. For instance, their legs are longer than those of other ant species which raises their bodies off the ground and their bodies are covered in reflective hairs which reduces heat absorption. They produce heat shock proteins to prevent protein denaturation and promote enzyme reactions at high temperatures, and they climb on sticks when the ground temperatures become too high.

But why have the ants evolved to last in such high temperatures? A review article by Boulay et al. (2017) suggests *C. bombycina* forages at high temperatures to avoid the effects of interspecies competition for resources, and to avoid predation by less thermotolerant vertebrates.

Image: Pavel Krasensky/Shutterstock.com

Figure 13 Saharan silver ants (*C. bombycina*) have numerous structural, physiological, and behavioural adaptations which allow them to deal with temperatures up to 70 °C.

Adapting to the desert: plants 2.2.5.3

OVERVIEW

Plants have a number of common structural and physiological adaptations which allow them to live in the harsh conditions present in the desert.

THEORY DETAILS

In order to survive in hot and dry environments, plants must 1) decrease their heat intake, 2) maximise their water uptake, and 3) minimise their water loss.

Decreasing heat uptake

Plants, like animals, have a temperature tolerance range and maintaining a temperature closest to the optimal is beneficial. In hot environments, this usually requires the plant to limit heat absorption to limit temperature increases. Three common strategies to limit heat absorption include:

- having lightly coloured or reflective leaves (or **photosynthetic organs**)
- producing leaves of smaller surface area
- orienting their leaves vertically to minimise the surface area exposed to the sun.

photosynthetic organs the macro structures that are the site of photosynthesis in plants, including leaves and photosynthetic branches

Figure 14 The saltbush (*Atriplex nummularia*) has white-coloured leaves to minimise heat absorption.

Figure 15 The desert oak (*Allocasuarina decaisneana*) of central Australia has vertically hanging photosynthetic stems. These stems take the place of leaves.

Increasing water uptake

Plants get the vast majority of their water by absorbing water through their roots. Due to the little precipitation in the desert, many long-living desert plants have extensive deep root systems capable of reaching groundwater reserves. Other desert plants spread roots horizontally to absorb the maximum amount of surface water during the brief periods of rain, and store this water for later use.

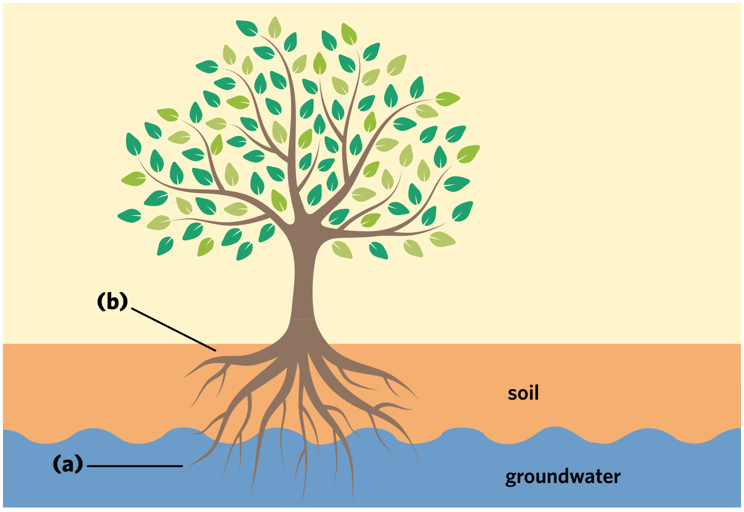


Image: alazur/Shutterstock.com

Figure 16 Many desert plants have **(a)** deep root systems capable of reaching underground water reserves and others **(b)** spread roots horizontally to catch water during infrequent periods of rain.

Water storage

To increase the availability of water, rather than developing highly complex root systems to gain water all year round, some plants collect huge amounts of water during the rainy season and store this water for use in the dry season. For example, baobabs store large reserves of water in a hollow trunk and cacti store water in cells in their stems or underground.

Image: Ragulina/Shutterstock.com

Figure 17 Baobabs store water for use in the drier months of the year.

Minimising water loss

A large part of reducing the rate of water loss to the environment in plants is by reducing the rate of water lost through the **stomata** during the day. Plants can minimise this by reducing their stomatal density, by using sunken stomata that produce pockets of humid air (Figure 18), or by maintaining a humid environment around the leaf by folding or rolling their leaves (Figure 19).

Stomata are regulated by **guard cells**. During the hottest parts of the day, when the water loss to transpiration is highest, the guard cells lose water and turgor pressure within the cell drops. Consequently, the guard cells become flaccid and the stomata close, preventing the exchange of gases with the environment (Figure 20).

stoma (pl. stomata) small pores on the leaf's surface that open and close to regulate gas exchange

guard cell a pair of curved cells that surround a stoma. When hot they lose turgor pressure and become flaccid, closing the stomata to limit water loss

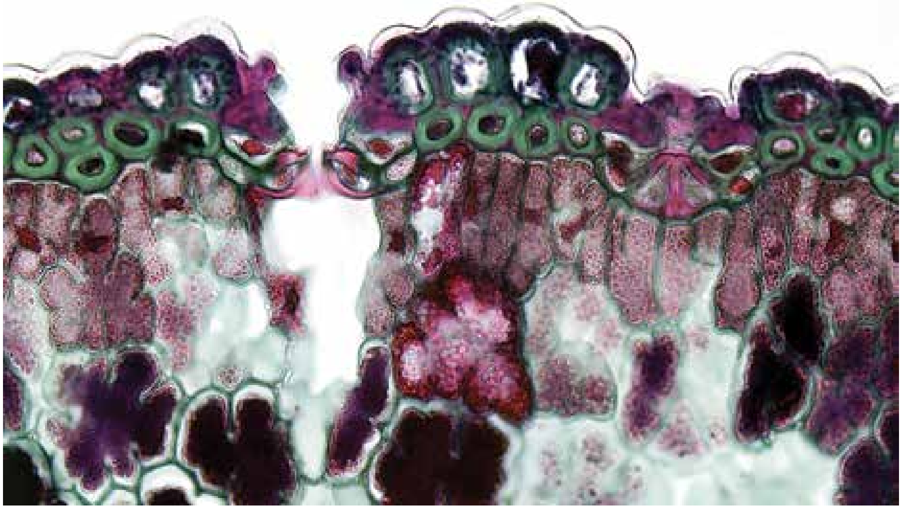


Figure 18 By placing their stomata at the bottom of a pit, plants maintain a humid environment around their stomata which limits the rate of water loss to the environment.

Figure 19 The European marram grass (*Ammophila arenaria*) has rolled leaves to reduce water loss.

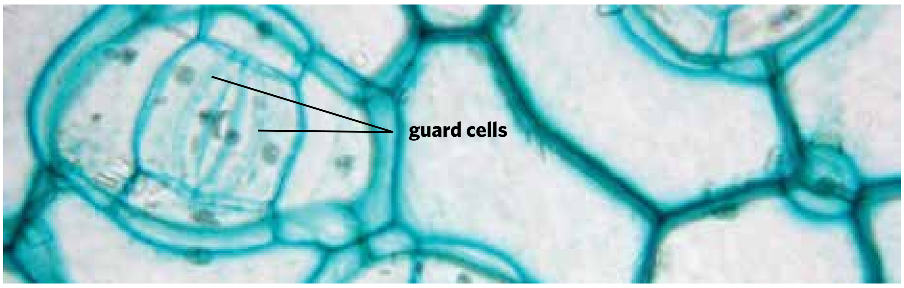


Image: W.Y. Sunshine/Shutterstock.com

Figure 20 An open stomata surrounded by two guard cells. As the guard cells lose water they become flaccid and the stomata will close.

Theory in context

ADAPTATIONS TO FIRE OF EUCALYPTS

Over millions of years, the Australian landscape has become increasingly subjected to fire due to changing climates and human intervention. Eucalypts have developed three general strategies to not only deal with fire but also to directly benefit from it. These strategies are:

- post-fire growth via epicormic buds – these buds are protected by thick layers of bark during fires, and quickly sprout epicormic shoots after a fire. This allows eucalypts to regenerate much quicker after a fire than many competing species.
- post-fire lignotuber growth – lignotubers are masses of high-energy reserves which are found in the roots of many eucalypt species. When the above-ground component of the tree is severely damaged during a fire, sprouts quickly form from the lignotuber, supporting rapid regeneration after a fire.
- post-fire germination – sometimes, intense fires will completely wipe out every plant species in an area. Some eucalypt species have adapted so that their seeds open up and release during intense heat, germinating within days of the fire. As very few other species are growing during this period, the eucalypt seedlings experience very little interspecies competition for resources, which allows the eucalypt species to dominate.

Not only are eucalypts adapted to deal with fire, but their highly flammable barks, leaves, and oils can actually promote the intensity and frequency of fire.

Image: Daria Nipot/Shutterstock.com

Figure 21 Rejuvenation from epicormic shoots

Image: Daria Nipot/Shutterstock.com

Figure 22 Rejuvenation from subterranean lignotubers

Theory summary

The desert is an incredibly tough environment, but many organisms thrive there despite the harshness. These organisms have evolved interesting and efficient structural, physiological, and behavioural adaptations to deal with tough abiotic and biotic influences in the desert.

While the strategies to maintain balance are as numerous as there are desert species, there are common strategies that many animals and plants have adopted.

Table 1 Some structural, physiological, and behavioural adaptations of animals and plants to hot deserts

	Temperature balance	Water balance
Animals		
Structural adaptations	• Insulation techniques • Surface area to volume ratio (SA:V)	• Capillary channels in skin
Physiological adaptations	• Endotherms versus ectotherms • Heat release via dilation of blood vessels and peripheral circulation • Evaporative cooling (e.g. sweating and panting)	• Excretion of concentrated urine • Low water content faeces • Reliance on metabolically produced water
Behavioural adaptations	• Nocturnal behaviours • Endurers versus evaders • Evaporative cooling (e.g. wallowing) • Burrowing	• Nocturnal behaviour • Endurers versus evaders
Plants		
Structural and physiological adaptations	• Light coloured or reflective leaves • Leaves of low surface area • Vertically hanging leaves • Regeneration after fire	• Deep root systems • Water storage mechanisms • Sunken stomata • Rolled and folded leaves • Guard cells and the regulation of stomata

!?

We can release heat into the environment via sweating and flushing but dogs cannot. Instead, they have evolved to use evaporative cooling of their saliva to remove heat from their body. When they are panting very heavily and changing their behaviours to avoid the sun, this is an indication that your dog may be too hot.

This does not mean that you should only invite your dog inside after you notice these traits. Your dog is part of your family, and many people think it should be allowed into the air-conditioned house whenever it wants to come in.

Image: Javier Brosch/Shutterstock.com

10A QUESTIONS

Theory review questions

Question 1

Biotic factors

A are not considered when describing an environment.

B describe the effect of other living things on an individual.

C include only the effects of bacterial, protozoan, and archean life forms.

D describe the effects of temperature, water, and nutrient availability on an organism.

Question 2

A structural adaptation

A refers to evolved changes in the shape and size of an animal to environmental factors.

B can only be an adaptation to abiotic factors and not biotic factors.

C would not describe the thickness of a mammal's fur.

Question 3

Categorise the following as **structural**, **physiological**, or **behavioural** adaptations.

I A modification to red blood cells which enables a resistance to the malarial parasite. __________

II Wombats have evolved long claws which are necessary to dig burrows. __________

III Possums have a fine-tuned flight response, and will often flee at the first sign of danger. __________

IV When hot, many birds will begin to pant, which reduces their temperature via evaporative cooling. __________

Question 4

Which of the following would likely be an advantageous adaptation to a desert environment? (*Select all that apply*)

I a thick layer of insulating fat everywhere on the body

II high metabolic rate

III production of seeds which are susceptible to desiccation

IV production of high concentration urine

V large leaf size with high stomatal density

Question 5

Match the adaptation to the benefit conferred to the organism.

Description of the adaptation

- muscle cells with high mitochondrial counts
- ability to run quickly on two legs over hot sand
- a light-coloured epidermis in a hot and sunny environment
- baring teeth when threatened
- increased number of light-receiving cells in the eye

Benefit conferred to the organism

I __________ improved ability to see in the dark

II __________ increases the proportion of reflected light, reducing heat absorbed by the organism

III __________ enables the animal to undergo physical exertion for long periods of time

IV __________ looks more threatening, warding off potential competitors and predators

V __________ reduces the total time and surface area in contact with hot sand, reducing the heat absorbed and chance of being burnt

SAC skills questions

Case study analysis

Use the following information to answer Questions 6–13.

Woolly monkeys (*Lagothrix* spp.), endemic to the Amazon, are one of the many primate species at risk of extinction. Threats include declining habitat ranges, hunting, and black-market trading.

Conservation organisations are working on rehabilitation programs to re-establish woolly monkey populations where they have previously become extinct. However, this intervention may not save woolly monkeys, as only 26% of reintroduction programs worldwide successfully establish self-sustaining populations (Fischer & Lindenmayer, 2000).

This low success rate is attributed to living conditions that rarely reflect the wilderness. Animals raised in these programs lack the set of skills and knowledge necessary for survival outside of rehabilitation, and instead develop behaviours that help them survive whilst in captivity. These behaviours that make their transition back to life in the wild less successful are known as maladaptive behaviours. When released, monkeys raised in captivity spend more time on the ground, seem unable to recognise food in the wild, and lack fear aversion to humans.

Image: Edwin Butter/Shutterstock

One conservation company placed captive woolly monkeys in enclosures that more closely reflected their native habitat for a period of six months, whilst under constant medical supervision and care to ensure proper health. After the training period, six of the 11 monkeys were released into the Huila nature reserve. Two were recaptured, two went missing, and two died. Perhaps a cold climate and difficulty feeding contributed to the lacklustre results? Researchers stress that more work is required before populations can be established.

Question 6

A successful reintroduction means that

A a self-sustaining population has been established in the area.

B released individuals can feed themselves in the wild.

C all members are still alive after six months.

Question 7

The text suggests that the low success rate of reintroduction attempts is caused by

A the release of small animal populations.

B animals lacking key knowledge and skills.

C prevalent genetic diseases in released individuals.

Question 8

Researchers noted multiple maladaptive behaviours. Which of the following is not a maladaptive behaviour described in the text?

A lack of learned fear response when seeing humans

B inability to recognise potential food sources

C lack of social grooming practices

D reduction of time spent in trees

Question 9

Abiotic influences in the Huila nature reserve could include

A the cold temperatures, low fruit availability, and competition for resources.

B arid conditions, hot temperatures, and consistently high rainfall.

C high rainfall, low temperatures, and plentiful sunlight.

Question 10

Which of the following could not be a physical adaptation of the woolly monkey?

A thick fur to deal with cold temperatures

B long fingers and a prehensile tail for an arboreal lifestyle

C monkeys grooming each other to remove parasites such as ticks

D large, forward-facing eyes to help them judge distances with ease

Question 11

Researchers suggest that woolly monkeys kept in captivity stop displaying behaviours that help them survive in the wild. Researchers believe that these behaviours

A are encoded within the genome, and that monkeys in captivity have lost the genes that encode these behaviours.

B have not been forgotten, the monkeys will simply start these behaviours again following their release.

C are not necessary for the monkeys in captivity, as their life is relatively easy.

D can only be learned from the parents of the monkey.

Question 12

Eleven monkeys received the training but only six were released. What is the most likely reason for the conservationists not releasing all 11 of the monkeys?

A Five of the monkeys had not learned enough of the skills required for survival during the training.

B Woolly monkey population sizes of more than four individuals have far lower rates of survival.

C Five of the monkeys died during the six-month training course.

Question 13

To increase the chances of reintroduction success, the conservationists could

A improve upon the training process by using capable woolly monkeys to teach the captive individuals.

B give the monkeys jackets before they release them into the environment.

C introduce the monkeys into colder areas outside their native range.

Exam-style questions

Within lesson

Question 14 (1 MARK)

Susan was attempting to characterise the environmental conditions which may affect amphibians living in a tropical rainforest. She identified high humidity as a potential influence.

High humidity is

A a biotic influence.

B an abiotic influence.

C a symbiotic influence.

D an aerobiotic influence.

Question 15 (1 MARK)

The following picture is of a bearded dragon native to Australia's deserts.

Image: Robert Eastman/Shutterstock.com

Which of the following provides the strongest evidence that the bearded dragon is adapted to a hot and arid environment?

A a spiky epidermis

B sharp claws on toes

C light coloured scales

D a frill that makes the lizard appear larger

Use the following information to answer Questions 16–18.

The wet tropics of Northern Queensland were added to the international list of World Heritage sites in 1988. Some of the reasons given for its addition is that the tropics possess immense intrinsic natural beauty, are one of the most biodiverse sites in all of Australia, and host many ancient plant species that exist nowhere else on the continent. While covering only 0.2% of Australia's total area, the wet tropics host 30% of all native frog species, 30% of the marsupial species, 60% of bat species, and 65% of the native fern species.

Image: Dan Campbell/Shutterstock.com

Dendrocnide moroides (known locally as the Gympie-Gympie) is one of the many plant species endemic to the wet tropics of Northern Queensland. *D. moroides* grow in the dense rainforest underbrush with little to no direct sunlight and are known for causing excruciating pain when touched by humans.

Question 16 (1 MARK)

Which of the following supports the idea that the wet tropics have remained relatively unchanged for millions of years?

A The wet tropics cover only 0.2% of the total landmass of Australia.

B 65% of all of Australia's native fern species are found in the wet tropics.

C Many people consider the wet tropics to possess an immense intrinsic beauty.

D Previously widespread ancient plant species have flourished in the wet tropics whilst they have died out in all other parts of the continent.

Question 17 (1 MARK)

The leaves of *D. moroides* are covered in tiny hairs filled with a powerful and painful toxin. These hairs embed themselves into the skin and break off, and have been known to cause pain for years after the initial injection.

The production of the toxin to cause pain is

A a structural adaptation.

B a behavioural adaptation.

C a physiological adaptation.

D not an adaptation to the environment.

Question 18 (1 MARK)

The leaves of *D. moroides* can grow up to 50 cm wide. The large leaves are most likely an adaptation to

A increase the surface area of the leaves to maximise the amount of light absorbed for photosynthesis.

B maximise the surface area to volume ratio to increase heat dissipation to the environment.

C provide a good food resource for the herbivore species of the wet tropics.

D increase the amount of water that can be released to the environment.

Multiple lessons

Question 19 (6 MARKS)

A study was carried out comparing camels, cattle, and sheep. The average amount of body water the mammals lost per day when the temperature was 42 °C was calculated.

Mammal	Body water lost each day (%)
camel	1–2
cattle	7–8
sheep	4–6

a Using the information given, explain which animal will survive for the least amount of time in a hot, dry environment. (1 MARK)

Adapted from VCAA 2005 Exam 1 Section B Q8a

b Some of the water loss experienced by the mammals was due to evaporative cooling. Identify two ways the mammals may behave to reduce the amount of water lost in evaporation. (2 MARKS)

Adapted from VCAA 2003 Exam 1 Section B Q4bi

c Describe a structural adaptation in the kidney that has taken place in species that live in dry environments, and explain how this helps them survive in these environments. (2 MARKS)

Adapted from VCAA 2005 Exam 1 Section B Q8d

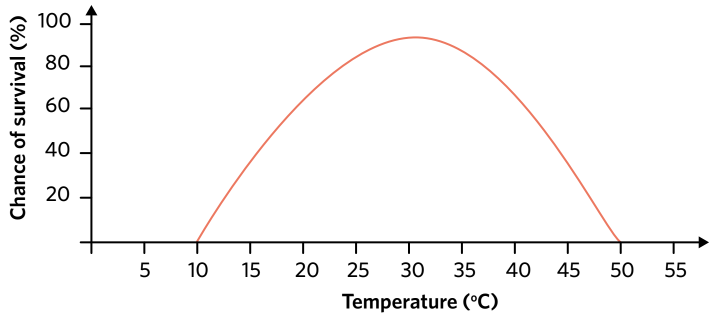
d Temperature is an abiotic factor that impacts organisms. Describe what is meant by the term ‘abiotic’. (1 MARK)

Adapted from VCAA 2005 Exam 1 Section B Q8

Key science skills and ethical understanding

Use the following information to answer Questions 20 and 21.

The graph shows the rate of survival for members of species X at different environmental temperatures.



Question 20 (1 MARK)

The graph shows

A the tolerance range for species X over different environmental temperatures.

B the chance of species X survival as water availability is altered.

C the effect of body temperature on survival in species X.

D enzyme denaturation over a temperature gradient.

Question 21 (1 MARK)

Species X has a 40% survival rate at which temperature(s)?

A 60 °C

B 40 °C

C 15 °C and 45 °C

D 20 °C and 40 °C

Question 22 (9 MARKS)

The rate of heat loss from a body can be described by the heat loss equation, $H = kA(T_s - T_a)$, where:

- H – heat loss over skin (J/s)
- k – cooling constant (J/s/°C/m^2)
- A – skin surface area (m^2)
- T_s – skin temperature (°C)
- T_a – air temperature (°C).

Assume k is always positive.

a How does the rate of heat loss over the skin change with skin surface area? (1 MARK)

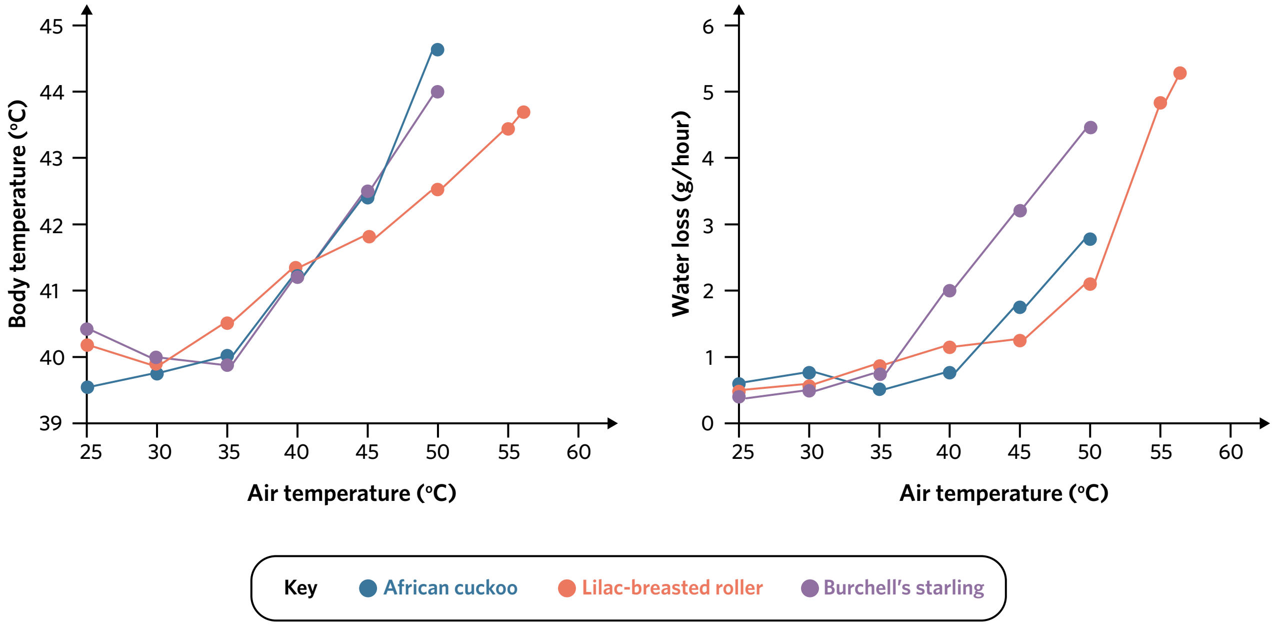
b In desert environments, the surface air temperature can exceed the skin temperature of many desert-dwelling inhabitants.

  i Using the heat loss equation, explain the effect of an air temperature that is greater than the skin temperature of an animal. (1 MARK)

  ii How might an animal modify its behaviour in response to excessive surface air temperatures? (1 MARK)

c In dry conditions where the air temperature exceeds skin temperatures, the most effective method for heat loss is evaporative cooling.

To test temperature regulation in birds that are adapted to the desert, scientists exposed multiple bird species to air temperatures greater than the critical internal body temperatures for each particular species. The results of the experiment are shown in the two graphs.



Source: adapted from Smit et al. (2018).

i Using one ethical principle, describe any potential issues with the scientists' methodology. (2 MARKS)

ii Which species had the highest internal body temperature, and at what air temperature did this occur? (1 MARK)

iii Which species is able to tolerate the greatest air temperature? (1 MARK)

iv Explain why evaporative heat loss is such an effective heat loss mechanism. (2 MARKS)

10B ADAPTATIONS FOR COLD ENVIRONMENTS

*In most cases when the water inside an animal freezes, that's the last we hear of that animal. However, this rule does not apply to the wood frog (*Lithobates sylvaticus*) of North America. Research suggests that these frogs can survive multiple days exposed to –6 °C in laboratory conditions, and up to seven months at –18 °C in the wild. Even when up to 65% of the water in their body freezes, the frogs are able to survive and thaw out once conditions become warmer whilst remaining completely unharmed. How exactly are these amphibians able to survive such cold conditions, even when the water inside their body literally freezes?*

Image: Viktor Loki/Shutterstock.com

Lesson 10B

In this lesson you will learn about how some organisms have developed a set of structural, physiological, and behavioural adaptations to help them survive in cold environments.

◀ Prerequisite knowledge

Years 7–10
Natural selection acts on the phenotype of an organism so that individuals with beneficial adaptations are fitter and have more offspring.

Chapter 6
Organisms have evolved a variety of thermoregulatory mechanisms to maintain homeostasis in cold environments.

Lesson 10A
Many of the adaptations to release heat in hot and dry environments are modified to conserve heat in cold environments.

Future applications ▶

Year 12
We can determine the genes which convey a phenotypical advantage in one species and, using genetic engineering technologies such as CRISPR, insert these genes into another species to convey the same phenotypic advantage.

Year 12
Hot environments can act as a selection pressure that leads to changes in allele frequencies of a population.

Study design dot point

- structural, physiological, and behavioural adaptations that enhance an organism's survival and enable life to exist in a wide range of environments

Key knowledge units

The challenges of cold environments	2.2.5.4
Adapting to the cold: animals	2.2.5.5
Adapting to the cold: plants	2.2.5.6

The challenges of cold environments 2.2.5.4

OVERVIEW

The most influential abiotic factor in a cold environment is extremely low temperatures. To help survive in their environment, animals have evolved sets of structural, physiological, and behavioural adaptations, whereas plants have only evolved structural and physiological adaptations.

THEORY DETAILS

Many environments experience freezing conditions for part of or all of the year. Even in Australia, a relatively hot continent, temperatures in our Alpine regions can reach −23 °C. Much like the hot deserts explored in the previous lesson, cold environments are exceedingly complex and can be characterised by their **abiotic** and **biotic** factors. The most influential factors impacting organisms in cold environments include:

- low temperature – at low temperatures the reactions required for life slow down or stop. Additionally, water may freeze cell contents and rupture cells.
- piercing winds – high winds can exert strong pressures and forces on plants, and can dramatically increase the heat lost by an organism.
- low availability of nutrients – plants absorb nutrients from the soil, and use nutrients as the building blocks of macromolecules such as proteins. A lack of nutrients restricts macromolecule synthesis and overall growth rate.
- precipitation as snow – snow falling instead of rain, and surface water freezing in sub-zero temperatures, make it difficult for organisms to obtain the liquid water required for their survival.

Again, much like in deserts, we will explore the set of evolved adaptations in plants and animals in response to these four abiotic factors. When considering these adaptations, notice that most fall into one of two categories: **structural** or **physiological adaptations**. Additionally, animals often possess **behavioural adaptations** that enable them.

abiotic factor a property of the environment relating to non-living things. Examples include temperature, nutrient availability, and water availability

biotic factor a property of the environment relating to living things. Examples include predator-prey relationships, competition, and symbiotic relationships

structural adaptation evolved modifications to an organism's physical structure

physiological adaptation evolved modifications to an organism's internal functioning or metabolic processes

behavioural adaptation evolved modifications to an organism's actions

Adapting to the cold: animals 2.2.5.5

OVERVIEW

Animals have evolved a set of structural, physiological, and behavioural modifications to deal with cold-temperature environments.

THEORY DETAILS

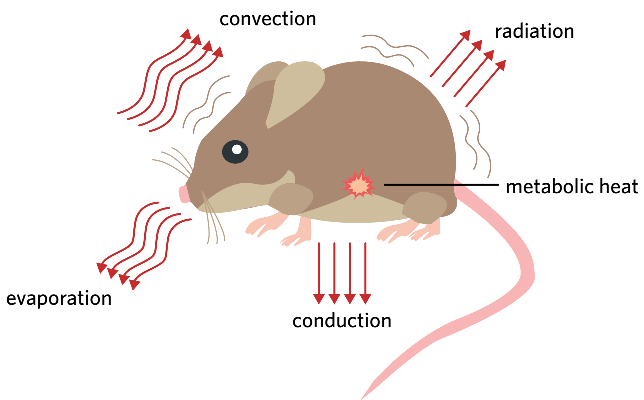


Figure 1 It's just as important to maintain a temperature balance in a cold environment as it is in the desert. In cold environments, organisms evolve adaptations to minimise heat loss via convection, radiation, evaporation, and conduction, and to maximise heat gain.

Structural adaptations

Animals living in cold environments can have a similar set of structural adaptations to those we observe in desert environments, only now animals are trying to conserve heat rather than release it into the environment.

Insulation

In cold environments, you will often find animals that have a thick insulating layer covering their entire body. Such insulation is usually composed of thick fur, plumage, or subdermal fat to provide maximum protection against heat release into the environment.

Surface area to volume ratio

An animal's surface area to volume ratio can severely impact the rate of heat transfer both into and out of a body. By reducing their surface area to volume ratio, an animal will release heat slowly, increasing the time it takes for body temperature to drop. In cold environments, the more you resemble a sphere (the object with the lowest SA:V ratio), the easier it is to maintain a constant body temperature in a cold environment.

Image: Mikhail Cheremkin/Shutterstock.com

Figure 2 The walrus has a thick layer of insulating fat and a low surface area to volume ratio, reducing unnecessary heat loss in both the aquatic and terrestrial environments.

Image: Studio Romantic/Shutterstock.com

Figure 3 Which of these two do you think would survive out in the cold for longer? Consider both SA:V and insulation.

Physiological adaptations

Endotherms versus ectotherms

We tend to find a greater proportion of endotherms, rather than ectotherms, in cold environments. This is because animals cannot obtain heat (e.g. via convection, conduction, etc.) from an environment with a lower temperature than their body, so maintaining a stable body temperature via internal metabolic processes is typically advantageous. Given that the body temperature of ectotherms generally matches that of the ambient temperature, cold-adapted ectotherms must be able to tolerate extremely low temperatures.

Many cold-adapted animals will burrow underground during the coldest months of the year, where the temperature remains just above freezing. Once the temperature rises during the summer, these animals will return to the surface to feed and breed.

Torpor

In lesson 10A, you learned about one kind of **torpor**, aestivation. There are actually two other kinds of torpor, **hibernation** (in endotherms) and **brumation** (in ectotherms), both of which are triggered by seasonal drops in temperature. Hibernation and brumation help an animal survive extended periods in a state of low metabolic activity and body temperature. A state of torpor is beneficial as the reduction in metabolic rate allows the animal to survive on very little food or water, and remaining inactive in shelter allows animals to avoid harsh weather.

torpor a physiological state in which the metabolism of an animal is reduced to conserve energy

hibernation prolonged torpor in response to seasonal cold conditions. Occurs in endotherms such as mammals and birds

brumation prolonged torpor in response to seasonal cold conditions. Occurs in ectotherms such as snakes and lizards

Theory in context

PYGMY POSSUMS AND THE AUSTRALIAN ALPS

The mountain pygmy possum (*Burramys parvus*) is a tiny marsupial, on average weighing only 40 g, and is the only marsupial restricted entirely to the alpine and subalpine regions of south-eastern Australia. The mountain pygmy possum is one of Australia's only hibernating marsupials, and they are able to subject themselves to seven months of yearly torpor.

During hibernation, mountain pygmy possums burrow beneath a thick layer of insulating snow. In this state their resting metabolic rate drops drastically and their internal body temperature is able to fall as low as 2 °C without causing damage. Once the environmental temperature begins to rise in early spring, the mountain pygmy possum will resurface to feed and breed.

The species was known only from fossils and was believed to be extinct until a live individual was discovered on Mount Hotham, Victoria in 1966. Considered critically endangered, only 2 000 of these possums are left in the wild. Challenges faced by the mountain pygmy possum include decreasing habitat ranges due to ski resort construction, global rising temperatures, invasive predators, and a dwindling supply of the possum's favourite food source, the bogong moth.

Image: Gwoeii/Shutterstock.com

Figure 4 The mountain pygmy possum, one of Australia's most critically endangered species

Circulation

As you learned in lesson 10A, the circulatory system can support a massive amount of heat loss into a desert environment through vasodilation. In a cold environment the circulatory system is equally critical, only here, adaptations to the circulatory system conserve heat rather than releasing it. As blood is pumped out of the heart it is the same temperature as the animal's core body temperature. If blood of this temperature were to circulate to the peripheries, the temperature gradient between the body and the environment would be quite large, causing lots of heat to be lost. There are two main ways to prevent heat loss from blood: vasoconstriction and countercurrent circulation.

The opposite of vasodilation, **vasoconstriction**, occurs when the diameter of small blood vessels in the skin and overall blood flow is reduced. When many animals are required to conserve heat, the body sends signals to constrict these blood vessels and heat loss is minimised (Figure 5).

vasoconstriction the narrowing of blood vessels

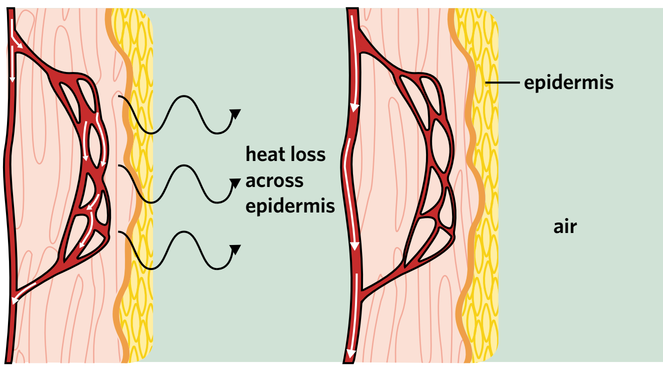


Figure 5 Animals can conserve heat by the vasoconstriction of superficial blood vessels.

Countercurrent circulation techniques use the heat in blood travelling from the heart to heat cool blood returning from the animal's periphery, meaning that the core body temperature is not lowered. Additionally, this cools the blood heading towards the **periphery**, so the temperature gradient between the periphery and the environment is reduced and less heat is released to the environment (Figure 6). The combination of both of these effects means that countercurrent circulation makes it much easier to maintain a stable core body temperature.

countercurrent circulation an efficient heat transfer method where separate components of the circulatory system flow next to each other in opposite directions. Used to cool blood heading to the outer surface and heat blood heading back to the body's core

periphery the outside surface or boundary of a structure. In an animal, the peripherals refer to structures such as the arms, legs, or skin

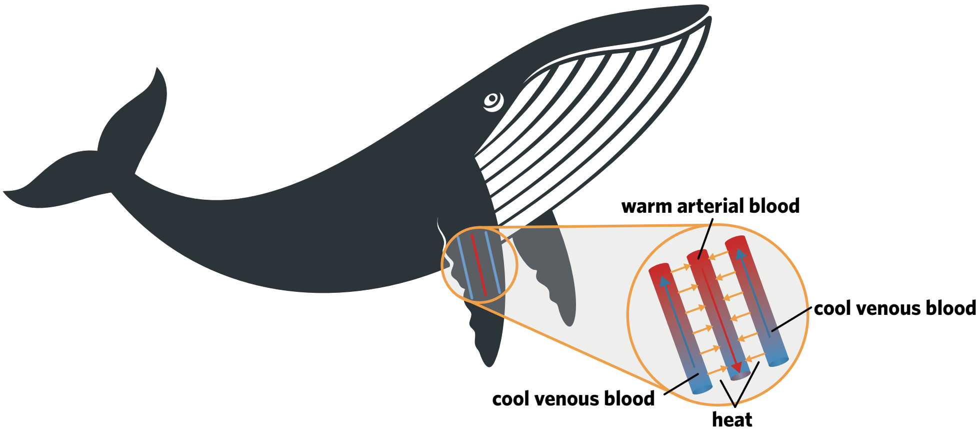


Image: Oleg7799/Shutterstock.com

Figure 6 Marine mammals (such as humpback whales) have evolved countercurrent heat exchange mechanisms to reduce heat loss to the environment and maintain a stable core body temperature.

Lesson link

In ***lesson 6B*** you learned that in response to the cold, humans will shiver to generate heat. Shivering to generate heat is a trait shared by most endothermic animals, and is considered a physiological adaptation as it's initiated after a stimulus-response pathway without any behavioural input.

Behavioural

Reducing exposed surface area

Objects with lower surface area to volume ratios release less heat, so many animals will reduce their surface area to volume ratio by hiding or protecting their peripherals as temperatures drop. For instance, in response to the cold many mammals will curl up, and birds may stand on only one leg (Figure 7).

Image: Diana Leadbetter/Shutterstock.com

Figure 7 As their legs have little insulation, birds often stand on only one leg to conserve heat.

Huddling

You've probably seen emperor penguins huddling during the Antarctic winter, where the temperatures often reach as low as –40 °C. By huddling, animals artificially decrease their individual surface area to volume ratio, decreasing the amount of heat released by the emperor penguin colony into the environment.

Figure 8 By huddling, emperor penguins reduce their individual exposed surface area, lowering the average amount of heat lost per penguin in the huddle.

Seeking shelter

Critically low temperatures and wind chill can quickly drop body temperature, causing permanent damage or even death. By seeking shelter, animals can surround themselves in a stable microclimate with little or no wind and more forgiving temperatures. Animal shelters typically include underground burrows, dens, or rocky outcrops.

Image: Elena Birkina/Shutterstock.com

Figure 9 Polar bear cub leaving its den in the snow after hibernating for the winter.

Migrating to a warmer climate

During warmer summer months, alpine regions bloom into areas that are rich in biodiversity and resources. During winter, however, these same areas are often covered in a thick layer of snow, making it difficult to access food and water. Rather than adapt to the cold, many animals will simply **migrate** to a lower altitude or more moderate latitudes where resources are more readily available. Warmer climates are also typically easier for breeding and raising newborns.

migration the seasonal movement of animals from one area to another

Image: Paul S. Wolf/Shutterstock.com

Figure 10 Humpback whales spend their entire lives migrating around the world to avoid low temperatures, track food sources, and to mate and give birth.

Adapting to the cold: plants 2.2.5.6

OVERVIEW

Plants have a number of common structural and physiological adaptations which allow them to live in the harsh conditions present in a cold climate.

THEORY DETAILS

Visualising the problem: tree lines

Freezing presents a large and very real stress for alpine and cold-adapted plants, where the barrier between tolerable and intolerable temperatures can be drastic. If you need proof of this, look at the tree lines in Figures 11 and 12. Low temperatures are the major cause of tree lines, although precipitation, wind, and nutrient availability can also play a role.

Lesson link

In ***lesson 5B*** you learned about the transport of water from the roots to the leaves via the xylem, and the transport of nutrients around a plant via the phloem. Both of these systems rely on water and, if that water freezes, neither system can function. This is part of the reason why we observe tree lines over a temperature gradient.

Figure 11 Above this tree line in the Tararua Ranges of New Zealand, the temperature is too low to support large tree growth.

Figure 12 In cold air drainage valleys, the temperature on the valley floor can be too low to support large tree growth, making an inverted tree line on the valley floor.

Freezing presents a problem for a number of reasons. One is that the enzyme and protein-driven reactions progress slowly at lower temperatures. Additionally, the formation of ice crystals within the cell can rupture cell membranes and other cell contents, and the vascular system of plants cannot transport nutrients when blocked by ice.

How to prevent freezing

At low temperatures, cell membrane fluidity decreases, which can quickly lead to disruption of the lipid bilayer, decreased membrane protein effectiveness, and cell contents leaking out. To deal with this, many cold-adapted plants modify the lipid and chemical composition of their cell membranes to increase their functioning in low temperatures.

The freezing point of distilled water is 0 °C. As the concentration of solutes increases, the lower the freezing point becomes. Plants use this phenomenon to their advantage. When the temperature drops, plant cells receive signals to increase the concentration of solutes such as glucose in their cells, which increases a plant cell's resistance to freezing.

In addition, particular cold-adapted plants can produce antifreeze proteins in response to cold temperatures. These proteins disrupt the formation of ice crystals within the cell, enabling water to remain liquid at lower temperatures.

Theory in action

WHY DOES INCREASING THE SOLUTE CONCENTRATION IN WATER DECREASE ITS FREEZING POINT?

Materials

- Ice cubes
- Table salt (NaCl)

Method

1. Freeze two ice cubes.
2. Pour table salt on the first ice cube.
3. Leave the second ice cube alone.
4. Observe the ice cubes for 5 minutes.

Questions

1. Describe what happened to the two ice cubes.
2. What was the point of the second ice cube?

Explanation

When water drops in temperature, individual water molecules lose kinetic energy (or heat), and they begin to condense into a solid lattice structure, or ice. The solid lattice gives ice its rigid feel and appearance (Figure 13a). When you pour salt on the ice, the salt dissolves and individual Na^+ and Cl^- ions begin to disrupt this lattice structure, and ice becomes liquid water again (Figure 13b). The chemistry term used to describe the lowering of freezing temperature due to the addition of solutes is 'freezing point depression'. This is why salt is used to de-ice roads in winter.

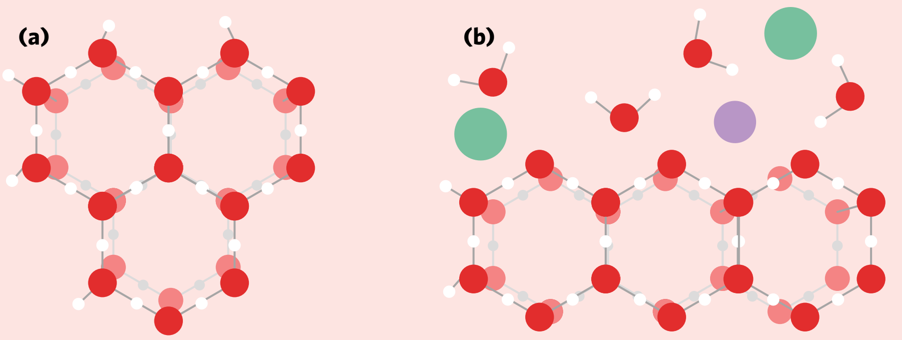


Figure 13 When **(a)** frozen water molecules arrange themselves in a solid lattice structure they form ice. Dissolved solutes **(b)** disrupt this lattice structure, lowering the freezing point of water.

Deciduous trees

A deciduous tree is a tree that seasonally drops all of its leaves at once to avoid harsh conditions. While there are some drought-adapted trees that drop their leaves due to excessive water loss during hot and dry periods, the most common and recognisable deciduous trees are cold-adapted. When compared to evergreen trees, cold-adapted deciduous trees have several advantages:

- Deciduous trees avoid frozen leaf tissue during winter.
- Deciduous trees require less energy and water to survive during winter months.
- Deciduous trees experience less branch breakage during periods of heavy snowfall and strong winds.

Figure 14 By dropping all their leaves in winter, deciduous trees are able to avoid damage to leaf tissue, conserve energy and water, and avoid branch breakage due to snowfall and wind.

Seed dormancy

A dormant seed is one that is unable to germinate during a specific time under certain environmental conditions. Seed dormancy is a trait of many cold-adapted plants, where seeds will be dispersed before the winter months, and then remain dormant until warmer spring weather. When the seeds detect increases in temperature or light availability, they quickly sprout and grow during the favourable living conditions of the summer months.

Theory in context

CUSHION PLANTS

Many alpine regions appear little more than barren rocky outcrops, littered here or there with a few round 'cushions' of grass. However, these little cushions, known as cushion plants, are far more complex and interesting than you might initially expect.

Each individual cushion plant is often a tight knit community of similar, yet completely individual, species. These species work together to form a complex net facing outwards towards the environment, reducing the exposed surface area of individual leaves and providing resistance to wind and snow. The cushion plant has a hollow interior which is separated from the harsh environment and warmed by the metabolic activities and stored heat of the plant, providing resilience to freezing.

Figure 15 From afar, **(a)** you might mistake cushion plants for regular moss but upon closer inspection you would realise **(b)** that each plant is actually a tight knit community of many different species. Both pictures show cushion plant communities found near Cradle mountain, Tasmania.

Theory in context

ANTIFREEZE PROTEINS IN PLANTS AND FISH

Plants can prevent freezing by producing antifreeze proteins, but did you know that some fish can do the same thing?

Because of their high salt content, oceans of the Antarctic remain liquid at down to −1.9°C. But these waters are still populated by ectothermic fish, such as the notothenioids, whose bodies resist freezing in the frigid conditions. They do this by producing similar antifreeze proteins as plants, preventing the formation of large ice crystals in the body.

These antifreeze proteins are limited not only to plants and animals, however, and similar proteins have been found in every other kingdom of life.

Figure 16 The emerald rockcod (*Trematomus bernacchii*)

Theory summary

A cold environment poses just as many challenges as a hot one, but many organisms thrive there despite the harshness. These organisms have evolved interesting and efficient structural, physiological, and behavioural adaptations to deal with tough and unique abiotic challenges associated with a cold environment.

While the strategies to maintain balance are as numerous as there are cold-adapted species, there are common strategies that many animals and plants have adopted.

Table 1 Some structural, physiological, and behavioural adaptations of animals and plants to survive in cold environments

Animals	
Structural adaptations	• Insulation techniques • Decreased surface area to volume ratio (SA:V)
Physiological adaptations	• Endotherms versus ectotherms • Vasoconstriction of peripheral blood vessels • Countercurrent circulation • Torpor • Antifreeze proteins
Behavioural adaptations	• Reducing exposed surface area • Huddling • Seeking shelter • Migration
Plants	
Structural and physiological adaptations	• Modifications to the cell membrane • Increasing solute concentration (freezing point depression) • Seed dormancy • Antifreeze proteins

Even though 65% of the water in the wood frog (Lithobates sylvaticus) *freezes, it's all about* where the water freezes, *not* how much water freezes. *When wood frogs sense steep temperature drops they accumulate urea and glucose inside their cells to concentrations much greater than normal conditions. They also begin producing specific antifreeze proteins that accumulate within their cells. This massively reduces the freezing temperature due to freezing point depression, ensuring that intracellular tissue remains liquid at low temperatures. However, the concentration of urea and glucose in the extracellular liquid is not greatly increased and while these fluids may freeze, ice crystals in these regions do relatively little damage. When the environmental temperatures rise naturally, this extracellular fluid unfreezes and the frog can get back to its business.*

10B QUESTIONS

Theory review questions

Question 1

Fill in the blanks in the following sentences.

All environments can be described by their __________ factors (the living properties of the environment) and __________ factors (the non-living properties of the environment). Alpine environments generally have __________ temperatures and nutrient availability, and __________ wind and snow pressures.

Question 2

A lower SA:V in a cold environment would

A increase heat released to the environment.

B decrease heat released to the environment.

Question 3

An animal curling up to reduce its exposed surface area is an example of a

A physiological adaptation.

B behavioural adaptation.

C structural adaptation.

Question 4

An adaptation of plants to cold environments includes

A the production of antifreeze proteins which increases the freezing point of water.

B the production of seeds which sprout only during warmer months.

C decreasing the concentration of solutes in the cytosol.

Question 5

Match the adaptation to the benefit conferred to the organism.

Description of the adaptation		Benefit conferred to the organism
• thick layer of insulating fat and fur over the entire body	**I** __________	reduces the energy requirements of the animal enabling it to survive for long periods of time with little food
• entering into a state of low metabolic activity and body temperature	**II** __________	lowers the freezing temperature of water, preventing the formation of ice crystals
• increased concentrations of dissolved cellular solutes	**III** __________	reduces the amount of heat lost over the skin due to conduction and convection
• countercurrent blood circulation in the periphery	**IV** __________	reduces heat released by reducing the temperature gradient between an organism and the environment

SAC skills questions

Data analysis

Use the following information to answer Questions 6–14.

Despite being economically, socially, and ecologically critical, the alpine ecological communities of south-eastern Australia are barely understood. What is known, however, suggests that species diversity and ecological composition vary across an altitudinal gradient.

A group of intrepid young researchers performed a study exploring which environmental factors influence the overall rate of growth within particular areas. Using a quadrat sampling technique, the group surveyed three sites at every 100 m altitude interval up Mount Kosciuszko, beginning at 1 500 m and ending at 2 100 m, stopping short of the peak at 2 228 m. At each site, they estimated aboveground biomass within the quadrat and, using climate data, they were able to estimate the average daily temperature for each altitude during the month of May. The students were able to construct a graph showing all their recorded data.

Over the course of the 600 m climb each member of the group found that the *Eucalyptus pauciflora* dominated woodland slowly gave way to herbfield and heathland.

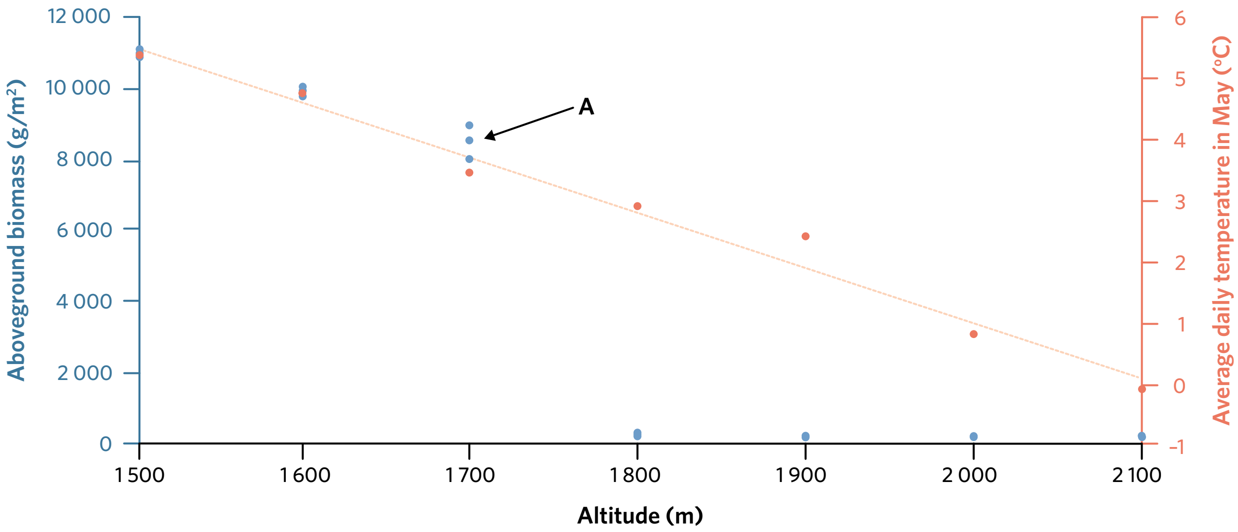


Figure 1 The summit of Mount Kosciuszko

Image: metriognome/Shutterstock.com

Figure 2 Environment at an unknown altitude

Figure 3 Environment at an unknown altitude

Question 6

What units did the scientists use to measure the aboveground biomass at each site?

A kg

B gm^{-2}

C g/mm^2

Question 7

At each altitude whilst in the field, the scientists

A surveyed three individual sites.

B measured five different variables.

C recorded the average daily temperature for the month of May.

Question 8

The datapoint marked 'A' on the graph represents

A the temperature at one of the sites at 1 700 m.

B the aboveground biomass found in a single quadrat.

C the average biomass per m^2 at an altitude of 1 700 m.

Question 9

Which statement is supported by trends observed in the data?

A A decrease in the aboveground biomass per site causes a drop in temperature.

B As the altitude increases, the aboveground biomass per site decreases.

C The aboveground biomass decreases linearly as altitude increases.

Question 10

At an altitude of 1 900 m, you would expect to find an ecological community most closely resembling

A Figure 2.

B Figure 3.

Question 11

The scientists were planning on surveying another site at an altitude of 2 050 m. What average daily temperature would the scientists expect the site to have?

A 170 gm^{-2}

B 140 gm^{-2}

C 1.0 °C

D 0.6 °C

Question 12

Another group of scientists set up a temperature recording station at an unknown altitude on the same mountain. They found that the site experiences an average daily temperature of 3.8 °C in the month of May. The scientists would expect that site would be located at an altitude between

A 1 500–1 600 m.

B 1 600–1 700 m.

C 8 000–9 000 gm^{-2}.

D 9 000–11 000 gm^{-2}.

Question 13

The trend in aboveground biomass observed between 1 700–1 800 m could best be explained by

A a change in species composition at the tree line.

B random error in experimental sampling procedure.

C small scale bushfires reducing aboveground biomass in each site.

Question 14

Which of the following conclusions is supported by the data?

A Temperature alone is the major determining factor in aboveground biomass growth.

B Species diversity decreases as the altitude increases.

C Vascular plant growth is not possible above 1 800 m.

D Aboveground biomass increases at lower altitudes.

Exam-style questions

Within lesson

Question 15 (1 MARK)

An abiotic factor in an alpine region during winter would include

A low competition for resources.

B strong predation by wolves.

C high temperatures.

D strong winds.

Question 16 (1 MARK)

Which of the following is not an advantage of torpor?

A Torpor allows an animal to avoid harsh conditions for long periods of time.

B Torpor lowers an animal's metabolic rate, meaning it requires less food for survival.

C Torpor increases the allocation of resources to insulation, meaning an animal will lose heat slower.

D Torpor enables an animal to lower its body temperature, reducing the energy required to maintain its body temperature.

Question 17 (1 MARK)

Mammals that live in very cold environments have evolved behavioural adaptations that help reduce the rate at which they lose heat.

One behavioural adaptation in a cold environment would be

A laying out flat in the snow.

B digging a burrow into the snow.

C having a thick layer of insulating fat.

D eating large amounts of snow for hydration.

Adapted from VCAA 2005 Exam 1 Section A Q24

Question 18 (1 MARK)

Many organisms live in conditions that would be considered 'extreme' for humans, and consequently they have been dubbed 'extremophiles'. The archaea *Acidianus brierleyi* thrives in highly acidic sulfur pits, with pH levels falling as low as 1.5. The most likely reason that the archaea are able to carry out their metabolic functions in this environment is that the archaea

A release a base which increases the overall pH of the sulfur pit.

B use enzymes with a high tolerance to acidic conditions.

C express proteins that only function at high pH.

D have a high species rate of replication.

Adapted from VCAA 2006 Exam 1 Section A Q19

Multiple lessons

Question 19 (1 MARK)

Many endotherms (including humans) shiver as a thermoregulatory mechanism. By shivering, muscles all around the body produce heat, raising the animal's metabolism and increasing internal body temperature.

Shivering is an example of a

A structural adaptation.

B mechanical adaptation.

C behavioural adaptation.

D physiological adaptation.

Question 20 (1 MARK)

The amount of heat released into the environment varies between two animal species. A physiological adaptation that would not explain this difference is

A a longer loop of Henle in the nephrons of the kidneys.

B being either ectothermic or endothermic.

C different internal body temperatures.

D countercurrent circulatory methods.

Adapted from VCAA 2003 Exam 1 Section B Q4biii

Question 21 (3 MARKS)

Three different kinds of plants – mosses, grasses, and cushion plants – all have different adaptations for growing in alpine environments. For instance, mosses lack a vascular system, grasses have belowground rhizomes, and cushion plants can raise their temperature above that of the environment by trapping and conserving heat from the sun.

a Describe another adaptation of plants in alpine areas which enables them to tolerate cold temperatures. (1 MARK)

b Explain why it is rare to find trees above certain altitudes in alpine environments. (1 MARK)

c Plants in alpine regions typically grow slower than those in tropical regions. This is attributed to lower temperatures, low nutrient soils, and generally harsher conditions.

How might low nutrient soils limit plant growth? (1 MARK)

Key science skills and ethical understanding

Use the following information to answer Questions 22 and 23.

Plants which produce antifreeze proteins are common in cold environments. These proteins prevent the freezing of water.

Up-and-coming food scientist, Dale Miller, decided to extract antifreeze proteins and inject them into different fruits, so that fruit can be safely stored in the freezer without going off. The range of modified fruit is being called 'Freezy fruit', marketed with the tagline 'The fruit your freezer can finally get along with!' The plan is to sell them at local fruit markets without approval from regulatory food bodies.

Question 22 (1 MARK)

Antifreeze proteins work by

A disrupting the formation of ice crystals inside cells, preventing cell damage.

B strengthening organelles, so that they are not damaged by ice crystals.

C increasing the temperature of a cell, preventing the freezing of water.

D increasing the freezing temperature of water.

Question 23 (1 MARK)

Some people may object to Dale's approach because they believe that circumventing the current established rules surrounding the selling of modified food is ethically wrong.

This objection follows

A no ethical approaches.

B the duty-based approach to ethics.

C the virtues based approach to ethics.

D the consequence-based approach to ethics.

Question 24 (10 MARKS)

Some organisms are bioluminescent, meaning they can produce a soft light due to a chemical reaction in their bodies. In most cases, bioluminescence is used to ward off predators, attract mates, or lure prey.

Image: Peter B Photography/Shutterstock.com

Despite records of bioluminescent fungi thousands of years ago, we still don't understand the functional evolutionary advantage of bioluminescence in fungi.

Two opposing theories have been proposed to explain the functional advantage of fungal bioluminescence:

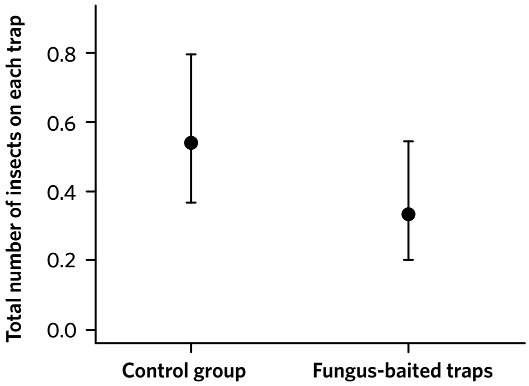
1. Bioluminescent fungi attract insects to the underside of the fungi, which increases spore dispersal.
2. Bioluminescence in fungi is an accidental byproduct of fungal metabolism.

To distinguish which theory supports the evolution of bioluminescence in the ghost fungus (*Omphalotus nidiformisi*) of south-eastern Australia and Tasmania, members of the Department of Ecology and Environmental sciences at the University of Adelaide performed the following experiment.

Sticky traps were set up in open woodland with no light pollution, within the native range of *O. nidiformisis*. Twenty-four traps were established, assigned to either the experimental group, or the control. The experimental group had a 5 × 5 cm fresh chunk of bioluminescent *O. nidiformisi* attached to the trap's top left corner. The control had a similar sized chunk of polystyrene, also attached to the top left.

Traps were left in the field for two individual nights during the month of June, for 10 hours on each night. Each morning, the traps were retrieved and the total number of insects on each trap was recorded.

Upon analysing the data, the scientists constructed the following graph.



Source: adapted from Weinstein et al. (2016).

a Is bioluminescence a structural, physiological, or behavioural adaptation? Justify your response. (1 MARK)

b Identify the dependent and independent variables. (1 MARK)

c The experimenters believe that insects assisted the dispersal of fungal spores. Suggest what their hypothesis is. (1 MARK)

d One of the fungus-baited traps caught five insects overnight. Experimenters discovered that the trap was within 1 m of a rotting animal carcass, and decided to remove this trap from the dataset. Did the scientists break the ethical principle of integrity? Explain your answer. (2 MARKS)

e After performing their experiment, the scientists returned to the lab to begin analysing and interpreting their results.

- **i** Which group caught the most insects? Use evidence from the graph to justify your response. (1 MARK)
- **ii** Which theory is refuted by the results of the experiment? Why? (2 MARKS)

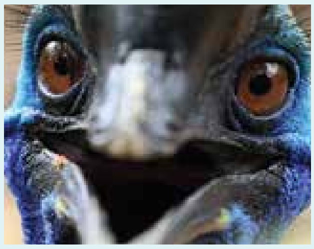
f The experiment ran over two nights in the month of June.

- **i** How does this limit the conclusions of the experiment? (1 MARK)
- **ii** Suggest one way that the experiment could be improved. (1 MARK)

10C INTERDEPENDENCIES BETWEEN SPECIES

What if I told you there was a gigantic bird, taller than most people, roaming the Australian wilderness? What if I told you that this direct descendant of the dinosaurs possesses claws capable of disembowelling a human with ease, and a thunderous call capable of striking fear into the most steadfast of foes? What if I told you that up to 200 people per year are attacked by this creature!

Why can't we just get rid of this bird? When will the Australian people finally be free of this plague? Free from what's been dubbed as 'the most dangerous bird in the world'? Free from the cassowary?



If eyes are the windows to the soul, then the cassowary clearly doesn't have one.

Image: 22August/Shutterstock.com

Lesson 10C

In this lesson you will learn that no species lives in isolation, but is instead greatly dependent on other species for survival. Keystone species are species that have a disproportionately large impact on the ecosystem as a whole.

◀ *Prerequisite knowledge* | *Future applications* ▶

Years 7–10

Ecosystems consist of communities of interdependent species and the abiotic factors of their environment.

Lesson 10D

The Aboriginal and Torres Strait Islander peoples have contributed to current western classification, and have their own understanding of Australian species and ecosystems.

Year 12

The natural selection of species is not only influenced by the abiotic pressures in an environment, but also pressures exerted by other species in an ecosystem.

Study design dot point

- survival through interdependencies between species, including impact of changes to keystone species and predators and their ecological roles in structuring and maintaining the distribution, density, and size of a population in an ecosystem

Key knowledge units

What's in an ecosystem?	2.2.6.1
Population size, distribution, and density	2.2.6.2
Interactions between species	2.2.6.3
The influence of keystone species	2.2.6.4

What's in an ecosystem? 2.2.6.1

OVERVIEW

Ecology is the study of how organisms interact with one another and their environment. Biological systems can be broken down into five levels of ecological organisation: cells, organisms, populations, communities, and ecosystems.

THEORY DETAILS

Scientists have long pondered the interactions between members of different species and their environment. Within the field of **ecology**, we are beginning to understand that organisms rely on complex interactions with members both within and outside of their own species to survive and that all of these interactions are what make up the **biodiversity** of an ecosystem.

To assist the study of ecology, we can break biological systems into five main levels of ecological organisation, each of which can be studied to gain information vital to proper ecological understanding. These five levels are:

- **Cell** – individual cells of a larger organism. Individual cells or systems of cells can be studied to help determine the processes that occur within an organism which help to maintain its survival
- **Organism** – an individual living thing, such as an animal, plant, or single-celled form of life
- **Population** – a group of organisms of the same species living in the same geographical region
- **Community** – a group of interacting populations of different species in the same geographical region
- **Ecosystem** – multiple communities interacting with one another and their physical environment. Ecosystems are made up of both **biotic** and **abiotic** factors and contain many individual and population interactions, as well as the flow of energy/nutrients between organisms.

ecology the study of how organisms interact with one another and their environment

biodiversity the variety of life in the world or within a particular habitat

cell the smallest functional unit of a living organism

organism a living thing made up of one or more cells

population a group of individuals of the same species living in the same geographic location

community a group of interacting populations of different species in the same geographical region

ecosystem multiple communities interacting with one another and their physical environment

biotic factor a property of the environment relating to living things. Examples include predator-prey relationships, competition, and symbiotic relationships

abiotic factor a property of the environment relating to non-living things. Examples include temperature, nutrient availability, and water availability

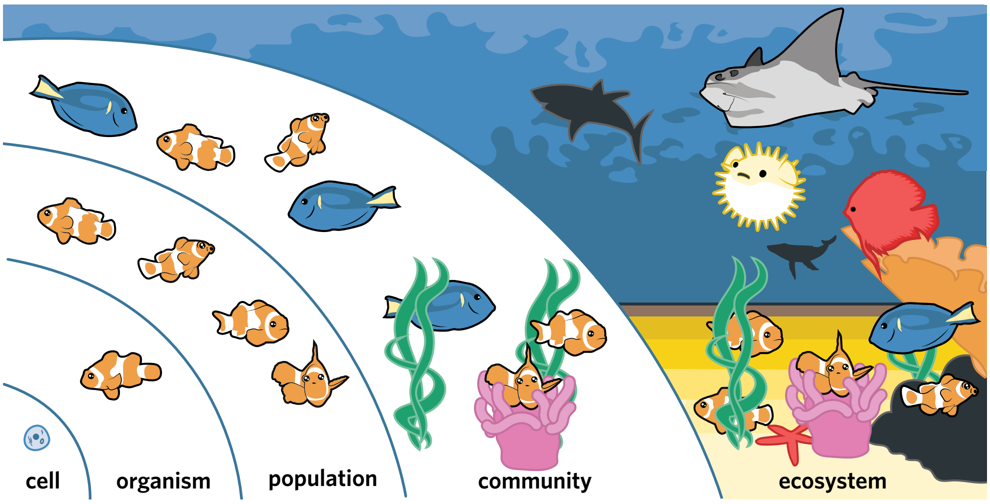


Figure 1 The levels of ecological organisation

Population size, distribution, and density 2.2.6.2

OVERVIEW

The population of a single species can be characterised by its size, distribution, and density.

THEORY DETAILS

When attempting to understand populations within an ecosystem, it is important to consider the factors that make up a population's structure. The three most common measures of population structure are the size, population distribution, and density.

Population size

The **population size** of a species is exactly what it sounds like – it's a simple count of the total number of members within any given population. Over time the population size may change, but there are limits as to how many individuals an environment can support and sustain. This limit is referred to as the **carrying capacity** of the environment. It is possible to exceed this value, but individuals will then suffer as they cannot all be sustained by the environment.

population size the number of individuals in a population

carrying capacity the maximum population size that an environment can sustain indefinitely

As time goes on, the population size can increase or decrease. Components that alter a population's size include the total births and deaths within a population and any **immigration** or **emigration** between populations. The population change of a single species can be predicted using the population growth model:

$N_{i+1} = N_i$ + births – deaths + immigration – emigration

- N_{i+1} = future population size
- N_i = initial population size

Many biotic and abiotic factors of an ecosystem can influence the births, deaths, immigration, and emigration seen in a population and therefore the overall population size. For example, greater disease prevalence within a population may lead to an increase in deaths, and less resource availability may cause more emigration. For these reasons, calculating the true size of a population is difficult. Nevertheless, this model can be used as a valid predictor.

immigration the migration of individuals into a population

emigration the migration of individuals out of a population

Memory device

You can think of the carrying capacity like seats on a bus. There are only a set number of seats, and while you could have more people on the bus it would be a little uncomfortable. Some buses (environments) have more seats (greater carrying capacity) than others.

The carrying capacity of an environment also depends on the species in question. For example, if we're trying to fit 100 adults on a bus it's going to be much less comfortable than 100 toddlers on a bus. Therefore, we can fit more seats on the toddler bus (greater carrying capacity) compared to the adult bus.

Theory in context

r AND K REPRODUCTIVE STRATEGIES

The population growth rate of reproducing organisms is influenced by the amount of offspring produced by an individual or pair of individuals in each generation.

For organisms that live in very unstable environments, it might be better to produce a larger number of short-living offspring and let them take their chances in the hopes of some surviving until reproductive age. For organisms that live in stable environments, a better strategy might be to produce fewer offspring but invest more resources in each individual to proactively increase their life-spans and chances of survival until adulthood. This is what biologists have coined the r/K reproductive strategies. However, it is important to note that r/K reproductive strategies exist on a spectrum. Therefore, you can say that a species is more 'K-selected' or more 'r-selected' when compared to another species.

r-selection

Often referred to as the 'quick and many' strategy, this method involves producing large numbers of offspring more regularly, while placing little or no parental care into each offspring. This typically leads to a higher mortality rate. Species who employ the r-selection strategy will reach sexual maturity quickly, and will become self-sufficient adults earlier than other organisms. Population growth in r-strategists is often boom and bust, where large explosions in the population are often followed by a massive die off.

Many aquatic animals, insects, and rodents are more r-selected.

K-selection

Often referred to as the 'slow and few' method, this method involves producing much smaller numbers of offspring, which are often much larger in size and more dependent on parental care. Species who employ the K-selection strategy will reach sexual maturity much slower, and will therefore breed later in their lifespan than other organisms. Population growth in K-strategists will remain constant at the carrying capacity of an environment.

Most mammals, including humans, chimpanzees, whales, and elephants are generally more K-selected.

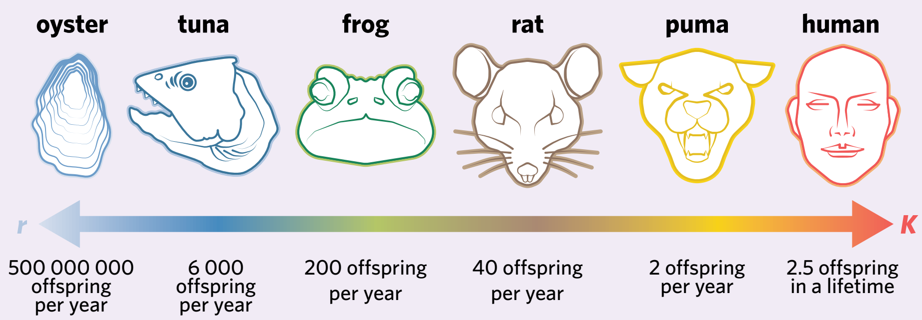


Figure 2 r/K selection theory represents a trade off between producing either many cheap offspring, or few expensive offspring.

Population distribution

The **population distribution** of a species refers to its geographical spread across different areas. The population distribution is limited by the ideal habitat of a species and its ability to tolerate different environments. Distributions over larger areas are often represented by coloured areas on a map (Figures 3 & 4).

population distribution the range of geographical areas that members of a population can be found in

Figure 3 The red kangaroo (*Macropus rufus*) can be found in most of the hot and arid regions of central Australia. Estimates suggest that as many as 50 million red kangaroos range across the continent.

Figure 4 The critically endangered leadbeater's possum (*Gymnobelideus leadbeateri*) survives in two distinct populations north-east of Melbourne. Estimates suggest only 2 000–11 250 individuals remain in the wild.

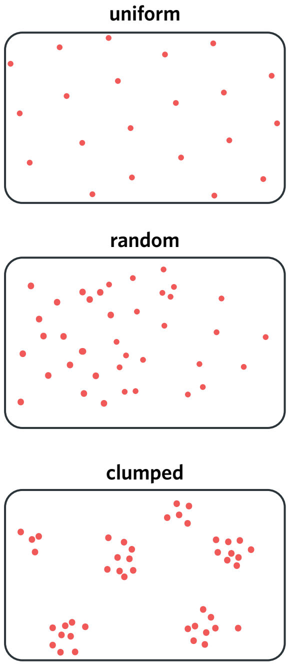


Figure 5 The population distribution of a species is influenced by a whole range of factors, and can be uniform, random, or clumped.

The population distribution of individuals within a local area can be a uniform, random, or clumped arrangement (Figure 5). The reasons for a species to be distributed a certain way varies between species. For example, one species distribution may be clumped as individuals distribute around pools of resources but another species distribution may be uniform as individuals require a large amount of space. Over time, distributions are not static and will change due to environmental factors such as temperatures, rainfall, invasive species, and habitat loss.

Population density

The **population density** of a species refers to the number of individuals found in a given area, such as individuals per square kilometre. While this may seem like a simple calculation, it proves extremely useful when predicting population growth rates and the carrying capacity for a particular species.

population density the number of individuals in a population per unit area

It is easy to recognise how population density could influence the rate at which population size increases. For example, dense populations would use up the available resources in an ecosystem more quickly than less dense populations.

Many biotic and abiotic factors can influence the rate of births, deaths, immigration, and emigration in a population. Some of these factors influence populations in the same way, regardless of their population density. For example, the rainfall of an area will impact a high-density population in the same way as a low-density population. However, other factors such as disease will have a more intense influence as population density increases. We refer to these types of factors as **density-independent** and **density-dependent factors**:

- Density-independent factors – properties of the environment that are unaffected as density changes, such as climate. The same density-independent factor will have the same effect on two populations of different densities.
- Density-dependent factors – properties of the environment that change with the density of a species, such as the availability of resources. As the density increases, the effect of the density-dependent factors becomes stronger. For example, food might become more scarce as more organisms compete for it.

density-independent factors environmental factors that affect population growth but are not affected by population density

density-dependent factors environmental factors that affect population growth and become stronger as population density increases

Table 1 Density-independent and dependent factors

Density-independent factors	Density-dependent factors
Climate	Disease
Natural disturbance events (e.g. cyclone, volcanic eruptions)	Predation
Functionally unlimited resources (e.g. O_2, CO_2)	Competition
	Resource availability
	Accumulation of waste

At low population densities, the population growth of a species over time can be exponential. When the density is low, density-dependent factors will have almost no influence on population growth. However, as the density increases and the effect of density-dependent factors becomes more severe, the population growth rate will begin to slow until the population size remains constant (Figure 6). Different species have different requirements in terms of what they need from their environment to be able to survive. Because of this, different species have different carrying capacities within the same environment (Figure 7).

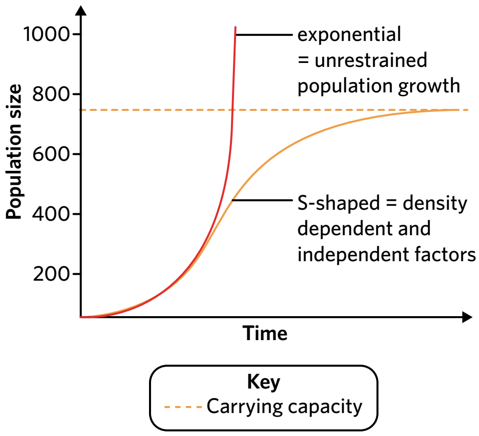


Figure 6 The effect of density-independent and density-dependent factors

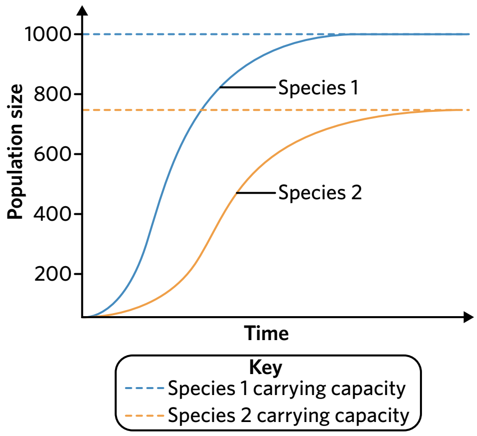


Figure 7 Population growth rates for different species are limited by their individual species requirements and carrying capacities.

Interactions between species 2.2.6.3

OVERVIEW

An ecosystem is composed of a complex network of interactions and interdependencies between species. Interactions between two species can have beneficial, neutral, or negative impacts on one or both species.

THEORY DETAILS

In ecosystems, many species share habitats and interact with each other in a variety of ways. It is no stretch of the imagination to say that currently there is not a single species on Earth that exists completely independently. Several different types of **symbiotic** interactions between organisms exist, including mutualism, commensalism, amensalism, and parasitism. Additionally, predation and competition are two types of interactions that greatly influence ecosystem structure.

symbiosis an interaction between two organisms of different species living in close proximity to each other

Mutualism (+/+)

A **mutualistic** relationship exists between individuals that both benefit from interacting with each other. For example, the dazzling arrays of colours in a coral reef are not caused by the coral themselves, but from photosynthetic algae living inside coral tissue. The algae produce glucose and oxygen for the coral, and the coral gives the algae a safe place to live (Figure 8). Both organisms end up better off as a result of the symbiosis compared to if they did not interact at all.

mutualism interactions between two organisms of different species where both parties experience some overall benefit

Commensalism (+/0)

Commensalism describes interactions between two or more different organisms of different species where one gains some benefit while the other experiences no significant benefit or harm. While theoretically possible, examples of true commensalism are rare in nature. For example, one classic example describes the relationship between cape buffalo and cattle egrets (which are a type of bird). These birds follow herds of buffalo around the savannah, feeding off insects that are stirred up out of the grass by the buffalo, benefiting from the relationship. While they seemingly have no effect on the buffalo themselves, closer investigation reveals that egrets often feed on ticks attached to buffalo, and may inadvertently warn buffalo when predators approach (a mutualistic relationship).

commensalism interactions between two organisms of different species where one gains some benefit while the other experiences no significant benefit or harm

predation interactions between different species where one organism hunts and kills another organism for food

Predation (+/-)

Predation describes interactions between two or more organisms of different species where one organism (the predator) hunts and kills another organism (the prey) for food. The predator receives the benefit of obtaining food, whilst the prey has the obvious downside of being killed and eaten. In response, many prey species have evolved adaptations to evade their predators. For example, camouflage is an evolutionary adaptation that enables prey species to blend into their environment, making it more difficult for predators to detect them. Conversely, predators have evolved adaptations to be able to hunt their prey more effectively. For example, they often have 'weapons' such as claws and teeth, or better eyesight to distinguish their prey from the environment.

Image: Timothy Baxter/Shutterstock.com

Figure 8 Coral reefs are ecological hotspots for mutualisms and other complex interactions between species.

Image: Nicola_K_photos/Shutterstock.com

Figure 9 Is the relationship between cape buffalo and cattle egrets commensal or mutualistic? Turns out 'it's complicated.'

Theory in context

PREDATOR-PREY RELATIONSHIPS

Life in a boreal forest during the 18th and 19th centuries of northern Ontario, Canada, was particularly difficult. Especially considering that one of the main sources of food and fur, the snowshoe hare, would seemingly disappear once every ten years. While the disappearances were easy to predict, the reasoning behind them was not as well known. That is until Charles J. Krebs and crew decided to take it upon themselves to answer this question, and study the hare and its natural predator – the lynx.

To establish an explanation, Krebs et al. (1995) used multiple 1 km^2 blocks of undisturbed boreal forest. Each block was split into four different experimental groups: 1) supplemented with food sources for the hare, 2) supplemented with a fertiliser, 3) excluded lynx via an electric fence, and 4) excluded lynx and received supplementary food. Additionally, blocks that received no food, fertiliser, and were accessible to lynx were also established.

When testing snowshoe hare populations in each block, the researchers found that a) fertiliser treatments barely affected hare populations, b) that independently, both the supplementary food and lynx exclusion treatments drastically increased hare populations, and c) that combining lynx exclusion and supplementary food treatment supported the highest number of snowshoe hares.

Krebs et al. (1995) published their landmark paper which experimentally proved that snowshoe hare population cycles were heavily impacted by the availability of resources and predation by the native lynx. Further research has gone on to prove snowshoe hare population cycles are mirrored by that of the lynx.

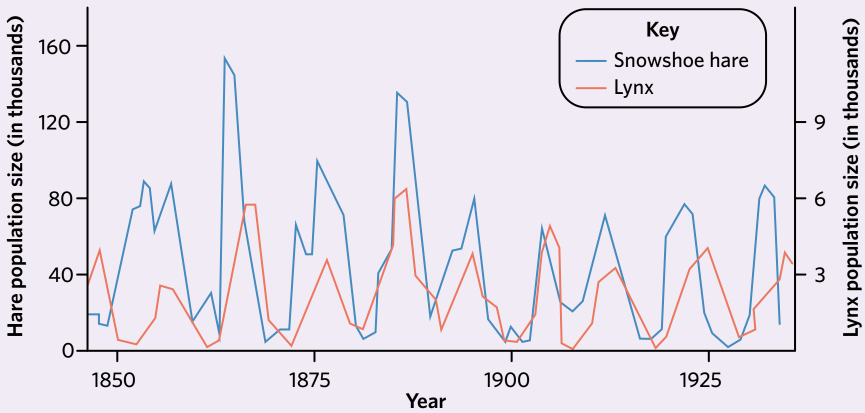


Figure 10 Cycles in the predator-prey relationships between snowshoe hare and lynx populations

Want to read the studies this is based on? Find the free articles by searching:

"Krebs, C. J., Boutin, S., Boonstra, R., Sinclair, A. R. E., Smith, J. N. M., Dale, M. R., ... & Turkington, R. (1995). Impact of food and predation on the snowshoe hare cycle. *Science, 269*, 1112–1115."

"Krebs, C. J., Boonstra, R., Boutin, S., & Sinclair, A. R. (2001). What Drives the 10-year Cycle of Snowshoe Hares? The ten-year cycle of snowshoe hares—one of the most striking features of the boreal forest—is a product of the interaction between predation and food supplies, as large-scale experiments in the yukon have demonstrated. *BioScience, 51*, 25–35."

Theory in context

PREDATOR-PREY COEVOLUTION – AN EVOLUTIONARY ARMS RACE?

As humanity has added to our knowledge of the animal kingdom, we have often erroneously dubbed many animals as the 'most toxic animal in the world.' Currently, the golden dart frog (*Phyllobates terribilis*) is thought to hold the record. The skin of the golden dart frog secretes a lethal batrachotoxin, with each frog thought to contain enough of this toxin to kill between 10–20 fully grown adult humans. Interestingly, rather than synthesising these toxins themselves, many believe that the frogs obtain the toxin from the food they eat, likely a particular species of beetle. The strength of the batrachotoxin is often considered 'overkill', as only the tiniest amount would kill most potential predators. Only one species is known to be able to tolerate the toxins of the golden dart frog – the fire-bellied snake (*Leimadophis epinephelus*). In fact, due to this tolerance, *L. epinephelus* is thought to be the only natural predator of the golden dart frog.

This has led to many evolutionary biologists describing their relationship as an 'evolutionary arms race', where the frog has evolved deadlier toxins, and the snake has evolved greater resistance against the toxins.

Image: Thorsten Spoerlein/Shutterstock.com

Figure 11 The golden dart frog (*Phyllobates terribilis*)

Parasitism (+/–)

Parasitism describes interactions between two or more organisms of different species where one organism (the parasite) obtains nutrients at the expense of another organism (the host). Predation differs from parasitism in that while predators always kill their prey, parasites obtain nutrients without immediately causing the host's death (though they may weaken the host enough to cause death). Mosquitoes and ticks are ectoparasites, as they live external to the host, whilst organisms such as parasitic worms, fungi, and amoeba can be endoparasites that live inside a host.

Amensalism (0/–)

Amensalism describes interactions between two or more organisms of different species where one organism experiences some negative effect whilst the other experiences neither a beneficial nor a negative effect. For example, ungulates, which are animals with hooves, often walk on grasses and small shrubs which kills or damages them, but the animals themselves receive neither benefit nor harm.

Competition (–/–)

Competition describes interactions between two or more organisms rivalling for the same pool of resources. When two organisms compete for the same limited resource, the availability of the resource in the environment decreases. Therefore, two competing organisms must invest more in obtaining the limited resource, which has a negative effect on each organism, and by extension a negative effect on both species. For example, weeds growing in a vegetable garden compete with vegetables by absorbing water and nutrients, thereby limiting vegetable growth. However, vegetables absorbing water and nutrients also limits weed growth in the exact same way. There is never a 'winner' in competition, rather there are two individuals trying to 'outcompete' one other.

Notably, competition can exist between organisms of different species, as well as between organisms of the same species. **Interspecific competition** describes competition between two individuals of different species such as weeds and vegetables competing for water and nutrients in a garden. On the other hand, **intraspecific competition** is competition between two individuals of the same species such as two male red kangaroos fighting to establish dominance and win over a female mate.

parasitism interactions between two organisms of different species where one organism obtains nutrients at the expense of a host organism

amensalism interactions between two organisms of different species where one organism experiences some negative effect while the other experiences neither a beneficial nor negative effect

competition interactions between two or more organisms competing for the same pool of resources

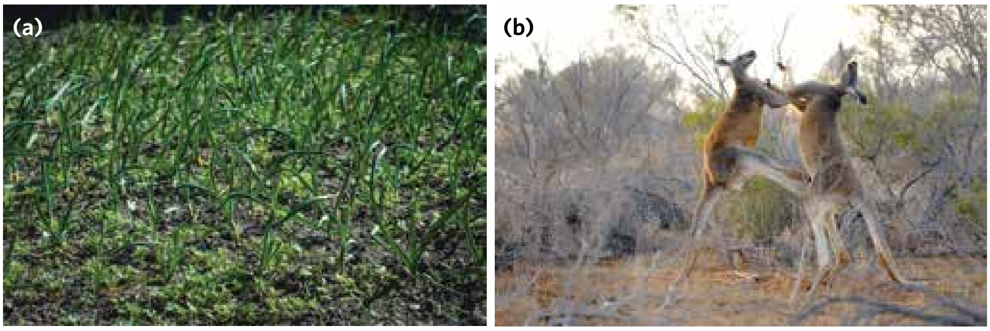
Figure 12 Parasitic wasps hatch, feed, and grow inside live caterpillars.

Image: Donna White/Shutterstock.com

Figure 13 Ungulates, such as cattle, sheep, and deer, trample shrubs and grasses while receiving no benefit or harm.

interspecific competition the competition for resources between members of different species

intraspecific competition the competition for resources between members of the same species



Images (left to right): Oleksandr Yakoniu, John Carnemolla/Shutterstock.com

Figure 14 Competition can exist between organisms of **(a)** different species such as a weed species and spring onion (*Allium fistulosum*) in a garden, or **(b)** the same species such as male red kangaroos (*Macropus rufus*) fighting to win over a female mate.

The influence of keystone species 2.2.6.4

OVERVIEW

Keystone species play a much larger role in maintaining ecosystem structure and composition than other species.

THEORY DETAILS

The interconnected relationships between species in an ecosystem help give the ecosystem structure and stability. Within any given ecosystem, there are certain species that play a disproportionately large role in maintaining this structure. These species are known as **keystone species**. As such, removing a keystone species typically has a larger effect than the removal of other species.

However, because the removal of any species has an effect on the ecosystem, and because no one truly knows where the line is drawn between a keystone species and a regular species, keystone species are generally hard to identify. Fortunately, we tend to find that keystone species adopt the same sorts of roles within an ecosystem. Two common roles that keystone species fulfill are **apex predators** and **ecosystem engineers**.

keystone species a species whose effects on an ecosystem are greater than expected relative to its population size

apex predator a predator that has no natural predators and is at the top of its food chain

ecosystem engineer an organism that creates, significantly alters, or maintains the structure of an environment

Apex predators

Within ecosystems, certain predators will sit at the 'top of the food chain' as they have no natural predators. These top predators are referred to as apex predators. Apex predators are responsible for controlling the numbers of their prey and, subsequently, the number of many other organisms within an ecosystem. To illustrate this, let's look at an example.

The great white shark (*Carcharodon carcharias*) is an apex predator in its ecosystem. The sharks prey upon sea lions, seals, and large species of fish, keeping their populations at a healthy number. Because the sharks are responsible for controlling sea lion numbers, we can therefore say that they are responsible for controlling the numbers of what the sea lion eats (e.g. medium-sized fish species). Because of this, we can say that the sharks are responsible for controlling the numbers of what the medium-sized fish eats (e.g. smaller-sized fish species), and so on.

Image: Sergey Uryadnikov/Shutterstock.com

Figure 15 Great white sharks are apex predators and a keystone species in their ecosystem.

As a result, the great white sharks are responsible for keeping the intricate ocean ecosystem in balance. If great white sharks were to be removed, their prey species like sea lions would lose a major predator and be free to increase in population size. This would impact the numbers of medium fish that the sea lions prey on, disrupting the balance of the ecosystem. Additionally, we can say that the sharks are also responsible for keeping populations of prey physically and genetically healthy. They achieve this by removing the weaker, older individuals that are easier to catch. Given their immense impact on their ecosystem, we can classify great white sharks as a keystone species.

Ecosystem engineers

Ecosystem engineers interact with and significantly alter the physical environment of their ecosystem. The greater bilby (*Macrotis leucura*) is an ecosystem engineer within the Australian environment. Whilst foraging for food, the bilby digs many small pits in the soil.

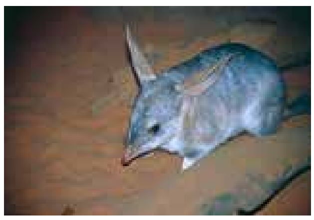
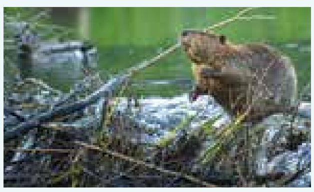


Figure 16 The greater bilby is an ecosystem engineer within its ecosystem.

These pits can then fill with leaves, trap seeds, and increase water permeability and provide a microhabitat. In essence, each one of these holes has the potential to become a fertile pocket of nutrients, allowing native grasses, shrubs, and trees to grow in soil with few nutrients.

As keystone species are critical for ecosystem functioning, they are often the focus of conservation efforts. A few examples of keystone species are listed in Table 2.

Table 2 Examples of keystone species

Keystone species	Type of keystone species	Importance in ecosystem	Photo
Grizzly bears (*Ursus arctos horribilis*)	Apex predator and ecosystem engineer	Grizzlies regulate the numbers of several prey species such as moose, elk, and salmon. Grizzlies leave the carcasses of salmon in forests, fertilising the soil and supporting the growth of trees. Grizzlies also undertake large amounts of digging, which aerates the soil and improves soil quality.	 Image: Adam Van Spronsen/Shutterstock.com
Purple sea star (*Pisaster ochraceus*)	Apex predator	Carnivorous sea stars are the top predators in many intertidal regions. When removed, species of barnacles and mussels can dominate the pools and overgraze the algae. After the algae decline, so do the numbers of barnacles and mussels because there is not enough food, causing the ecosystem to collapse.	 Image: lauraslens/Shutterstock.com
Sea otters (*Enhydra lutris*)	Apex predator	Sea otters feed on sea urchins that, when uncontrolled, overgraze kelp. Kelp forests are important as they provide habitats for numerous other species, protect coastal areas from erosion, and also sequester large amounts of carbon from the atmosphere.	
Mound-building termite species	Ecosystem engineer	Termite mounds provide areas for species to build their nests and raise their young. Termite mounds also promote the growth of nearby trees due to their high levels of nutrients.	
African bush elephant (*Loxodonta africana*)	Ecosystem engineer	Elephants preserve the grasslands of African savannas by eating young, low-hanging trees. Without elephants, the savannas would be invaded by trees and shrubs and eventually turn into forests.	 Image: Katja Forster/Shutterstock.com
North American beaver (*Castor canadensis*)	Ecosystem engineer	Beavers construct dams and create wetlands where many species of fish such as salmon and trout live.	 Image: Chase Dekker/Shutterstock.com

Theory in context

HOW WOLVES CHANGE RIVERS – A TROPHIC CASCADE

By the 1920s, the number of grey wolves (*Canis lupus*) in Yellowstone National Park, USA, had declined to zero as a result of human hunting. Over the next 70 years, as a direct result of the removal of grey wolves from the ecosystem, a rapid increase in the population size of the wolves' main prey – elk (*Cervus canadensis*) – occurred, leading to the intense grazing and trampling of vegetation. Because of this, the ecosystem suffered and human efforts to control elk populations were futile.

In 1995, a small number of wolves were reintroduced into the park and their impact was profound. While the direct impact of the wolves was the hunting and lowering of elk numbers, there were many more indirect impacts. The presence of the wolves changed the behaviour of the elk, causing them to avoid dangerous areas. In these areas, trees and other vegetation rapidly grew and increased, and this catalysed many more changes:

- Birds began to move into the newly forested areas, as did beavers.
- The new dams constructed by beavers provided habitats for otters, ducks, fish, reptile, and amphibian species.
- The wolves also hunted coyotes in the park. Fewer coyotes lead to greater numbers of rabbits and mice, which then lead to more hawks, weasels, foxes, and badgers.
- Raven and bald eagle numbers increased to scavenge the carrion left by the wolves. Greater amounts of carrion and berry trees also caused an increase in bear numbers.
- The bears also hunted the elk, reducing their numbers further and reinforcing the positive impacts of reduced elk.

As the forest regenerated, the banks of rivers stabilised and collapsed less often due to the presence of vegetation. The rivers became fixed in their path, channels narrowed, and more pools formed, providing more habitat opportunities. Impacts stemming from the return of a keystone species are clear. This scenario is an example of what's known as a trophic cascade – an ecological process that starts at the apex predator and tumbles all the way down the food chain.

Figure 17 Grey wolves are a keystone species in the Yellowstone National Park.

Theory in action

Check out Scientific Investigation 10.1 to put this into action!

Theory summary

A population is a group of organisms of the same species living in the same geographic region. Populations can be described by three specific features – distribution, size, and density. When two or more species live in close proximity to one another within an ecosystem, they can exhibit various types of relationships shown in Table 3.

Keystone species are species that have a greater effect on the ecosystem than you would expect given their population size, and often fall into the role of either an apex predator or an ecosystem engineer.

Table 3 Summary of the relationships between species

Relationship	Description
Mutualism (+/+)	Interactions where both organisms benefit
Commensalism (+/0)	Interactions where one organism benefits and the other is not seriously harmed
Predation (+/–)	Involves one organism hunting and killing the other for food
Parasitism (+/–)	Interactions where an organism obtains nutrients at the expense of a host
Amensalism (0/–)	Interactions where one organism experiences some negative effect while the other is unaffected
Competition (–/–)	Interactions between two organisms (can be different species or the same species) where they are competing for the same pool of resources

The answer is: it's not that simple. We can't simply remove a species from an ecosystem as that would disrupt the delicate balance between other species within the ecosystem. The cassowary plays a critical role within its native habitat, the rainforest. Being a frugivore (an animal that feeds mainly on fruit), the cassowary is critical in assisting seed dispersal, which a number of species rely on for survival. Without the cassowary, these species would likely become locally extinct within a short period of time. For this reason, the cassowary can be considered an ecosystem engineer and a keystone species.

Also, while you should be casso-wary around cassowaries, they will not attack without reason so there's no need to be casso-worried. The majority of the 200 attacks per year stem from erroneous attempts to feed them, and the best way to avoid a cassowary attack is to simply respect them and admire their beauty from a distance.

Image: Michal Tesar/Shutterstock.com

10C QUESTIONS

Theory review questions

Question 1

A population is

A a group of a single species living in the same geographical area.

B a group of multiple species living in the same geographical area.

Question 2

Match the population statistic to its description.

Population statistic	Description
• distribution	**I** __________ the number of individuals within a population
• size	**II** __________ the number of individuals in a given area
• density	**III** __________ the total range of areas that a population or species extends to

Question 3

Which of the following are unlikely to be affected by increases in population density? (*Select all that apply*)

I resource availability

II temperature

III competition

IV predation

V disease

VI rainfall

Question 4

Which of the following species interactions have little to no effect on one or more parties? (*Select all that apply*)

I predation

II mutualism

III parasitism

IV competition

V amensalism

VI commensalism

Question 5

A keystone species is any

A species that has a disproportionately large effect on ecosystem structure.

B apex predator that has a disproportionately large effect on ecosystem structure.

Question 6

Which of the following describes a keystone species? (*Select all that apply*)

I Scientists have hypothesised that if the African elephant was removed from its native habitat, the savannah would flourish and quickly grow into dense forest.

II The removal of predatory sea stars from rockpools is followed by rapid increases in prey population sizes, overgrazing on algae, and subsequent declines in certain population sizes.

III Conservationists often dedicate resources to maintaining the populations of certain species that, if removed, would likely have widespread and significant impacts on ecosystem structure.

IV A flowering plant has become locally extinct in a small region in southwest Victoria. Following its extinction, the role of the flowering plant was quickly filled by another species of flowering plant.

SAC skills questions

Case study analysis

Use the following information to answer Questions 7–13.

Australia experienced some of the most devastating bushfires in history during the summer of 2019–2020. Some ecologists believe that up to one hundred native species could have been pushed towards extinction, and that upwards of a billion animals in total could have died as a result of the fires. What's more, for those species who managed to survive extinction, a subsequent lack of food, shelter, and breeding grounds continue to put them at risk.

A particularly devastating effect of the bushfires was the large quantities of eucalyptus trees that were destroyed, whose hollows housed many species of birds. While the eucalypts themselves weren't affected by the nesting habits of hollow-dwelling birds, a lack of hollows will ensure those birds suffer immensely. Such trees may take years, or even decades, to return to a state capable of supporting wildlife again.

Entomologists, people that study insects, would argue that the number of species pushed towards extinction by the fires was much larger than previous estimates. This is because the estimates made by the ecologists had neglected insect species. Within the ecologists' estimates, it is suggested that only four mammal species (including the greater glider and the Kangaroo Island dunnart) may be pushed towards the brink of extinction. We know that worldwide, for every land mammal species there are approximately 185 insect species. Therefore, we can predict that 740 insect species are at risk of extinction as a result of the bushfires.

Question 7

For every land mammal there are approximately how many species of insects?

A over a billion

B 20–100

C 185

D 740

Question 8

An example of a species mentioned in the text is

A insects.

B the greater glider.

C the land mammals.

Question 9

The interaction between native birds and old eucalypt trees is an example of

A commensalism.

B amensalism.

C mutualism.

D predation.

Question 10

Old hollows in trees are often considered a limited resource for native bird populations. Native birds fighting for the right to use an old hollow would be an example of

A predation.

B parasitism.

C competition.

D amensalism.

Question 11

The death of many insect species will impact the livelihoods of surviving bird species as many feed upon a variety of insects. The relationship between these birds and insects is an example of

A predation.

B parasitism.

C competition.

D amensalism.

Question 12

A potential issue with the prediction of the number of insect species to become extinct is that it

A does not consider every type of insect species.

B assumes that the ratio of land mammals to insects is the same in every habitat worldwide.

Question 13

Other estimates suggest that there are at least 5.5 million species of insects worldwide, giving us a ratio of approximately 1 000 insect species per every land mammal species. Assuming this is the case, how many species of insect are now predicted to have gone extinct as a result of these fires?

A 1 000

B 4 000

C 740 000

D >20 million

Exam-style questions

Within lesson

Question 14 (1 MARK)

All parasites

A have complex life cycles involving multiple different species.

B obtain nutrients at the expense of other organisms.

C live external to the host.

D do not kill the host.

Question 15 (1 MARK)

A population of native skinks has a population density of 2.7 individuals/ha. As their population increases, which of the following is likely to occur given no change to their population range?

A competition, predation, and disease would increase

B rainfall, temperature, and availability of resources would decrease

C predation, competition, and availability of resources would decrease

D temperature, the availability of resources, and competition would increase

Question 16 (1 MARK)

The number of individuals of a particular species is monitored at three sites over the course of five years, whereupon the number of individuals remains relatively constant for each site. This suggests that in each site

A the population size is steadily decreasing over time.

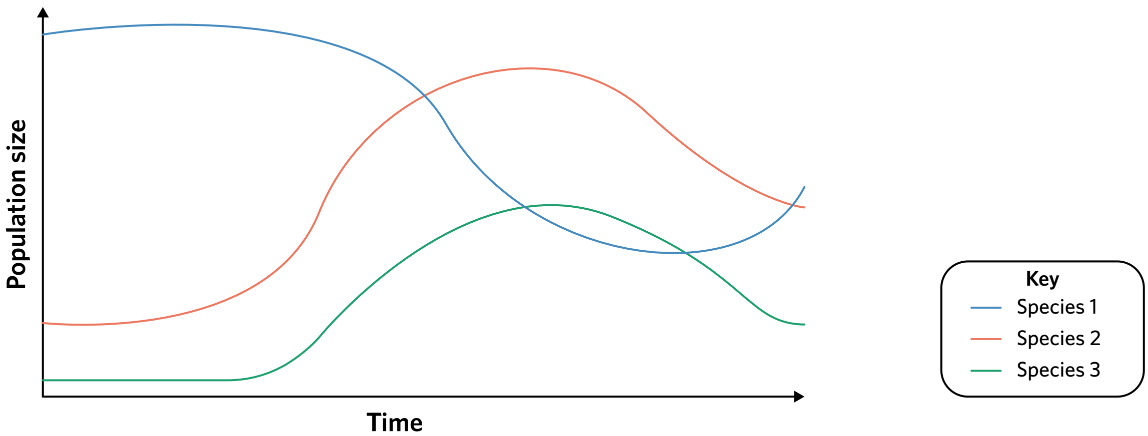
B the population size is approximately equal to the carrying capacity of each area.

C the density-independent factors are having a greater influence on population size than density-dependent factors.

D the density-dependent factors are having a greater influence on population size than density-independent factors.

Use the following information to answer Questions 17 and 18.

An experiment was conducted to monitor the population size of three separate species living in the same controlled area over an extended period of time. Monitoring showed that there were distinct interactions between Species 1 and Species 2, as well as between Species 2 and Species 3. Species 1 and Species 3 appeared to have no direct interaction with one another.



Question 17 (1 MARK)

Which of the following interactions could describe the population dynamics between Species 1 and Species 2?

A intraspecific competition

B commensalism

C mutualism

D predation

Question 18 (1 MARK)

Which of the following interactions could describe the population dynamics of Species 2 and Species 3?

A predation

B parasitism

C mutualism

D amensalism

Question 19 (4 MARKS)

Introduced species can dramatically alter an ecosystem.

a Historical and fossil records suggest that the introduction of dogs and cats onto mainland Australia during European colonisation was quickly followed by a decline in the population size of many of Australia's small mammal species and similarly sized native predators.

  i Why was a decline in the population size of small mammal species observed? (1 MARK)

  ii Suggest the reason behind the decrease in population size of the native predators. (2 MARKS)

b State the term used to describe competition between members of different species. (1 MARK)

Multiple lessons

Question 20 (4 MARKS)

An ecosystem comprises many interacting species.

a What is a keystone species? (1 MARK)

b A particular species of dragonfly will lay over 100 eggs per reproductive bout, the majority of which will not survive to reproductive age.

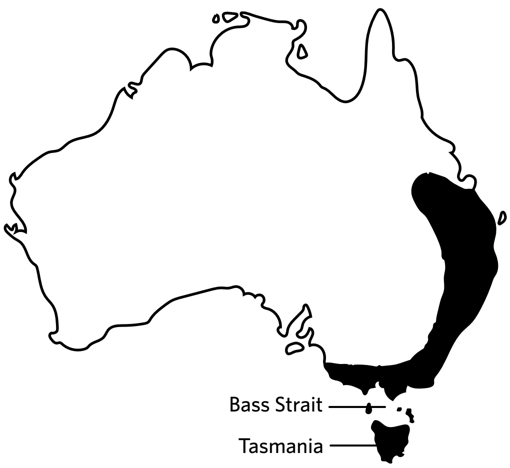
  i Describe an environment in which reproduction via the fusion of gametes would be favourable. (1 MARK)

  ii Name and describe the two processes of meiosis that are primarily responsible for increased genetic diversity in sexually reproducing populations. (2 MARKS)

Key science skills and ethical understanding

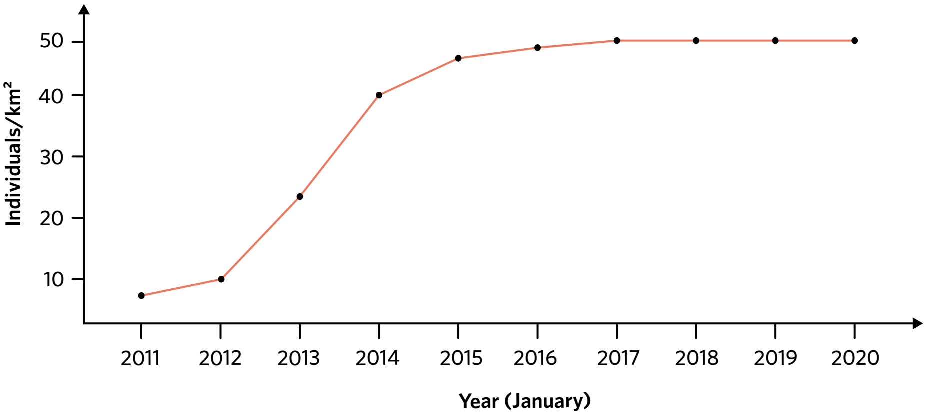
Question 21 (8 MARKS)

The map shows the distribution of the red-necked wallaby (*Macropus rufogriseus*) in Australia.



a Explain what is meant by the term distribution. (1 MARK)

b After noticing low maximum population densities of approximately 30 individuals/km^2 on mainland Australia, a group of scientists established several populations of *M. rufogriseus* on isolated islands off the coast of mainland Tasmania. The population growth on one of these islands is shown in the graph.



- **i** During which one year period did the wallaby population experience the largest growth? Use evidence from the graph to justify your answer. (1 MARK)
- **ii** What is the carrying capacity of the island? Refer to the graph to support your answer. (1 MARK)

c The first group of scientists continued to observe and record population growth and decline over many years. To do so, the group had to trap the wallabies to tag them, before releasing them back into the wild and continuing the observation. Based on their ongoing results, they could conclude whether or not each island area was suitable to support a population of *M. rufogriseus*.

A second group of scientists used a complex model to estimate potential habitable areas for the wallaby, based on weather conditions and patterns, local predator species, available food sources, and environmental stability, without trapping or observing the wallabies.

- **i** How might the bioethical concept of non-maleficence support the use of the second group's method over the first group's? Explain your answer. (2 MARKS)
- **ii** How might a consequences-based approach to bioethics be used to support the methodology of the first group of scientists? (2 MARKS)

d Account for the differences in carrying capacity between mainland Australia and the established population off the coast of Tasmania. (1 MARK)

10D INDIGENOUS KNOWLEDGE OF THE AUSTRALIAN ECOSYSTEM

Here are two pictures – the first is emu poo, the second is a quandong fruit. One has a tart, peach-like flavour. The other... I don't even want to think about it. At first, you might think that these two things have nothing to do with each other. But, to Indigenous Australians from certain tribes who are able to draw upon more than 60 000 years of cultural knowledge and history, these two things are utterly dependent on one another. What binds the emu and the quandong together?

Name a more iconic duo. I'll wait.

Image: Raffaella Simoncini, mastersky/Shutterstock.com

Lesson 10D

In this lesson you will learn about Australian Aboriginal and Torres Strait Islander peoples' understandings of the Australian ecosystem.

◀ Prerequisite knowledge

Years 7–10
Human activity such as hunting or pollution can alter the interactions between species in an ecosystem.

Lesson 10C
Understanding the relationships between different species has allowed Indigenous Australians to survive in the harsh Australian landscape for thousands of years.

Future applications ▶

Year 12
Fire has been a key selection pressure acting on species in Australian environments.

Year 12
The migration of Australia's First Peoples to Australia over 60 000 years ago can be tracked using fossil and DNA evidence.

Study design dot point

- contribution of Aboriginal and Torres Strait Islander peoples' knowledge and perspectives in understanding adaptations of, and interdependencies between, species in Australian ecosystems

Key knowledge units

Indigenous Australian Ways of Knowing	2.2.7.1
Indigenous understanding of adaptations	2.2.7.2
Indigenous understanding of interdependencies	2.2.7.3

Indigenous Australian Ways of Knowing 2.2.7.1

OVERVIEW

Indigenous Australians' knowledge of the Australian ecosystem has enabled them to survive in the harsh Australian landscape for over 60 000 years. The extent of their understanding of the Australian ecosystem can be seen in their cultural practice of fire management, and their utilisation of interspecies relationships such as that between the emu and the quandong.

THEORY DETAILS

Lesson 10C introduced the concept of **Indigenous Australian Ways of Knowing**. Indigenous Ways of Knowing focus on interconnections and relationships within systems and between nature and people, in an attempt to generate a **holistic** understanding of the world. In contrast, many areas of Western science seek to understand the world by focusing on small parts of a system – think molecular biology or cell theory.

Indigenous Australian Ways of Knowing a system of knowledge and beliefs cultivated and preserved by Indigenous Australians

holistic an approach to knowledge that views all things as intimately connected

It's important to understand, however, that whilst Indigenous Ways of Knowing and Western science may offer different explanations of phenomena or focus on different areas of inquiry, they have arisen in comparable ways. Indigenous Ways of Knowing have been generated through the processes of questioning, observation, investigation, experimentation, and application that have been repeated across generations for thousands of years – similar to the way Western science has developed. The knowledge generated through these processes has allowed Indigenous people to survive in Australia for over 60 000 years, making Australian Aboriginal culture the oldest existing human culture on earth (Figure 1).

Image: Little Adventures/Shutterstock.com

Figure 1 Australian Aboriginal art is the oldest unbroken form of art in the world and takes many forms. Represented here is the Gulgurn Manja ('hands of young people') Shelter, where rock art in the form of paintings depicting emu tracks and handprints can be seen. This shelter can be found in The Grampians National Park (Gariwerd) on Djab Wurrung and Jardwardjali country which has the largest number of rock art sites in Southern Australia.

Australian Aboriginal people and Indigenous communities around the world have a deep and detailed knowledge of their native ecosystems and environment. This knowledge relates to a wide variety of topics, including natural cycles, seasons, climate, and the adaptations of, and interdependencies between, different species. This knowledge has been used by Indigenous people to inform their economic practices, gathering of food, and utilisation of resources.

In this lesson, we will examine two examples in which Indigenous peoples' understanding of adaptations of, and interdependencies between species can be seen – first, through the cultural practice of fire management, and secondly, through the way in which Aboriginal people have utilised the relationship between the emu (*Dromaius novaehollandiae*) and the quandong tree (*Santalum acuminatum*) to generate food and resources.

Indigenous understanding of adaptations 2.2.7.2

OVERVIEW

Indigenous Australians have a longstanding and rich cultural knowledge of the role that environmental adaptations play in the survival of a species. One way this understanding of adaptations can be seen in Indigenous history is by examining the Indigenous practice of cultural fire management.

THEORY DETAILS

One key way that Indigenous Australians have contributed to our understanding of Australian ecosystems is through their utilisation of fire to maintain **Country**. Country is the physical place and all the animals, plants, and people that live there, not just now, but in the past and in the future. Furthermore, Country also encompasses the spiritual meaning and feelings of deep connection and attachment associated with that area for a community and an individual. For Indigenous people, Country is a living thing and the language that is used when describing Country reflects this. For example, they consider Country that is managed well to be 'healthy' Country, and that poorly managed Country to be 'sick' and needs human intervention to bring it back to good health.

Country an area that is traditionally owned and looked after by an Aboriginal language group or community, or by certain people within that group. The term may indicate more than simply a geographical area – it is also a concept that can encompass the spiritual meaning and feelings of deep connection and attachment associated with that area

pyrophilic a plant for which fire is a necessary part of its life cycle

epicormic shoots a fresh growth from a plant that is stimulated to develop after the plant has been damaged

It is believed that when Indigenous Australian people first arrived in Australia over 60 000 years ago, the continent was already drying – that is, rainfall was decreasing and temperatures were increasing. As a result, much of the vegetation was changing from rainforest and grassland towards more arid and semi-arid woodlands and forests dominated by *Eucalyptus* plants. In this more fire-prone environment, **pyrophilic** plant species came to dominate. Wild bushfires occurred frequently and, as a result, many of these plants adapted to tolerate fire and heat – many species in the *Eucalyptus* genus have evolved to produce **epicormic shoots** after fires and have developed seeds that survive the intense heat generated by bushfires (Figure 2).

Image: Pru Sanderson/Shutterstock.com

Figure 2 Epicormic shoots can be seen growing here on this *Eucalyptus* tree after a bushfire in Marysville, Victoria.

In order to live in this arid environment, Aboriginal Australians had to understand these adaptations and learn how to use fire to control and stimulate plant growth to their advantage. They utilised fire in a variety of ways, including to clear shrubs from grasslands and woodlands, promote various species of plants, and to break up Country and therefore reduce the intensity and extent of wildfires (i.e. generating fire breaks). This type of burning preserved the canopy of trees, which is important as it provides both shade and food for animals as well as protection that can be used to escape from the fire below. It also reduces the amount of carbon released by the fire, as tree canopies release large amounts of carbon when they burn.

Figure 3 *Arthropodium milleflorum* produces flesh tubers that can be eaten.

Plants stimulated to grow by fire served as food for both grazing animals and Indigenous Australians themselves – many plants that grew as a result of this practice were used by Aboriginal people as food, including the Vanilla Lily *Arthropodium milleflorum* (Figure 3).

If you're planning on burning land, however, you need somewhere you and all the animals can go so you don't get burned yourself! Indigenous Australians, therefore, would burn in small patches and let other areas regenerate for cover. These sorts of burnings often would stimulate a wide variety of seeds in the soil to sprout, as well as removing shrubs and old, woody plants that interfered with the growth of plants eaten by animals. Additionally, some woody plants cease to produce flowers when they are over 12 years old so burning these away provides space for new, flowering growth to develop, benefiting animals such as nectar-eating possums and birds.

Whilst the exact fire management behaviours varied from region to region throughout Australia, there were nevertheless some common characteristics. Aboriginal managers would walk Country and were able to see where fire was needed, using it appropriately to address any issues they discovered. The type of findings that might have triggered a decision to burn include the presence of:

- long, dry grass
- a large amount of leaf litter on the ground
- dead standing shrubs
- choked and impassable areas
- fire hazards around camps, paths, and areas of fire-sensitive vegetation like rainforest.

The fires created under Aboriginal management were smaller, more frequent, and less damaging than wild bushfires (Figure 4). Because of this, they're often referred to as 'cool burns.' These fires resulted in an overall reduction in fuel loads in the ecosystem, meaning that wild bushfires became less intense, preserving important and limited ecosystem components such as habitat trees and hollows.

Indigenous fire management, therefore, actually promoted local biodiversity, resulting in the creation of a complex patchwork of different vegetation types. This **fire mosaic** was significantly more varied and created an environment that was safe from out of control, intense heat-producing bushfires, allowing the growth of various plants and animal foods (Figure 5).

fire mosaic the pattern created by Indigenous Australian cultural fire management in which some areas of land are burned while others are left to regenerate

This form of fire management contrasts with current 'hazard reduction burns' that are conducted widely across Australia in preparation for bushfire season. These burns are conducted on a large scale and are often ignited from the air via helicopter. Table 1 illustrates the difference between Indigenous 'cool burns' and 'hazard reduction burns'.

Table 1 Comparison between 'cool burns' and hazard reduction burns

	Indigenous 'cool burns'	Hazard reduction burns
Purpose	fuel reduction, weed control, healing Country, cultural practices, access to Country	fuel reduction
Burn speed	slow	fast
Temperature	low	high
Height	knee-height	over 1.5 metres
Impact on wildlife	low – speed and intensity of fire allows animals to escape, leaves/seeds/roots/soil intact, animal habitats (e.g. logs) are preserved	high – speed of fires means animals don't have time to escape, leaves/seeds/roots/soil are destroyed, animals habitats are also burned to ash
Time taken for environment to recover	short	long

Image: Steve Todd/Shutterstock.com

Figure 4 Cultural burning conducted in accordance with Indigenous fire knowledge, like this burn seen in Kakadu National Park in the Northern Territory, results in small, controlled fires that reduce the risk of catastrophic bushfires.

Image: Daniel Mitchell/Shutterstock.com

Figure 5 In areas without land management, fires can burn uncontrollably at incredibly high temperatures and damage significant amounts of wildlife both in the short term (due to the fire itself) and the long term (due to the destruction of habitats).

It's important to understand that the fire management principles used by Aboriginal people to take care of Country are not just practical, but also cultural and spiritual as 'the cultural use of fire is a socially and ecologically complex practice, governed by kinship, eldership, spiritual connections to Country, and environmental interactions with fire' (Victorian Traditional Owner Cultural Fire Knowledge Group, 2020). Young Indigenous people are taught about fire management by practical instruction and observation, learning from **Dreamtime** stories and ancestors who show the right way to take care of Country using fire, and the dangers and responsibilities of those engaging in fire management practices (Figure 6).

Dreamtime the set of stories and beliefs of some Indigenous Australians, particularly pertaining to the world and its creation

Image: sunnypicsoz/Shutterstock.com

Figure 6 According to the legends of the Woiwurrung people (who lived on the banks of the Yarra River), *Waung* the crow was responsible for stealing fire from a woman named *Kar-ak-ar-ook* and bringing it to humanity.

In Victoria, there has recently been a push for greater Indigenous involvement in our planning and management of bushfire season. It is becoming increasingly clear that Indigenous knowledge about fire and how to maintain a flourishing ecosystem in an increasingly fire-prone environment is valuable as we experience longer, more intense bushfire seasons due to the consequences of climate change. In areas of the Northern Territory where Indigenous fire management has taken place, bushfires seem to have become more easily controlled, with fewer fires able to travel large distances and wipe out entire habitats.

The Victorian Traditional Owner Cultural Fire Strategy is an initiative that acknowledges Aboriginal fire knowledge and seeks to include and learn from Aboriginal people's fire management principles. Victorian Forestry is employing Aboriginal cultural burning across the state and recognises that the fire knowledge held by Indigenous Australians can be used to reduce hazardous wildfires, promote biodiversity, and restore the cultural values of land for Aboriginal people and the broader community.

Theory in context

You can read the handbook of the Victorian Traditional Owner Cultural Fire Strategy to understand how Aboriginal people in Victoria view land, Country, and use fire as a management tool. It can be found at: knowledge.aidr.org.au/media/6817/fireplusstrategyplusfinal.pdf

Indigenous understanding of interdependencies 2.2.7.3

OVERVIEW

Interdependencies between species within an ecosystem are well understood by Indigenous Australians, as seen in their knowledge of the mutualistic relationship between quandong trees and emus to obtain food and wood.

THEORY DETAILS

There's no getting around it – emus are weird birds (Figure 7). They have huge bodies but tiny wings, can survive up to two weeks without eating anything, and are the only bird with calf muscles (emus never skip leg day). All this aside, emus play a central role in the Australian ecosystem – something that Indigenous people understand incredibly well.

Image: Nesru Markmedia/Shutterstock.com

Figure 7 Emus are widely regarded as the least funny of bird species because they are never 'emused'. They are also the most easily confused, and live in a constant state of b...emusement.

The emu is the largest bird in Australia, and eats a diet primarily consisting of fruit and seed plants. Like many other birds, emus swallow their food whole and then process it along their digestive tract, including in the gizzard where rocks and grit help to break up consumed matter. These digested materials are then excreted as faeces. As emus can travel up to 25 km per day, many plants have developed a **mutualistic** relationship with emus, relying on them for seed dispersal via their faeces. One such species is the quandong tree.

mutualism interactions between two organisms of different species where both parties experience some overall benefit

Lesson link

If you'd like to learn more about the digestive system of birds, fly back to ***lesson 5C*** to find out more.

The quandong is a species of parasitic tree that grows on the roots of a host plant (Figure 8). The tree bears large quantities of fruit throughout spring and summer which have very nutritious flesh that contains a large amount of vitamin C and other nutrients. Germination of the fruit's seed is difficult, however, as it is surrounded by a very hard, durable seed coat. Despite this, quandongs are very widely distributed through arid and semi-arid Australia from the Kimberley in Western Australia, to the Murray Darling region of Victoria. How is this possible? The answer – emu poo.

Lesson link

If your relationship with relationships between species has become complicated, turn back to ***lesson 10C*** to rekindle the romance.

Image: Serj Malomuzh/Shutterstock.com

Figure 8 The quandong tree

Emus eat the fruit of the quandong tree. As the seed traverses through the digestive tract, the seed coating softens allowing it to germinate more easily. Emus then excrete this softened seed in their faeces. In this way, emus both disperse the seed widely and assist in germination and the plant's early life, as the emu droppings provide a source of fertiliser for the young plant. The behaviour of emus also means that quandong seeds are distributed to appropriate habitats – in the shade, and in proximity to host trees and water.

This relationship between the emu and quandong tree is well understood by Indigenous Australians. Aboriginal people looked for quandong trees where emus resided, particularly near water and in shady areas where the birds might rest. Even more importantly, Aboriginal people noticed that the seeds of the quandong that passed through the emu's digestive system were softened. This would allow them to be cracked and processed for food and oil.

Table 2 describes ways that some Indigenous people have used the quandong fruit and seeds.

Table 2 Uses of the quandong fruit and seed

Use	Part of Plant	Method
Food	Fruit flesh	Aboriginal people eat the fruit fresh, however, can also roll it into flat sheets or balls which are dried in the sun. This process concentrates the sugars and nutrients and results in a 'fruit leather' that can be stored as an emergency food source.
Food	Kernel	The kernels of the seeds are full of lipids that can be eaten as an energy-rich and nutritious food.
Medicine	Leaves and oil from the seeds	The leaves are used by bush medicine practitioners to treat arthritis, and the oil from the seeds has been used to treat general pain.
Fire	Seed oil	The oil is applied to firesticks to aid in starting fires as it is flammable.
Increase distribution	Seeds	Aboriginal people have distributed digested quandong seeds in arid areas to ensure a harvest of fruit and seeds, and to attract emus. Emus then eat the fruits, digest the seeds, and continue the cycle of seed softening and dispersal.

Quandongs have played a central role in the history of Aboriginal Australians in certain regions. In the Riverina, an area of southern New South Wales home to a variety of Aboriginal language groups including the Yorta Yorta and the Wiradjuri, large assemblages of stone anvils used for cracking the seeds have been discovered (Figure 10). This is especially notable because hard stones such as these are very rare in the region – this suggests that Indigenous people transported the stones for many tens of kilometres to the areas where the quandongs grew.

Figure 9 Quandong stones were used to crack open the tough seeds of the Quandong fruit.

Finally, quandongs are now starting to develop significant economic potential as food products. Aboriginal people have played an important role in establishing this industry, and it is important that certain groups of Aboriginal people with millennia of knowledge about the quandong be involved in the commercialisation of them. Part of the nature of Aboriginal culture and knowledge is that plants and animals have cultural importance and that it is the responsibility of particular knowledge holders to care for them. It was also Aboriginal knowledge that allowed Western science and culture to discover the plants in the first place. Early European explorers of Australia who were accompanied by Aboriginal guides were often given quandong fruit to save them from scurvy. Given these considerations, it is important to acknowledge the intellectual property rights of Indigenous Australians when discussing the economic potential of quandongs.

Theory summary

Indigenous Australian cultures have a rich understanding of the Australian ecosystem. This knowledge has allowed Indigenous Australians to utilise the adaptations of, and interdependencies between, species that exist in Australia to ensure not only their survival but also the flourishing of the native ecosystem. Indigenous knowledge of Australia's ecosystem can be used in conjunction with Western scientific approaches to help us solve a number of important problems, including how to best manage the increasing risk of catastrophic bushfires occurring in Australia due to climate change.

The relationship between the quandong tree and the emu is one that Romeo and Juliet themselves would be envious of. Emus eat the fruit of the tree, getting nutrients and energy. The tree, on the other hand, uses the emu as a means of seed softening and dispersal. This relationship was well understood by Indigenous Australians, who were able to use this knowledge to harvest fruit and wood. Aboriginal Australians' deep knowledge of the local ecosystem and ability to live in harmony with it has allowed Indigenous Australian culture to survive for a staggering 60 000 years.

10D QUESTIONS

Theory review questions

Question 1

Indigenous Australian Ways of Knowing have been generated through

A repetition and experimentation.

B guessing and storytelling.

Question 2

Which of the following are included in the use of the Indigenous concept of 'Country'? (*Select all that apply*)

I only living organisms

II sense of connection

III spiritual meaning

IV geographic area

Question 3

Fill in the blanks with the following terms.

- increase
- reduction
- fire mosaic
- cultural burning

__________ is a millennia-old practice in which Indigenous Australians have cultivated land. It results in a notable __________ in biodiversity, and potentially a __________ of Australia's carbon emissions by lowering the number of out of control bushfires. The pattern created by the practice, in which some areas are burned while others are left to regenerate, is called a __________.

Question 4

Fill in the blanks in the following sentences.

Emus and quandongs have a __________ relationship. Emus eat quandong fruit and digest the seed in their __________. This digestion softens the seed, making it easier for it to __________.

SAC skills questions

Bioethical deep dive

Use the following information to answer Questions 5–11.

Medications that we use in our daily lives contain chemicals taken from nature. For example, many analgesics (medications that are used to reduce pain) such as morphine are produced by compounds extracted from the flowering plant the opium poppy (*Papaver somniferum*). One area of research responsible for uncovering plants that may provide medicinal benefits is ethnobotany, the study of a region's plants and the ways they are used by Indigenous cultures.

Whilst this practice has resulted in the discovery of many different forms of treatment, Indigenous cultures rarely receive any benefits from it. Many times throughout Australian history, plants, animals, and other materials have been removed without the consent of Indigenous people. For Indigenous communities with a strong connection to Country, this can cause significant spiritual, cultural, and economic harm. They also do not typically have their intellectual property rights protected, and do not receive any commercial benefits of the discovery, and associated economic gain, that was made using their knowledge.

In 2020 the Queensland government reformed a law governing 'biodiscovery'. According to this reform, anyone partaking in 'biodiscovery' – that is, the use of native biological materials for commercial applications – must undertake all reasonable measures they can to form an agreement with the custodians of the Indigenous knowledge being used, including a benefit-sharing agreement.

Question 5

Analgesics are a class of medication that

A manage pain.

B treat the cause of pain.

Question 6

Ethnobotany is the study of

A how Western medicine uses Indigenous knowledge to create new treatments.

B how Indigenous cultures use plants from their region.

Question 7

Which of the following is a typical consequence of ethnobotany for Indigenous cultures?

A They often do not receive any financial benefit for the products developed using their cultural knowledge.

B Their intellectual property rights are acknowledged, ensuring that they benefit from any future commercial interests generated by their knowledge.

Question 8

Which of the following represents an approach to commercialisation of the quandong tree that is in line with Queensland's 2020 biodiscovery reforms?

A Use of quandong supplements should be offered to Indigenous people first.

B Consultation with Indigenous cultures should take place to ensure benefit-sharing agreements are put in place.

Question 9

Using the information presented in the article, the exclusion of Indigenous Australians from fire management practises disregards which ethical concept?

A Justice, because there is a duty to include them in fire management practises.

B Integrity, because much of what we know about land management comes from Indigenous cultures.

C Non-maleficence, because Indigenous people have a strong spiritual and cultural connection to Country.

Question 10

Which of the following statements from the extract could be referred to by someone utilising the ethical concept of non-maleficence to argue for the reforms to the 'biodiscovery' laws that have taken place in Queensland?

A 'medications we use in our daily lives contain chemicals taken from nature'

B 'whilst this practice has resulted in the discovery of many different forms of treatment, Indigenous cultures rarely receive any benefits from it'

C 'anyone partaking in "biodiscovery"... must undertake all reasonable measures they can to form an agreement with the custodians of the Indigenous knowledge being used'

Question 11

Which of the following arguments for the inclusion of Indigenous cultures in the development of products based on their knowledge best demonstrates the ethical concept of respect?

A Excluding Indigenous cultures from this process creates a significant amount of spiritual and cultural harm.

B Indigenous cultures should benefit from this process and have equal access to the benefits brought about by it.

C The beliefs and welfare of Indigenous cultures are inherently valuable and worthy of consideration and appreciation.

D Businesses and commercial enterprises that utilise Indigenous knowledge during product development should be transparent about this and disclose the origins of their product.

Exam-style questions

Within lesson

Question 12 (1 MARK)

Fires created by cultural burning

A burn at lower temperatures but spread quickly.

B burn at high temperatures for a long period of time.

C burn at lower temperatures and do not burn the canopy.

D burn at high temperatures and maintain habitats for animals.

Multiple lessons

Use the following information to answer Questions 13 and 14.

The emu and quandong exhibit a mutualistic relationship in which emus eat the fruit of the quandong tree, soften the seed in their digestive tract, and then widely distribute the seed via excretion of the softened seed in their faeces.

Question 13 (1 MARK)

In a mutualistic relationship

A individuals from both species benefit from the relationship.

B an individual from a species benefits from the relationship at the expense of the other species.

C an individual from a species benefits from the relationship by killing and eating the other species.

D one of the species gets a benefit from the relationship, whilst the other experiences no benefit or harm.

Question 14 (1 MARK)

Which of the following statements about mutualisms is correct?

A Facultative mutualisms involve two species where one gains some benefit while the other experiences no significant benefit or harm.

B Obligate mutualisms involve two species where individuals are completely dependent on the other species for their survival.

C Facultative mutualisms involve two species where individuals can't survive without mutualism.

D Obligate mutualisms involve two species where individuals can survive without mutualism.

Question 15 (3 MARKS)

Indigenous Australians utilised a number of what are now termed 'traditional' management strategies to ensure the environment in which they lived was not damaged by their presence. One such strategy included instituting taboos (or bans) on the hunting of certain species that were important to a local ecosystem, including keystone species.

a Explain what is meant by the term keystone species. (1 MARK)

b Describe the role apex predators and ecosystem engineers play in an ecosystem, and explain why it is important to maintain each type of species. (2 MARKS)

Key science skills and ethical understanding

Question 16 (1 MARK)

A company wants to develop a new pharmaceutical product using tea-tree oil, which has been used by Indigenous Australians for thousands of years. Which of the following responses to the information given adheres to the ethical concept of respect?

A A trial should be conducted on a large sample of people to ensure the product is safe and effective.

B The company should be transparent about the source of its product and the results it obtains in clinical trials.

C An economic agreement should be made to compensate Indigenous Australians to acknowledge the value of their heritage and knowledge.

D Indigenous Australians should be consulted on how best to use the product, and the company should then apply for patents to protect their product.

Question 17 (5 MARKS)

Whilst much media attention is given to bushfires that occur in southern areas of Australia, the majority of wildfires occur in the north of Australia – specifically, in areas in which the vegetation is classified as 'tropical savannah.' The table shows the proportion of total carbon emitted by fires, according to the major vegetation classes by state or territory.

Vegetation type	**% total carbon emitted**								
	NSW	**TAS**	**WA**	**SA**	**VIC**	**QLD**	**NT**	**ACT**	**AUSTRALIA**
Tropical savannah	0	0	89	0	0	88	100	0	89
Open woodland and temperate grassland	10	6	–	34	5	0	0	0	–
Forest, Prescribed	15	13	2	0	41	2	0	10	2
Forest, Wildfire	49	80	8	0	33	3	0	90	6
Cereals	24	1	2	66	21	3	0	0	3
Sugar	2	0	0	0	0	4	0	0	0
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Source: adapted from Meyer et al. (2004)

a According to the table, which vegetation type contributes to the largest amount of carbon being emitted in Victorian fires? (1 MARK)

b Indigenous fire management principles are used extensively in northern Australia in areas of tropical savannah to reduce the risk of wildfires. These fire management principles emit approximately half the amount of greenhouse gases produced by wildfires and therefore have the potential to reduce greenhouse gas emissions.

   i Describe and explain one way Indigenous fire management principles reduce the risk of wildfires whilst emitting lower levels of greenhouse gasses relative to wildfires. (2 MARKS)

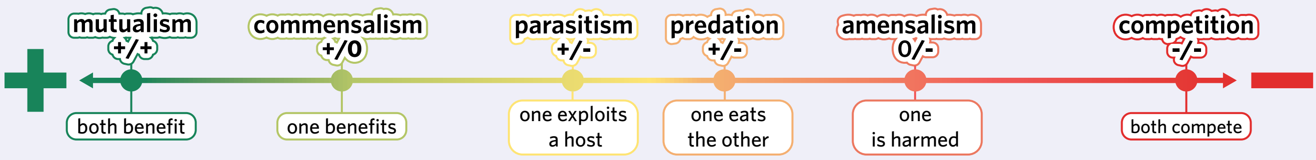
   ii Using the information provided, describe how a person adopting a consequences-based approach to bioethics would argue in favour of Indigenous fire management. (2 MARKS)

CHAPTER 10 SUMMARY

		Adaptations in the hot and cold		
		HOT		COLD
		Temp balance	Water balance	
Animals	Structural	• Insulation techniques • SA:V	• Capillary channels in skin	• Insulation techniques • SA:V
	Physiological	• Endotherms vs ectotherms • Vasodilation of blood vessels • Evaporative cooling	• Concentrated urine • Low water faeces • Metabolically produced water	• Endotherms vs ectotherms • Vasoconstriction of blood vessels • Countercurrent circulation • Torpor • Antifreeze proteins
	Behavioural	• Nocturnal • Endurers vs evaders • Evaporative cooling • Burrowing	• Nocturnal • Endurers vs evaders	• Reducing exposed SA • Huddling • Seeking shelter • Migration
Plants	Structural and psychological	• Light coloured leaves • Low SA leaves • Vertically hanging leaves • Fire regeneration	• Deep roots • Water storage mechanisms • Sunken stomata • Rolled/folded leaves • Guard cells and stomata regulation	• Modifications to cell membrane • Increasing solute concentration (freezing point depression) • Seed dormancy • Antifreeze proteins

Interdependencies between species

Two species within an ecosystem can interact in a number of ways. These can be positive relationships where both individuals benefit (mutualism), detrimental to both individuals (competition) or various combinations of benefits and drawbacks.



Native Australian ecosystem

Indigenous Australians have an ever-growing understanding and appreciation of the Australian ecosystem that has spanned over 60 000 years. The understanding of adaptations of species and interdependencies between species has allowed Indigenous Australians to survive for millennia whilst also ensuring the Australian ecosystem remains healthy. Examples of such knowledge include the use of cool burns and the benefits for pyrophilic plants and their ecosystems, as well as the utilisation of quandong plants and the relationship the plants share with emus.

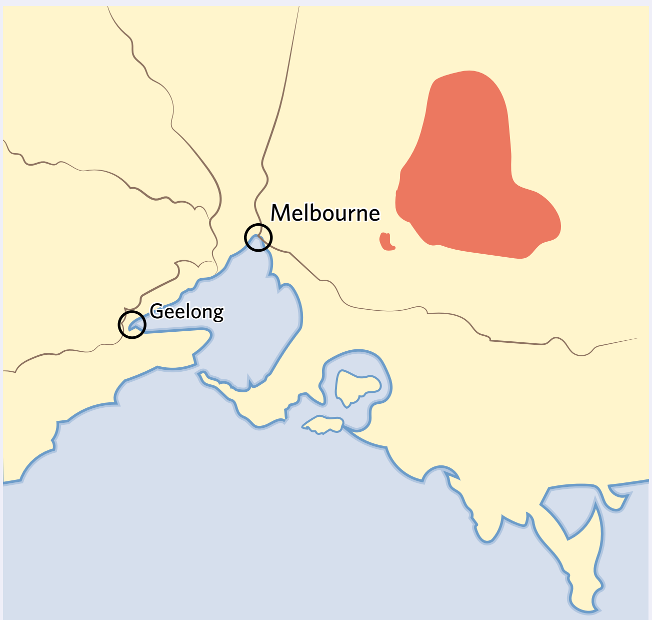
Keystone species

- The effects of a keystone species on an ecosystem are greater than expected relative to its population size.
- Apex predators have no natural predators and are at the top of the food chain.
- Ecosystem engineers create, significantly alter, or maintain the structure of an environment.

Population distribution, size, and density

- Population distribution is the range of geographical areas that members of the population are found in.
- Population size is the total number of individuals within a population.
- Population density is a metric for the number of individuals per unit area.

The leadbeater's possum native to Australia is critically endangered. Its population distribution is restricted to the forests of the Central Highlands in Victoria, as shown on the map. The population size of the leadbeater's possum is estimated to be 2 500 individuals. The area of distribution is approximately 3 500 km^2, therefore the population density of the possum is 0.71 individuals/km^2.



CHAPTER 10 SAC PRACTICE

SAC skills covered in this section:

✓ Case study analysis ✓ Bioethical deep dive

ADAPTING TO YOUR ENVIRONMENT (21 MARKS)

Red kangaroos

Red kangaroos (*Macropus rufus*) are found across large areas of Western and Central Australia. The red kangaroo can grow to three metres in length from head to tail, and they have been known to be able to cover 9 metres of distance with a single bounce. Sometimes, red kangaroos live and travel together in groups of up to 1 500 individuals. In the central Australian areas, in particular, red kangaroos are faced with the challenges of an arid environment. Fortunately, the kangaroos have evolved a number of physical, physiological, and behavioural adaptations to help them survive in this environment.

Image: Benny Marty/Shutterstock.com

One example of this is an evaporative cooling mechanism called saliva spreading. Red kangaroos will give their forelimbs a 'spit bath' by licking them until the fur is soaking wet. The forelimbs of the kangaroos have a large network of blood vessels within them near the surface of the skin.

1 Match each type of adaptation in red kangaroos to its description. Note that the types of adaptations may be used more than once or not at all. (4 MARKS)

Adaptation

- increased water input
- evaporative cooling
- insulation
- decreased water output
- evasion

Description

I __________ the kangaroo's fur is the optimal thickness to allow for heat release

II __________ kangaroos are less active during the day and stay in the shade when it's too hot

III __________ resting kangaroos pant

IV __________ selective eating of green, moist, grass in large amounts rather than drier grass

V __________ sweat glands allow for the evaporation of water during exercise

VI __________ kangaroo kidneys produce concentrated urine

2 Explain how 'spit baths' can cool red kangaroos down. (2 MARKS)

3 Does the term 'groups of 1 500 individuals' refer to population distribution, size, or density? (1 MARK)

Red kangaroos and dung beetles (of the family Scarabaeidae) native to Australia share an unusual relationship. Dung beetles collect kangaroo faeces, so that female dung beetles can lay their eggs within the faeces.

Red kangaroos also share a relationship with bacteria living within their digestive system. The bacteria are sheltered and receive a source of food whilst the bacteria aid the kangaroo's digestion.

4 Name the type of relationship between red kangaroos and dung beetles. (1 MARK)

5 Name the type of relationship between red kangaroos and the bacteria in their stomach. (1 MARK)

Red kangaroos are of great cultural and spiritual significance to Indigenous Australian people across Australia. Kangaroo meat was, and continues to be, a staple food source for Indigenous people and is a rich source of protein. Kangaroo pelts served many purposes such as clothing and rugs, and the skin could be crafted into water bags.

6 Indigenous Australians were known to use a variety of methods to hunt kangaroos, including the use of fire to draw kangaroos to easier hunting locations. Identify two other ways that Indigenous Australians were able to use fire to their advantage. (2 MARKS)

Indigenous Australian stories are rich with kangaroos. The Indigenous peoples have long-held a cultural appreciation for kangaroos, and the animals are a large component of Dreamtime stories.

Currently, populations of kangaroos across Australia are often culled as they can be viewed as a pest. Such decisions largely, or completely, exclude Indigenous peoples from the process, even though they have a deep spiritual connection and enhanced ecological understanding of the species.

7 Which ethical concept does this exclusion not adhere to? (1 MARK)

Blue whales

Much like red kangaroos, blue whales (*Balaenoptera musculus*) are faced with a number of challenges within their environment. Unlike kangaroos, however, this time it's the freezing cold that must be combatted. Blue whales are the largest animals on the planet, reaching up to 30 metres in length and weighing up to 200 tonnes – the equivalent of roughly 30 African bush elephants! The heart of a blue whale is the size of a car and its stomach can hold a tonne of krill.

Image: Chase Dekker/Shutterstock.com

Blue whales have developed a number of adaptations that allow them to survive in their cold environment including blubber, migration, and countercurrent circulation.

8 Explain how migration can be beneficial for animals in cold environments. (2 MARKS)

9 Briefly describe the process of countercurrent circulation in blue whales. (2 MARKS)

While they are not apex predators, blue whales, along with other whale species, are still considered keystone species. Whales have a huge influence on the functioning of oceans, and surprisingly, it has a lot to do with their faeces. Whales feed on nutrient-rich food such as krill deep in the ocean. When they need to expel waste, whales actually swim to the surface. Ecologists believe this is because they have trouble defecating under the extreme pressures deep in the ocean. Due to their nutrient-rich diet, whale faeces are also extremely rich in nutrients. Releasing these nutrient-rich faeces at the surface fertilises the phytoplankton that is suspended at the ocean surface, benefiting the entire ecosystem.

10 State the name given to the keystone species like the blue whale. (1 MARK)

Image: Johnny Coate/Shutterstock.com

Many plants must also adapt to survive in extreme arid or cold environments.

11 How can adaptations to a plant's leaves enable it to survive arid environments? (3 MARKS)

12 What is 'freezing point depression' in plants? (1 MARK)

CHAPTER 10 EXAM PRACTICE

Section A (6 MARKS)

Question 1 (1 MARK)

A plant in a desert environment can evolve many adaptations to survive the extreme environment. Some of these adaptations may include

A having dark coloured leaves, extensive root systems, and a high metabolic rate.

B having small leaves, spreading their roots horizontally, and having high stomatal density.

C orienting their leaves vertically, having an extensive root system, and a low stomatal density.

D producing seeds that are susceptible to desiccation, spreading their roots horizontally, and having a low metabolic rate.

Adapted from VCAA 2005 Exam 1 Section A Q24

Question 2 (1 MARK)

The environmental factor that is most likely to be affected by an increase in population density is

A resource availability.

B oxygen availability.

C water availability.

D temperature.

Question 3 (1 MARK)

One major way that animals can adapt to cold environments is by physiological adaptations of the blood circulation system. The two main ways to prevent heat loss from blood are

A vasoconstriction, where blood vessels decrease in diameter, and countercurrent circulation, where warmer blood from the heart helps to warm cold blood returning to the heart.

B vasodilation, where blood vessels increase in diameter, and countercurrent circulation, where warmer blood from the heart helps to warm cold blood returning to the heart.

C vasoconstriction, where blood vessels increase in diameter, and countercurrent circulation, where warmer blood from the body helps to warm cold blood leaving the heart.

D vasodilation, where blood vessels reduce in diameter, and countercurrent circulation, where warmer blood from the body helps to warm cold blood leaving the heart.

Question 4 (1 MARK)

Which of the following is an example of commensalism?

A A tree in the forest grows tall and shades a smaller tree from the sun.

B Fungi produce compounds that can inhibit the growth of bacteria nearby.

C Golden jackals will follow tigers in order to feed on the remains of tiger kills.

D Bacteria live in the intestines of humans providing the human with digestive benefits.

Question 5 (1 MARK)

Which of the following statements about parasitism is most correct?

A A parasite lives within their host organism and parasitism is a form of predation.

B A parasite lives within their host organism and parasitism is not a form of predation.

C A parasite can live within, or on the outside of, their host organism and parasitism is a form of predation.

D A parasite can live within, or on the outside of, their host organism, and parasitism is not a form of predation.

Question 6 (1 MARK)

Indigenous Australians have used cultural burning methods as fire management practices for millennia. Which of the following statements best describes the aim of Indigenous 'cool burns'?

A To generate a slow-burning fire that reaches large heights and burns the canopy of trees to the ground, benefitting tree-dwelling animals.

B Utilise a fast-moving, high-temperature fire front to the advantage of the population by incorporating fire breaks.

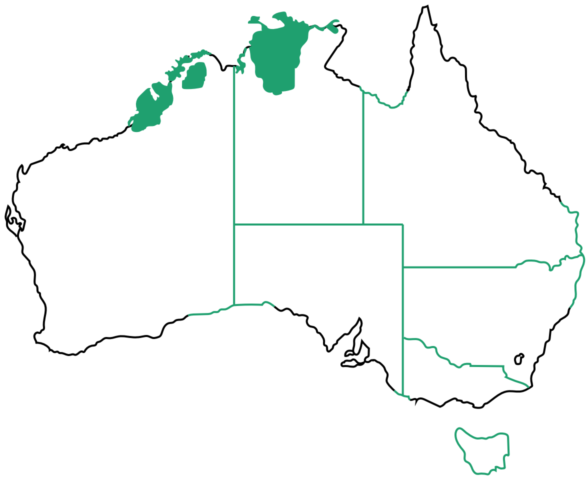
C Produce the smallest amount of harm to wildlife by fueling a fast-moving fire that will take less time to go out.

D To produce a knee-height fire that moves slowly, reduces fuel reduction, and removes future fire hazards.

Section B (14 MARKS)

Question 7 (7 MARKS)

The Kakadu plum (*Terminalia ferdinandiana*), also known as the billygoat plum or green plum, is a flowering plant native to Australia. The plum is found in the northern parts of Australia from Katherine to the Kimberley as shown. The Kakadu plum fruit has the world's highest recorded fruit content of vitamin C, meaning it has many potential applications in the food, beauty, and health industries. Indigenous Australians have long known about the nutritional value of the Kakadu plum and have utilised it for thousands of years.



a What type of characteristic of a population does the phrase 'from Katherine to the Kimberley' relate to? (1 MARK)

b Birds can disperse the seeds of a Kakadu plum after consuming it. This is a mutualistic interaction as the bird gains food whilst the plant has its seeds dispersed. Other plant species have adapted to create seeds that are well-suited to stick to the feathers of birds or fur of other animals. Typically the animal carrier is unaffected by the sticking seeds as they transport them around without even knowing.

Name the type of relationship between these seeds and the animal carrier. (1 MARK)

c Frequently in the past, commercial applications of native plants with desirable qualities have often left the native Indigenous people of the area out of any commercial gain, even though the Indigenous people are the ones that lead to the discovery of the plant. Identify an ethical concept that these actions do not adhere to. Justify your response. (2 MARKS)

d Northern parts of Australia can experience extremely hot weather, where temperatures can routinely exceed 40–45 °C. The Kakadu plum, as well as all other plants and animals that make up the ecosystem, must be able to withstand extreme heat to survive.

i Compare and contrast an endotherm and an ectotherm. (1 MARK)

ii Identify two adaptations relating to the internal balance of water that allow animals to cope with hot environments. (1 MARK)

Adapted from VCAA 2005 Exam 1 Section B Q8d

iii Briefly explain how the vasodilation of blood vessels in animals alters core body temperature. (1 MARK)

Adapted from VCAA 2005 Exam 1 Section B Q8bi

Question 8 (7 MARKS)

Samolus repens (creeping brookweed) is a flowering halophyte native to Australia. *S. repens* have been known to grow in and around saline creeks and bogs, especially in coastal regions.

Plants exposed to high salt stress may experience a reduction in the uptake of water by roots, even when the soils have high water content. In high salt soils, *S. repens* increases the concentration of Na^+ in its root cells to above the concentration of salt in the groundwater.

a Why is water uptake reduced in high salt soils? (1 MARK)

b Why does *S. repens* increase the concentration of Na^+ in its roots? (1 MARK)

c In colder environments, some plants have adapted to use salts and other solutes to their advantage. In such plants, when the temperature drops, the plant increases the concentration of solutes within their cells to increase their resistance to freezing. This works because as the concentration of solutes increases, the freezing point of water becomes lower.

Other than freezing point depression, identify two adaptations that plants can possess to cope with cold environments. (1 MARK)

Adapted from VCAA 2005 Exam 1 Section A Q24

d Two students, Sam and Aria, wanted to experiment on *S. repens*. They hypothesised that 'an increase in the salinity of the supplied water will increase the degree of wilting of *S. repens*'.

To validate this hypothesis, Sam and Aria ran an experiment. They planted ten *S. repens*, three of which were watered with rainwater, while the rest were watered with seawater. They ran the experiment for ten days.

On the tenth day, Sam and Aria measured the wilting of *S. repens* on a scale of 1 to 10, where 1 is no wilting and 10 is death. They also measured seven other variables. Neither Sam nor Aria recorded the methods they used to measure any of these variables. The outcomes of the experiment are summarised in the table.

	Rainwater group	**Seawater group**
Average growth	1 cm	3 cm
Average wilting	7	3
Average greenness of leaves	4	5
Average number of leaves	15	17
Average thickness of stem	1.5 cm	1.3 cm
Average length of leaves	3 cm	2.6 cm
Average width of flowers	6 cm	5 cm
Average salt content in leaves	1.4 mg/L	2.8 mg/L

i After running their experiment, Sam and Aria changed their hypothesis to 'an increase in the salinity of the supplied water will lead to increased salt content of *S. repens*'.

Why is it bad practice to change the hypothesis after running an experiment? (1 MARK)

ii In the experiment, Sam rated the greenness of the leaves by looking at them. Is this measurement reproducible and repeatable? Explain. (1 MARK)

iii In the saltwater treatment, Aria noticed salt crystals on the underside of the leaves of *S. repens*. This did not occur in the rainwater treatment. Where did this salt come from and what is the purpose of these salt crystals? (2 MARKS)

UNIT 2

AOS3

How do humans use science to explore and communicate contemporary bioethical issues?

In this area of study students explore a contemporary bioethical issue relating to the application of genetic knowledge, reproductive science, inheritance, or adaptations and interdependencies beneficial for survival.

Examples of investigation topics include, but are not limited to: genomic and epigenetic research; cloning for agriculture, horticulture or other purposes; assisted reproductive technologies; prenatal and predictive genetic testing; strategies for maintaining genetic diversity within a species or population; the impact of introduced species; changes to specific keystone species on populations and ecosystems; or the use of biomimicry to solve human challenges or biopiracy of Indigenous knowledge.

Students may develop a research question related to the applications included above or, in conjunction with their teacher, they may develop their own research question related to Area of Study 1 and/or Area of Study 2. Possible starting points when developing a research question may include stimulus material such as announcements of recent discoveries, an expert's published point of view, a TED talk or a YouTube presentation, an article from a scientific publication, public concern about an issue, changes in government funding, or new government initiatives.

Analysing and synthesising secondary data, students demonstrate and apply their knowledge and relevant key science skills to: explain the biological concepts specific to the identified bioethical issue; consider different perspectives; outline social, economic, legal, and/or political factors relevant to the selected issue; choose a position or course of action on the basis of reasoning and reflection; and communicate their findings.

The application of ethical understanding in VCE Biology involves the consideration of approaches to bioethics and ethical concepts.

Outcome 3

On completion of this unit the student should be able to identify, analyse and evaluate a bioethical issue in genetics, reproductive science, or adaptations beneficial for survival.

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HOW TO INVESTIGATE A BIOETHICAL ISSUE

As part of your assessment for Unit 2 Outcome 3 in VCE Biology, you are required to identify, analyse, and evaluate a bioethical issue of your choosing that relates to one of the three topics covered in Unit 2: either (1) genetics, (2) reproductive science, or (3) adaptations beneficial for survival. This task is set by the VCAA, and is designed to allow students to conduct their own research and demonstrate their skills in identifying and evaluating bioethical issues. We have included this lesson in your textbook to guide you through the process from start to finish!

This task will first require you to research and understand the concepts relevant to your chosen area of study, and then identify and analyse the broader social, economic, legal, and ethical implications that surround your chosen issue so that you can formulate your research question. Once your investigation is complete, you will then present your research in an appropriate format – such as a digital presentation, oral presentation, or a written report. This 'how-to' guide will help step you through each part of the process, and is broken down into key areas to mirror page 26 of the study design:

1. *Understanding the task*
2. *Scientific evidence*
3. *Scientific communication*
4. *Analysing and evaluating a bioethical issue*

We will even conduct a brief investigation of our own, and use that as an example throughout this guide for you to refer to. The research question we have chosen to explore is: ***'is it ethical to fund and undertake human-animal chimera research?'***

You may read this guide from start to finish, or simply refer back to certain sections of the guide whenever you are stuck on the corresponding section of your investigation. You may also wish to refresh your knowledge of the key science skills from lesson 1A, or sharpen the tools in your bioethical toolkit from lesson 1B – good luck!

Understanding the task

For Outcome 3 of Unit 2, you are required to identify, analyse, and evaluate a bioethical issue related to genetics, reproductive science, or adaptations that are beneficial for survival. To start this process, you must first choose a biological issue to explore, define your research question, and understand what the aims of your evaluation are.

Step 1: Choose a biological issue

Remember back to lesson 1B when we discussed the intersection between science and ethics. This is an incredibly important point for budding scientists, and is a capability that the VCAA wants to instill in VCE Biology students. As a result, to finalise Unit 2, the VCAA requires students to identify and evaluate a bioethical issue of their own choosing. To do this, you will be asked to identify a current bioethical issue related specifically to one of the following areas of research we've examined over the course of this unit:

1. Genetics (Chapters 7 and 8)
2. Reproductive science (Chapters 8 and 9)
3. Adaptations beneficial for survival (Chapter 10).

To decide which area of study you wish to investigate, it may be helpful to think about which topics caught your interest the most. Were there any specific questions you had when studying one of the areas? Did you find yourself wanting to know more about how a particular bioethical issue impacts on your own life or how the government regulates the research? As you know, almost all areas of biological research come with a range of social, economic, and political implications. Now it's just a matter of honing in on one of those implications and formulating a bioethical issue to investigate.

Lesson link

Figure 5 in ***lesson 1B*** provides a preliminary framework for identifying a bioethical issue, exploring the surrounding concepts, considering the different perspectives, as well as deciding on and reflecting upon a chosen course of action.

Lesson link

For further inspiration, you may want to refer to Table 1 of ***lesson 1B***, which outlines some current areas of research that raise bioethical questions. Moreover, there are many resources that provide interesting insights into current research and the ethics related to its applications, including the website: bioethics.com

Try asking broad 'application' style questions like: 'how would scientists use this on a larger scale?', 'how can this research be commercialised?', 'would everyone have equal access to this research?, and so forth. You can also go back to lesson 1B which covers bioethical issues in detail. Often, bioethical issues are in the news, discussed in TedTalks, or debated by politicians and scientists on TV.

Step 2: Formulate a research question

The bioethical issue you choose will typically need to be transformed into a testable research question, which you will attempt to answer in an informed manner using evidence from your research.

For example, if you were interested in reproductive science, you might be interested in honing in on cloning and consider the commercial applications of the current state of research. Remembering that your research question should aim to answer some form of bioethical concern, you might ask: 'how can we ensure that access to cloning technologies is fair and equitable between all Australian agricultural producers'? We can already see the bioethical concept of justice underwriting this question – it is concerned with access, fairness, and the consideration of different stakeholders, namely the different financial and contextual situations that make each 'producer' unique. Ultimately, you should ensure that your research question is testable and binary, so that you can arrive at a specific conclusion. For more information regarding the characteristics of a good research question, refer to lesson 1A.

Example

CHOOSING A BIOLOGICAL ISSUE AND RESEARCH QUESTION

The Biology Team at Edrolo has chosen the following research question to explore: **'is it ethical to fund and undertake human–animal chimera research?'**

For reference, a human–animal chimera is any cell or organism that is created via a mixture of human and animal material. This is a highly topical area of research in reproductive biology, and has enormous consequences regarding how we treat illnesses and exert control over genetics.

We will be exploring this research question throughout the rest of this guide.

Step 3: Understand what success looks like

Your final report may take a variety of different forms. The nature of this assessment is to provide you with the freedom to decide how best to communicate your research and answer a particular research question that interests you. That being said, there are a few broad things that you will want to be sure to include in your final report:

- Thoroughly explain the core biological concepts relevant to your area of study
- Discuss different opinions and points of view regarding your bioethical issue
- Analyse any legal, social, economic, and ethical implications that surround your bioethical issue
- Consider how you can use models and graphs to explain ideas and concepts effectively.

Depending on what presentation style you choose, Figure 1 may be helpful in structuring and formatting your presentation.

TITLE *(approx length: one sentence)*

Briefly indicate what the report is about. You may use your research question, or a one sentence summary of the biological issue.

INTRODUCTION *(approx length: 150–300 words)*

Your introduction should provide your reader with context on the biological issue you are presenting. You should include the aim of your study and your hypothesis.

You may include:

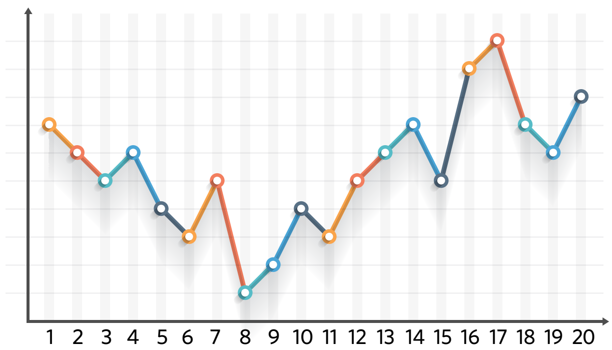
- a small explanation of the biological concept(s)
- a summary of the different opinions and/or social, legal, economic, and/or ethical implications
- the research that will be included

RESULTS *(approx length: 500–700 words)*

It may be helpful to think of the results as being in two sections:

1. The biological concepts
what are you exploring?

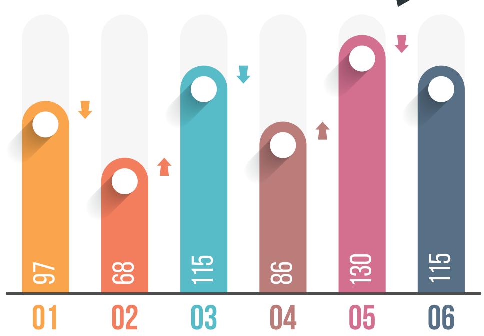
- Define key terms and explain the biological terminology for your reader
- It is often best to use models to explain the theory. Think like you are writing a short lesson about an area of biology
- Explore limitations in the research: have scientists explained everything there is to know about this area of study?



Effective communication
how can I represent ideas using models and visuals?

2. The issues
why are you exploring this?

- Here you want to outline any issues behind the concepts. Are there legal, social, economic, and/or ethical implications surrounding this area of study?
- What are the different opinions of stakeholders: what do scientists say? What about the public? What evidence (if any) are these opinions based off?
- Discuss the strengths and weaknesses of some of this evidence, considering its validity and authority.



DISCUSSION *(approx length: 500–700 words)*

Now it is time to engage with your research: distinguish between the types of evidence you've used, consider its strengths and weaknesses, and comment on its validity, reliability, and authority (including any sources of possible error or bias). This will help you come to a final position and conclusion re: your research question.

CONCLUSION *(approx length: 150–300 words)*

Comment on how your investigation has answered your research question. It is also a good idea to conclude with interesting areas of future research that your report didn't have space or scope to consider.

Figure 1 An example of a formatting style you could choose for this assessment

So, let's jump right into it and take a closer look at the steps needed to get to your final report. Remember to consider the examples we have provided and think about how each section might fit into your own report.

Stage 1: Scientific evidence

Stage overview

To go from an idea to a well-researched and comprehensive report, presentation, or poster, you must first conduct an investigation and collect solid evidence. This evidence will help you answer your research question.

Stage checklist

For this section of your investigation you need to demonstrate each of the following:

- the distinction between primary and secondary data
- the nature of evidence and information: distinction between opinion, anecdote and evidence, and scientific and non-scientific ideas
- the quality of evidence, including validity and authority of data, and sources of possible errors or bias
- methods of organising, analysing, and evaluating secondary data
- the use of a logbook to authenticate collated secondary data.

Each of these points should be addressed in your final report, given that they are taken directly from page 25 of the VCE Biology Study Design 2022–2026.

Step 1: Establish a logbook

Before doing anything, it is important to set up a logbook that can be used while researching and collecting data. This will help you to look back on your research and identify the sources you have used when constructing your report. There is no set format for using a logbook, so it is important to identify what works well for you. You could take handwritten notes, or type up your research with links. Make sure to enter the sources in chronological order from when you first used them, as this will enable you to map your train of thought and allow you to backtrack your research while acknowledging the source of the data.

Example

ESTABLISHING A LOGBOOK

A logbook was helpful in tracking the progress of our research across multiple days. The following is a small excerpt from our research logbook:

Source 1

- Date retrieved: 27/05/2020
- Name – Ethical arguments concerning human–animal chimera research
- Link: bmcmedethics.biomedcentral.com/articles/10.1186/s12910-020-00465-7
- Reference: Kwisda, K., White, L., & Hübner, D. (2020). Ethical arguments concerning human–animal chimera research: a systematic review. BMC Medical Ethics, 21(1). doi: 10.1186/s12910-020-00465-7
- Personal notes:
  - See discussion for percentage split between positive and negative endorsements.
  - See Strech and Sofaer (2012) for background on coding systems.

Step 2: Distinguish between primary and secondary data

When researching and collecting data to help answer your research question, it is important to distinguish between primary and secondary data. Make sure to explicitly mention the difference in your final report, and show when, where and why you decide to use each type.

- Primary data refers to results collected from experiments, interviews, or surveys undertaken by the researchers themselves.
- Secondary data refers to results from sources other than the researcher's own investigations, which may be discussed or leveraged by the researchers in the course of their own research.

Example

DISTINGUISHING BETWEEN PRIMARY AND SECONDARY DATA

In the case of human-animal chimera research, we might decide to conduct our own surveys, ask a large sample of people about their views, or interview experts. This would generate new responses, and would allow us to collect our own primary data and evidence.

On the other hand, secondary data can also be used. For example, in our investigation, we referenced a number of studies, including Kwisda et al. (2020), Shaw (2014), and Bourret et al. (2016)

Step 3: Discuss the nature of evidence

When considering data for your investigation, it is important to be able to draw evidence-based conclusions. In order to do this, you will need to evaluate the strength of different studies and the evidence they provide. Not all studies are the same, and not all studies include the same level and/or types of evidence.

To begin your evaluation, you should identify the nature of the information provided:

- Evidence – refers to primary and/or secondary data given in support of a position. This will typically be empirical and measurable, and obtained within the context of a formal research environment. Not all evidence is equal and certain evidence has more weight than other kinds. For example, data collected from a controlled clinical trial with a large and randomised sample is considered stronger than data collected from a case study using a small sample.
- Anecdote – a more informal type of evidence involving a personal account or report of a previous experience that may provide a certain level of support for a position. For example, a doctor might provide the anecdote: 'meditation cures anxiety. I prescribed daily meditation to a patient with severe anxiety, and after a week of practice, her symptoms had almost completely disappeared.' Often the key difference between anecdotal evidence and more rigorous empirical evidence discussed above is the absence of objective documentation, large sample sizes, and/or a controlled research environment.
- Opinion – refers to the personal belief or viewpoint of an individual, and is typically yet to be verified or deemed as fact. An opinion may be based on evidence and/or anecdote, but typically rests on grounds that are insufficient to arrive at complete certainty.

Example

COMPARING OUR EVIDENCE

- There is a large body of research and evidence associated with the bioethical issue of human-animal chimeras. Deciding which research to use was difficult. Certain categories of research that we used were:
- Evidence – Kwisda et. al. (2020) conducted a literature review of several scientific databases and retrieved 431 articles published between 2003-2017 in peer-reviewed journals.
- Anecdote – in another article, a particular geneticist discussed a bioethics conference that he attended and mentioned the comments of other experts in the field.
- Opinion – over the course of our research, we also found blog posts where many individuals expressed their opinions about human-animal chimera research. We decided to avoid using opinion in our final report, given that opinions are rarely verified and are typically the weakest form of evidence available. That said, we did use opinions as a starting point to help guide our research. For example, one blog post, written by a Biology professor, argued that animals with human DNA did not attain human status and therefore have less legal rights. This prompted further research into the scientific and legal literature to either verify or discredit the claim.

Step 4: Discuss the quality of evidence

Validity and authority of data

There are many ways in which we can judge the quality of data and evidence. Once again, these are discussed in great detail in lesson 1A, and include measures such as:

- repeatability – can the investigation be repeated by the same person using the same method and still obtain the same results?
- reproducibility – can other scientists follow the same method and get the same results?
- validity – does the research actually measure what it claims to measure? In other words, is our data answering our research question?

When deciding on relevant data to use for your investigation, make sure you consider the quality of the data in light of these measures. Further, look to see whether the data has been peer–reviewed and whether it is supported by other researchers. Just because the evidence that you use to justify and argue your position is not an anecdote or opinion, it does not automatically mean that it is therefore strong evidence. If the experiment from which the evidence is derived is not repeatable, reproducible, or valid, then the evidence is unlikely to be reliable. Make sure to familiarise yourself with this terminology and use it throughout your final investigation.

Sources of possible errors or bias

There are also a number of sources of possible error and/or bias that may exist in your chosen investigation. It is important to look for any potential errors or bias in the data you use for your investigation, and then mention these in your report. Often these will be explicitly mentioned by the researcher.

Some common errors to look for include (but are not limited to):

- Personal errors – which arise due to mistakes or miscalculations made by the researcher themselves. Counting incorrectly, rounding to the wrong decimal place, or labelling samples incorrectly are all examples of personal error.
- Systematic errors – which cause results to differ from the true value by a consistent amount each time, typically due to faulty equipment or calibration. They affect the accuracy of the experiment, and cannot be minimised through replication.
- Random errors – which affect the precision of the findings and are caused by unpredictable variations in the measurement process. For example, when a quantity is estimated by reading between the lines on a measuring cylinder.

Some common types of bias to look for include (but are not limited to):

- Confirmation bias – which refers to the tendency of researchers to only search for and/or include information that supports their personal beliefs, hypothesis, or the aim of their research.
- Selection bias – which refers to situations in which the selection of research participants is not properly randomised, meaning that the sample used to test the research question is not appropriately representative of the wider population that the research is hoping to draw conclusions about.
- Publication bias – which refers to situations in which the actual outcome or findings of a study determines whether it is published or not, and not only the merit or quality of the research. Journals will often publish studies with significant results (or 'positive' findings) more often and earlier than those with negative results or nonsignificant conclusions. Why is this a problem? All findings are important, whether they find something new or not. On a large scale, if publication bias exists then the published literature on a topic will not be properly representative of the actual available evidence, which means that the conclusions we draw from the existing scientific evidence may not accurately reflect the true phenomenon we are examining.

Example

JUDGING OUR EVIDENCE – LOOKING FOR ERRORS AND BIASES

The studies that we used for our investigation were taken from peer-reviewed academic journals. Further, we made sure to consider each study in light of potential errors or bias. For example:

- Kwisda et. al. (2020) included several databases for their screening to avoid selection bias towards a particular journal.
- Many of the literature reviews we looked at made use of searching software to avoid personal errors on the part of the researcher.
- Some of the research articles we examined as evidence were funded entirely by private research companies with strong stakes in the commercial application of human–animal chimera research. While this research is still helpful for our report, we were careful to consider the potential confirmation bias that the company might have in representing chimera research favourably.

You will notice that we mention potential errors and biases in our investigation, as well as where and how they are being controlled. Take the first two dot points for example. Here we are explaining that the researchers made sure to 'avoid' or 'control for' selection bias, which is just as important as identifying the actual presence of bias in the first place. This is because it shows that considerations were taken to make the evidence as reliable as possible. Look for opportunities to mention this in your report – it's a great way to demonstrate your skills as a researcher!

Step 5: Consider methods for analysing, organising, and evaluating

This investigation requires you to interact with lots of research and data. To do this, you must first analyse what you are reading to identify whether it is applicable to your research. Then, you should evaluate its strength or reliability before organising it in a way that makes sense to your reader. Let us look at these points in isolation.

Analysis

To analyse data you must compare the purpose of your investigation with the type of data you obtained – what is your research question and what type of data is needed to arrive at a meaningful conclusion? A clear understanding of what you are collecting data for will help you remain focused when analysing different sources and their relevance to your research question. To do this, you must consider the pros and cons of each different study through the lens of different measures, such as sample size, reproducibility, and the study's validity (Step 4).

Organisation

Organising data requires you to determine how best to display the key takeaways. This will typically involve transforming the data (e.g. into a table, line graph, or bar graph) to highlight any trend, pattern, or relationship that exists. For more information on how best to present data, see Table 7 in lesson 1A.

Evaluation

Once you have analysed and organised the data, it is now time to evaluate the strength of your findings and determine whether your research question is supported or not. This is known as coming to a position or course of action. You will judge the strength of the research based on the measures you considered in Step 4, and reach a judgement as to what the findings can tell you about your chosen area of research. This is likely where you will comment on any potential sources of error or bias (Step 4) and determine whether the researcher has acknowledged it themselves or not.

Example

ANALYSING, ORGANISING, AND EVALUATING

While researching, we came across many different types of information to help inform us as to whether human–animal chimera research is ethically justifiable. During our research stage, we collated any relevant and interesting data, and used our logbook to take notes on the strength and limitations of each resource based on the measures identified in Step 2.

cont'd

Example

ANALYSING, ORGANISING, AND EVALUATING – CONTINUED

Analysis:

- From there, it was time to analyse all of the data that we collected during our research stage. This involved considering all relevant perspectives surrounding the issue, and weighing up their strengths and weaknesses.
- We also identified studies that were not relevant to our research question, such as those that were outdated or beyond the scope. Given that our research question was focused on the ethics of 'funding' and 'undertaking' human–animal chimera research, this meant we excluded resources and evidence unrelated to these themes.
- Analysis of the data also allowed us to look for possible conclusions. For example, when we collated the information from our different sources, we realised that many of the arguments could be classified as either ethical pros or cons. From here we were able to flesh out both sides of the argument and establish whether the existing literature is predominantly for or against human–animal chimera research.

Organisation:

- Another decision that we made as researchers was to transform the secondary data from the literature reviews into a table that more clearly highlights the focus of our research question – namely, any ethical justifications for human–animal chimera research. The table was designed as follows:

Table # Ethical justifications

Ethical justification #1	Description	Source
Ethical justification #2	Description	Source
Ethical justification #3	Description	Source

Evaluation:

- Once we chose our data, looked for patterns, and organised the information in the most effective way possible, we finally evaluated the information in our report and came to a conclusion. This was the largest part of our discussion and included details about the strengths and weaknesses of our research as well as an overall statement about what our investigation had revealed.

Stage 2: Scientific communication

Stage overview

The last stage looked at how to conduct your research and collect your data. Now it's time to begin the process of presenting your findings – an exercise that requires a working knowledge of scientific communication. As you will soon see, this involves identifying an audience, communicating concepts effectively, and presenting data as clearly and creatively as possible.

Stage checklist

For this section of your investigation you need to consider each of the following:

- biological concepts specific to the investigation: definitions of key terms, use of appropriate biological terminology, conventions, and representations
- characteristics of effective science communication: accuracy of biological information, clarity of explanation of biological concepts, ideas and models, contextual clarity with reference to importance and implications of findings, conciseness and coherence, and appropriateness for purpose and audience
- the use of data representations, models and theories in organising and explaining observed phenomena and biological concepts, and their limitations
- the influence of social, economic, legal, and political factors relevant to the selected research question
- conventions for referencing and acknowledging sources of information.

Once again, each of these points should be clearly demonstrated in your final report, and are taken directly from page 25 of the VCE Biology Study Design 2022–2026.

Step 1: Defining key biological concepts

A major part of a successful investigation is defining the scope of your area of study, and communicating any key biological concepts that are needed to understand your research. This involves defining any key terms that might be relevant to your area of investigation, and informing your reader of any difficult biological concepts that underpin your chosen area of study.

For example, if you wanted to discuss cloning technologies in agricultural use, you'd want to explain what cloning is, the different technologies currently in use, what is meant by 'agricultural use', and any other background information you think is important.

Example

KEY CONCEPTS AND DEFINITIONS

It was clear that an important part of presenting our information was to define key terms that our readers would need to understand. For example, we began with a paragraph that explained the background information about our chosen area of research, including what a human–animal chimera is, as well as the current legal regulations around their research and applications. For instance, we define a human–animal chimera as any cell or organism that is created via a mixture of human and animal material. We also made sure to distinguish the different categories of chimera research, such as in vitro and in vivo research.

Step 2: Understanding the characteristics of effective communication

Often the most difficult part of a scientific investigation is understanding how to communicate your findings in the most effective way possible. This is usually determined by identifying who your audience is and, in turn, employing the most appropriate tone and formality for your writing style. Check who the hypothetical target audience for your investigation is with your teacher, and then consider the following questions regarding your audience:

- Have I presented difficult concepts in a way that is accessible for my chosen audience?
- Is the length of my investigation appropriate? Have I been as concise as possible?
- Have I framed my research question in a way that makes sense to my audience?
- Have I discussed the implications of my research in a way that is relevant to my chosen audience?

Example

SPEAKING TO OUR AUDIENCE

We decided to communicate our research findings to VCE Biology students. As such, we made sure to transform complex research and empirical data, which was originally written for an academic audience, into a more digestible format. This involved summarising long sections of intricate methods, and considering improved representations such as tables and graphs (Step 3).

Step 3: Deciding on data representation

Following on from Step 2, another important part of scientific communication is deciding how best to represent the data that you have collected during your research stage. When dealing with data from a number of different sources, it is important to decide how to represent all of the data in the most accessible way possible. Depending on the instructions given by your teacher, this might involve a presentation, an essay, a poster, a video, or a wide range of other presentation styles. This might also involve the use of tables and/or graphs, and will require you to consider both the benefits and limitations of choosing one representation style over another. For more information on models and visuals, refer to lesson 1A.

Example

HOW SHOULD WE STRUCTURE THIS THING?

In our report we broke information into subheadings, and supported complex ideas with diagrams and flowcharts. We also tried to make the investigation engaging by including figures and images. For inspiration on how to transform data into useful and accessible diagrams see figures 19–22 in lesson 1A.

cont'd

Example

HOW SHOULD WE STRUCTURE THIS THING? – CONTINUED

Some subheadings we chose to use included:

- Introduction
- Research
  - Biological concepts
  - Social implications
  - Economic implications
  - Legal implications
- Discussion
- Conclusion

Step 4: Considering outside influences

While a lot of this research would have been conducted during Stage 1, it is important to remind yourself to be aware of any social, economic, and political factors that might influence the research question in any way.

- Social factors will typically involve a person's lifestyle. This might require you to consider the presence of any possible discrimination, prejudice, or disadvantage based on race, gender, ethnicity, social class, and/or sexual orientation.
- Economic factors will typically involve money, and the use of goods and services. You may need to consider how your research might be applied at a larger scale, and any economic challenges this could entail – like time investment and cost.
- Political factors will typically involve government policy or messaging. You may need to consider any recent political discussion surrounding your research topic, as well as current government policies surrounding its application. Some of these may be found on news websites and TV outlets.
- Legal factors will typically involve current legalities and regulatory bodies that dictate the research and applications of your chosen topic. This could include current laws and acts, which you may need to research and mention in your report.

Example

PROVIDING CONTEXT – ARE THERE EXTERNAL FACTORS WORTH MENTIONING?

There were many outside influences relevant to our area of study. The level of depth you provide on these influences is dependent on how specific your research question is, as well as the word count and instruction of your teacher. Some of the outside influences we considered in the area of human–animal chimera research included:

- Social – there are groups in society who believe that human–animal chimera research threatens the inherent dignity of human beings. For example, many religions oppose the combination of animal and human DNA on the grounds that it violates the will of God.
- Economic – many researchers have expressed that the financial cost of creating a chimera organ large enough for sufficient research is far too high, and that our current healthcare system does not sufficiently reimburse researchers.
- Legal – under current Australian laws, the creation of human–animal chimeras is regulated under the Prohibition of Human Cloning for Reproduction (PHCR) Act 2002, which prohibits the development of hybrid embryos longer than 14 days. However, in other countries like China and the USA, these laws are often not as restrictive and encourage freer research practices.

Step 5: Referencing correctly

When using other people's work to support your research, you must provide a reference which outlines the source of the information and where the original piece of work can be found. There are many different forms of referencing, and the style that you choose will often depend on personal preference, the area of research, and/or the school or university guidelines. In this instance, we recommend checking with your teacher to determine which referencing format they would like you to use.

One commonly used scientific referencing convention is the Harvard referencing style. A general format for Harvard referencing is provided below:

1 In–text citations, which are smaller versions of the full citation and are used when directly quoting or paraphrasing a source in the body of your report. For example, if you wanted to quote or reference something that Francisco Ayala had written in his article: 'Cloning humans? Biological, ethical, and social considerations', then it would look like this:
   - "There are, in mankind, two kinds of heredity: biological and cultural." (Ayala, 2015)

     The format to follow is: (Last name, year of publication).
2 Reference lists, which are located at the end of your report and include full citations for all sources used in the creation of your work. These are listed in alphabetical order of the main author's last name, and if there are multiple sources used by the same author, by year of publication you observe the following format:
   - Ayala, F.J. (2015). Cloning humans? Biological, ethical, and social considerations. *Proceedings of the National Academy of Sciences*, [online] 112(29), pp.8879–8886. Available at: ncbi.nlm.nih.gov/pmc/articles/PMC4517218/.

     The format to follow is: Last name, First Initial(s). (Year published). Title. City: Publisher, Page(s).

Stage 3: Analysing and evaluating a bioethical issue

Stage overview

This assessment serves two purposes. Firstly, it requires you to engage with an area of Unit 2 in a deeper way, going beyond what was taught in class to read and learn about the applications of that knowledge. Secondly, it requires you to engage critically with these applications and consider broader bioethical concerns that might arise, whether they be social, economic, political and so on. As you know, to engage with bioethical issues, one must employ their highly specialised bioethical toolkit. Let's refresh ourselves now!

Stage checklist

For this section of your investigation you need to consider each of the following:

- ways of identifying bioethical issues
- characteristics of effective analysis of bioethical issues
- approaches to bioethics and ethical concepts as they apply to the bioethical issue being investigated.

Step 1: Sharpen your bioethical toolkit to analyse bioethical issues

Through gathering your evidence and presenting your findings, hopefully you have been able to evaluate your chosen bioethical concern and come to a conclusion on your research question. To do this, however, you would have needed your bioethical toolkit, which we took a close look at in lesson 1B. An effective analysis of bioethical issues will typically involve actively considering varied different perspectives. This can be achieved by using multiple bioethical concepts to explore the issue through different lenses.

To analyse a bioethical issue, you may decide to use a number of different approaches to bioethics and bioethical concepts. Each of these bioethical 'tools' may be used in isolation, but are more commonly used in conjunction with one another to help the individual consider all aspects of a bioethical concern. From lesson 1B, you should remember the approaches and concepts outlined below.

Approaches to bioethics:

1 **Consequences–based approach** – which aims to maximise positive outcomes while minimising negative outcomes
2 **Duty/rule–based approach** – which promotes the responsibility of the agent above all else, and places importance on following well established rules and guidelines
3 **Virtues–based approach** – which emphasises the individual goodness of the agent, and promotes acting in accordance with the values of a 'moral' person, such as honesty and compassion.

Bioethical concepts:

1 **Integrity** – which encourages a full commitment to knowledge and understanding as well as the honest reporting of all sources of information and results
2 **Justice** – which encourages fair consideration of competing claims, and ensures that there is no unfair burden on a particular group from an action
3 **Beneficence** – which encourages the maximisation of benefits while minimising the risks and harms involved in taking a particular position or course of action
4 **Non-maleficence** – which discourages causing harm – or when harm is unavoidable, ensuring that the harm is not disproportionate to the benefits from any position or course of action
5 **Respect** – which encourages the acknowledgment of the intrinsic value of living things, and considers the welfare, beliefs, customs, and cultural heritage of both the individual and the collective.

Example

OUR BIOETHICAL TOOLKIT IN ACTION

Approaches:

- Consequences-based approach – the risks and scientific uncertainty of creating hybrid organs for transplant using chimera research are largely unknown, and could potentially endanger life more than they might improve it. Similarly, the potential benefits of hybrid organs for patients with limited options could be immense, and could outweigh the potential harm. It is important to be aware that any one bioethical approach or concept can be used to both support and/or undermine a position.
- Virtues-based approach – regulations that restrict chimera research should be lessened, and the researcher should decide according to their personal judgement where to draw the line for safe experimentation.

Concepts:

- Non-maleficence – In vivo chimera research should be banned on the grounds that it uses sentient animals for research, which unnecessarily risks the health and welfare of animals.
- Respect – crossing species boundaries in chimera research is ethically wrong because it ignores the inherent dignity of the human being, and should be opposed on the grounds that it interferes with the sanctity of human life.

Theory summary

In this lesson, we broke down how to approach the task that is asked of you in Unit 2 Outcome 3, which is to identify, analyse, and evaluate a bioethical issue related to an area of biological research from Unit 2 of this course. In each section, we have considered the separate dot points of the study design. Throughout your final assessment, you will want to address each of these dot points clearly and fully.

Table 1 A summarised checklist for measuring success in your assignment

	High-performing student	
Identifying an issue	Issue relates directly to either genetics and/or reproductive science and is topical and relevant	✔ ✘
Research question	Research question relates directly to the chosen issue and is testable and binary	✔ ✘
Biological concepts	Demonstrated deep understanding of the biological concepts relevant to the chosen area of study	✔ ✘
Influences	Comprehensive outline of several social, economic, legal, and ethical factors relevant to the chosen area of study	✔ ✘
Opinions	All major opinions regarding the issue are presented impartially and supported with evidence and appropriate sourcing	✔ ✘
Errors/bias	A detailed discussion is given regarding any potential errors or sources of bias present in the research that is used	✔ ✘
Conclusions	A conclusion is drawn that is sound and based on a strong evaluation of the research used	✔ ✘
Formatting	An interesting and engaging presentation is used, including diagrams and visuals where appropriate	✔ ✘
References	Numerous references have been used and sourced correctly. Sources are reputable and varied, and a logbook is used while researching	✔ ✘

Scientific investigations

2.1 Yeasty boys

2.2 Photosynthesis in algae

2.3 The effect of surface area to volume ratio on the rate of diffusion

3.1 Observing osmosis using chicken eggs

4.1 Observing mitosis in onion root cells

5.1 Celery sucks

6.1 Factors affecting heart rate and respiratory rate

6.2 Allen's rule

7.1 Extracting DNA from strawberries

7.2 Modelling meiosis using lego bricks

7.3 Using genomic databases

8.1 Design a bird

8.2 Are you a supertaster?

9.1 Cauliflower cloning

10.1 Surveying biodiversity

Students undertake scientific investigations across Units 1 and 2 of this study. Scientific investigations may be undertaken in groups, but all work for assessment must be completed individually. The use of a logbook reflects standard scientific practice. Students undertaking this study must maintain a logbook of practical activities in each of Units 1 and 2 for recording, authentication and assessment purposes. All items in the logbook must be dated and clearly documented.

2.1 YEASTY BOYS

Scientific investigation type: Controlled experiment

This experiment relates to Chapter 2: What are cells?

INTRODUCTION

Yeast are eukaryotic, single-celled microorganisms that are classified as members of the fungi kingdom. As they are unable to photosynthesise, yeast must acquire the food molecules they need for respiration from their environment. Yeast do not require oxygen to respire; instead, they can undertake anaerobic cellular respiration in the following reaction:

$$\text{glucose} \longrightarrow \text{ethanol} + \text{carbon dioxide} + \text{energy}$$

Figure 1 Equation for anaerobic respiration in yeast

Anaerobic respiration is also referred to as fermentation. The energy produced is in the form of adenosine triphosphate (ATP). The reaction shown depicts anaerobic cellular respiration in plants and yeast, but in humans it is different. When we undertake anaerobic cellular respiration we produce lactic acid rather than ethanol and carbon dioxide. Consider this a good thing – if we produced ethanol whenever we anaerobically respired, we would get drunk whenever we exercised which would be a nightmare during school cross country!

Many different kinds of yeast exist in nature. In the wild, they are typically found growing on the fruits or grains of plants, from where they obtain a variety of food molecules. Several strains of yeast have been domesticated for human use, mainly for baking and brewing purposes.

The domesticated yeast we use in baking is typically fed refined sugar as a fuel source. As the dough rests, the yeast consumes the sugar and releases carbon dioxide bubbles, which causes the dough to rise.

In this activity, you will measure the rate of respiration in yeast that are provided with different food sources, or exposed to different temperatures and conditions. Some of the yeast will be provided with sugar, and some with artificial sweetener instead. Some will be kept at room temperature and others will be warmed to 32 °C, and some will be combined with water whilst others are combined with water and shampoo. How do you think these factors will influence the rate of respiration in yeast?

Resources

Risk assessments, lab tech notes, and answers are available online.

AIM

To observe the rate of respiration in yeast with varying food sources and conditions.

MATERIALS

- 4 × screw cap tubes with lids e.g. falcon tubes (or any tubes that can be covered by a lid and also fit a balloon on the end – see Figure 1)
- 1 × tube rack
- 1 × digital scale
- watch glasses
- pipettes or measuring syringe
- freeze-dried yeast
- sugar
- artificial sweetener e.g. stevia
- shampoo
- balloons
- 32 °C water bath

METHOD

1 Working in pairs or small groups, label four tubes as 1, 2, 3, and 4.
2 Use the watch glasses and scale to measure out and place 0.6 grams of freeze-dried yeast into each tube.
3 Use the watch glasses and scale to measure out and place 0.4 grams of sugar in tubes 1, 2, and 3. Don't put any sugar in tube 4.
4 Use the watch glasses and scale to measure out and place 0.4 grams of artificial sweetener in tube 4.
5 Use a pipette to add 2 mL of shampoo to tube 3. Don't put any shampoo in the other tubes.
6 Use a pipette to add 8 mL of water to tube 3. Cover the tube by placing the lid on and give the content a shake. Set aside in the rack for now.
7 Now use a pipette to add 10 mL of water to tubes 1, 2, and 4. Put the lids on the tubes and shake to mix the contents before setting them down in the tube rack.
8 One at a time, remove the lid of each tube and place a balloon over the top of each tube.
9 Place tubes 1, 3, and 4 in the 32 °C water bath.
10 Leave tube 2 in the tube rack on the bench.
11 After 1 hour has passed, observe your four tubes and measure the size of each balloon. Record your results in Table 2.

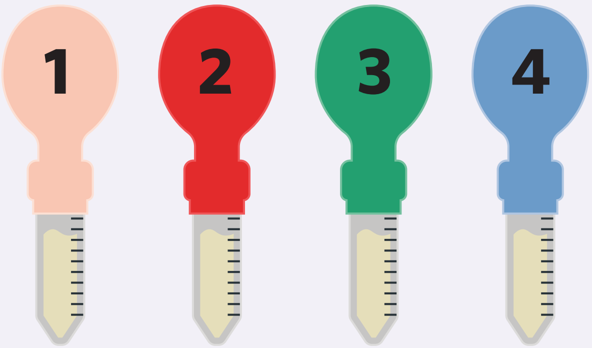


Figure 1 The four tubes containing yeast solutions covered in balloons to measure the respiration rate

Table 1 Summary of the components of the four tubes

	Tube 1	Tube 2	Tube 3	Tube 4
Freeze-dried yeast	✓	✓	✓	✓
Sugar	✓	✓	✓	-
Artificial sweetener	-	-	-	✓
Shampoo	-	-	✓	-
Water	✓	✓	✓ (8 mL)	✓
Placed in water bath	✓	-	✓	✓

RESULTS

Table 2 The diameter of balloons in each tube after one hour

	Tube 1	Tube 2	Tube 3	Tube 4
Size of balloon after one hour				

DISCUSSION QUESTIONS

1 What was your hypothesis for this experiment? Explain whether your results support your hypothesis.
2 Identify the main purpose of cellular respiration in organisms.
3 What is the difference between aerobic and anaerobic cellular respiration?
4 Which tube experienced the greatest rate of respiration?
5 Was there a difference in the result for tube 1 and tube 2? If so, account for this difference.
6 Why was only 8 mL of water added to tube 3 when all the others received 10 mL of water?
7 Was a control used in this experiment?
8 What do you think happened in tube 3? Why? Hint: shampoo is an emulsifier, meaning the molecules have a hydrophobic end and a hydrophilic end.
9 Considering the method, what steps could you add in or modify to increase the accuracy and precision of your experiment?
10 Yeast can use a variety of fuel sources. They can utilise a variety of sugars and starches, not just the packet sugar or artificial sweetener used in this experiment. If the experiment was to be repeated with the initial four tubes, plus the addition of a fifth tube containing honey and a sixth tube containing energy drink, how would these additional tubes be designed? Make sure you indicate whether each of the components listed in Table 1 are included in the tubes or not.
11 Other than the type of sugar, temperature, and presence of shampoo, there are many more variables that influence the rate of anaerobic cellular respiration in yeast. Select one of these variables, and design a method to test the effect this variable has on yeast anaerobic cellular respiration rate. Provide details of the following aspects of your hypothetical experiment:
   a How will you address replication?
   b What are the independent variables?
   c What is the control group?
   d What is the hypothesis?
   e How will errors be minimised?

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- whether the hypothesis was supported by referring to the results
- limitations of the experiment
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

2.2 PHOTOSYNTHESIS IN ALGAE

Scientific investigation type: Controlled experiment

This experiment relates to Chapter 2: What are cells?

INTRODUCTION

Algae are a group of photosynthesising protists found in aquatic environments. When measuring the rate of photosynthesis in algae, scientists often measure changes in CO_2 levels in their environment. This is because CO_2 is a direct input in the photosynthesis process, meaning that environmental levels should decrease as photosynthesise levels increase.

In this investigation, you will follow these same basic principles to observe algae undergoing photosynthesis in your classroom. The aim of this investigation is to determine whether the effect of algal density influences the rate of photosynthesis. As discussed, to measure the rate of photosynthesis, we will measure the changes in the CO_2 levels directly surrounding our algae sample. In order to visually observe this change in CO_2 levels, a pH indicator will be added to the algae. The pH indicator will change colour to tell you whether the pH surrounding your algae has increased or decreased. An increase in pH indicates a decrease in the amount of CO_2 surrounding the algae which in turn indicates an increase in the rate of photosynthesis.

Resources

Risk assessments, lab tech notes, and answers are available online.

AIM

To determine whether the algal density affects the rate of photosynthesis.

MATERIALS

- 100 × algal balls
- 5 × 7 mL empty dram vials
- 10 mL hydrogen carbonate indicator
- 1 × pH colour chart
- 2 mL distilled water
- 2 × 2 mL plastic pipettes
- light source
- 1 × strainer
- 1 × spoon
- 1 × tape measure

METHOD

1 Label your five vials with one of the following: A, B, C, D, and E.

2 Using your pipette, add 2 mL of distilled water into vial A.

3 In the vial labelled B, add 10 algal balls. Straining the balls may make it easier to distribute them.

4 Then, in the remaining vials, add the following:
   - 20 algal balls to vial C
   - 30 algal balls to vial D
   - 40 algal balls to vial E.

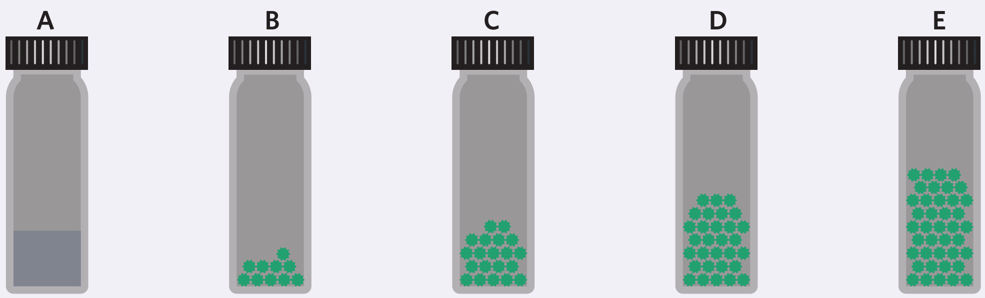


Figure 1 Water sample control and algal bloom set up

5 Using your pipette, add 2 mL of hydrogen carbonate indicator into all five vials then secure their lids.
6 Prior to any light exposure, estimate the pH of the solution within each vial using the pH colour chart and record both the colour and pH in the first column of Table 1 .
7 Place each of your vials at an equal distance from your light source using the tape measure and record the colour and pH of each solution after 10, 20 and 30 minutes in Table 1.

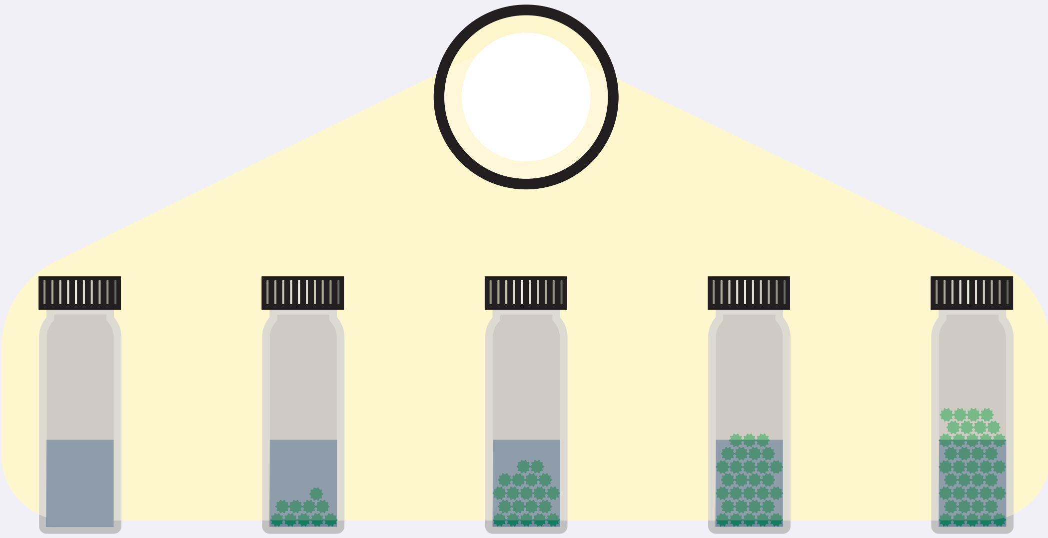


Figure 2 Set up of vials in front of the light source

RESULTS

Table 1 Results of the colour and pH of each vial

Vial	Prior to light exposure	10 minutes after light exposure	20 minutes after light exposure	30 minutes after light exposure
A				
B				
C				
D				
E				

DISCUSSION

1 Write out both the simplified chemical and worded equations for photosynthesis.
2 List the main functions of glucose in plant cells.
3 Identify the overall trend in colour and pH change over the course of the experiment.
4 Using your results, explain whether there is a link between the number of algal balls and the rate of photosynthesis.
5 Identify the independent and dependent variables in this experiment.
6 Explain why each vial was placed at an equal distance from the light source.
7 Considering your method, what steps could you add in or modify to increase the accuracy and precision of your experiment?

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- whether the aim was achieved by referring to the results
- limitations in the experiment
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

2.3 THE EFFECT OF SURFACE AREA TO VOLUME RATIO ON THE RATE OF DIFFUSION

Scientific investigation type: Controlled experiment

This experiment relates to Chapter 2: What are cells?

INTRODUCTION

Cells are constantly exchanging materials with their environment. These can include water, oxygen, wastes, and food. The movement of these substances is required for survival, and it is therefore important for a cell to transport them efficiently. Transport speed is dependent on the surface area to volume ratio (SA:V), which is dependent on both a cell's size and its shape.

This practical models what you have learned about surface area to volume ratio by using pink agar jelly cubes that vary in size to determine the effect that surface area to volume ratio has on diffusion rate. The agar cubes contain a phenolphthalein indicator, which visually indicates the acidity of an environment by changing colour. In low-acid, or alkaline environments, phenolphthalein turns pink, whilst in higher acidic environments it turns clear. Additionally, the agar cubes contain sodium hydroxide, an alkaline solution that allows the indicator, and thereby the cubes, to turn pink. Therefore, when we add an acid, sulphuric acid, we can expect that the cubes will gradually turn clear as acid diffuses inside and increases the acidity.

Resources

Risk assessments, lab tech notes, and answers are available online.

AIM

To observe and record the effect of surface area to volume ratio on the rate of diffusion.

MATERIALS

- pre-prepared agar jelly containing phenolphthalein indicator and sodium hydroxide
- 0.1 M sulphuric acid
- 4 × 250 mL beakers
- tongs
- 1 × scalpel or knife
- 1 × stirring rod
- paper towel
- 1 × ruler
- 1 × timer
- lab coat
- safety glasses
- gloves

METHOD

1 Use the scalpel/knife to cut the agar jelly into four cubes with sides of 10 mm, 30 mm, 50 mm, and 70 mm in length. Take care to ensure accuracy in your cuts.

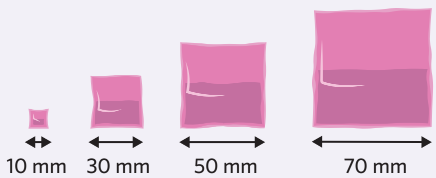


Figure 1 The four cut agar cubes

2 Pour 125 mL of sulphuric acid into the four beakers, or until half full.

3 Set the timer for 10 minutes.

4 Add one of the four cubes into each beaker of sulphuric acid, being very careful not to cause it to splash, then start the timer.

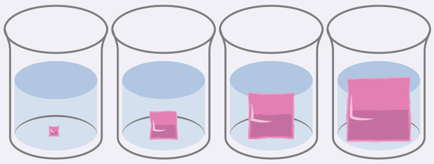


Figure 2 The four agar cubes added to each beaker

5 Stir gently every few minutes with the stirring rod.

6 After the 10 minutes is completed, remove the cubes using the tongs. Place them onto some paper towel.

7 Cut each cube in half using the scalpel/knife.

8 Use a ruler to measure the distance that the acid has diffused into the cube by measuring the distance of clear jelly from the edge of the cube, and record your results in Table 2.

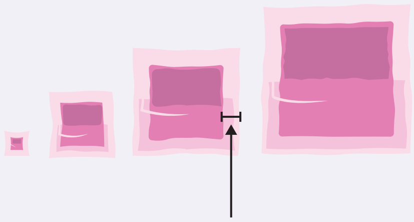


Figure 3 Agar cubes that have been cut. The pink sections represent inner cube volume, whilst the clear sections represent the diffused volume.

RESULTS

Surface area to volume ratio

Calculate the surface area to volume ratio of each of the cubes to complete Table 1.

Table 1 Surface area to volume ratio of each cube

	Cube size (mm)	Surface area (mm^2)	Initial volume (mm^3)	SA:V ratio
Cube 1	10 × 10 × 10			
Cube 2	30 × 30 ×30			
Cube 3	50 × 50 × 50			
Cube 4	70 × 70 × 70			

Percentage of diffusion

Complete the following steps and fill out the corresponding row in Table 2.

1 State the initial side length of the agar cube.

2 Measure and record the length of the clear region in each cube, to calculate the distance of diffusion.

3 Subtract the distance of diffusion from the total cube side length to calculate the inner, pink cube's side length.

4 Calculate the inner cube volume (inner cube side length)^3.

5 Subtract the inner, pink cube's volume from the initial total volume calculated in Table 1 to calculate the diffusion volume.

6 Calculate the percentage of volume diffusion by performing the following calculation:
percentage volume diffusion = 100% × (diffusion volume)/(initial cube volume)

Table 2 Percentage of diffusion

	Cube 1	Cube 2	Cube 3	Cube 4
1. Side length (mm)	10	30	50	70
2. Distance diffused by sulphuric acid (mm)				
3. Inner cube side length (mm)				
4. Inner cube volume (mm^3)				
5. Diffusion volume (mm^3)				
6. Percentage of volume diffusion (%)				

DISCUSSION QUESTIONS

1 Other than decreasing the size of an object, how could you increase the surface area to volume ratio?

2 Which cube had the greatest percentage volume diffusion after 10 minutes?

3 Explain how the colour change in the cubes occurred.

4 Explain the relationship between the surface area to volume ratio and percentage volume diffusion of a cube.

5 Identify any possible errors that may have affected your results. Be sure to state whether it was a personal, systematic, or random error.

6 Considering your method, what steps could you add in or modify to increase the accuracy and precision of your experiment?

7 With reference to the results in your experiment, explain why cells are so small.

8 When placed in a water and salt solution, potatoes can absorb the water and increase in mass. In your head or on spare paper, consider how you would design a method to measure the effect of surface area to volume ratio on the rate of diffusion of water into potatoes. Below, explain how you would include the fundamental elements of a strong experimental design (outlined by RICHES in lesson 1A) in this method.

- **a** How will you address replication?
- **b** What are the independent and dependent variables?
- **c** What is the control group?
- **d** What is the hypothesis?
- **e** How will errors be minimised?

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- whether the aim was achieved by referring to the results
- limitations in the experiment
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

3.1 OBSERVING OSMOSIS USING CHICKEN EGGS

Scientific investigation type: Controlled experiment

This experiment relates to Chapter 3: The plasma membrane

INTRODUCTION

The plasma membrane is a selectively permeable boundary that controls the movement of molecules into and out of the cell. Molecules can move across the membrane in a variety of ways, both actively and passively. The size and polarity of molecules, as well as their concentration either side of the membrane, determine if active or passive transport is used. Water, for example, moves from areas of low solute concentration to high solute concentration passively via osmosis. When a cell has more solutes than its environment, the cell is considered hypertonic and the environment is hypotonic. In this scenario, water will move into the cell. If the cell and the environment have the same concentration of solutes, then the solutions are isotonic and there will be no net movement of water.

Resources

Risk assessments, lab tech notes, and answers are available online.

The yolk of an unfertilised chicken egg is a single, very large cell. There is a small spot you can sometimes see, called the germinal disk, which is where the nuclear material is located. If the egg is fertilised, this is where the chick would grow. The rest of the yolk (the cell body) contains nutrients to feed the growing chick, and the plasma membrane is just inside the vitelline membrane. One layer out, we can see the egg white. The egg white is not made of cells, but rather albumin (a protein product of cells) and water, and it supports the yolk. The egg white also contains the chalaza, a proteinous fibre that connects the yolk to the inner membrane below the shell, as well as an outer membrane, which connects to the shell. Both of these membranes are mostly made of keratin, so do not resemble the plasma membrane.

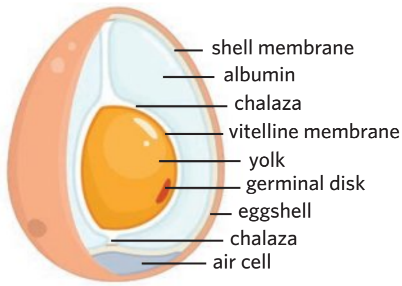


Image: ShadeDesign/Shutterstock.com

Figure 1 The composition of an egg

This scientific investigation is a controlled experiment that asks you to apply your understanding of the structure of the plasma membrane and the movement of substances across it based on their size and polarity. The experiment involves putting a shell-less egg in either distilled water, 5% NaCl solution, or 10% NaCl solution, and measuring changes in egg size and mass over time.

AIM

To investigate how varying levels of solute concentration affect the movement of water across a chicken egg membrane.

MATERIALS

- 3 × chicken eggs
- 5% NaCl solution
- 10% NaCl solution
- distilled water
- 1 × spoon
- 1 × electronic balance
- 3 × beakers
- 3 × jars
- vinegar
- paper towel

METHOD

Preparation – 24 hours prior to class

1 Pour one cup of vinegar or weak acid solution into each of the three jars.

2 Add an egg to each jar. You will notice bubbles rising from the shell. These bubbles are carbon dioxide (CO_2), which is released during 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 membrane.

4 Remove the eggs, examine them, and touch them gently to make sure the shells are gone.

Image: Denise Cogliando/ Shutterstock.com

Figure 2 A de-shelled egg

During class

5 Very carefully pick up a de-shelled egg with a spoon, rinse it with distilled water, and allow it to drip-dry on a paper towel.

6 Carefully weigh the first egg using a balance. Record your results in a table like the one in the results section, or in a spreadsheet.

7 Repeat steps 1 and 2 for the two other eggs.

8 Place the first egg in a beaker containing distilled water.

9 Place the second egg into a beaker with 5% NaCl solution.

10 Place the third egg in a beaker with 10% NaCl. Make sure that there is the same volume of solution in each beaker and that the egg is completely submerged.

11 Write a hypothesis that states what you expect to happen to each egg, and justify it with your understanding of the theory.

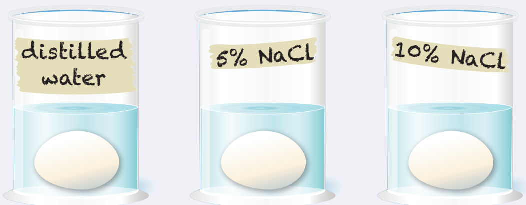


Image: Designua/Shutterstock.com

Figure 3 The experimental set up for this investigation

12 Leave the eggs in the solutions for 10 minutes. After the 10 minutes are up, remove the eggs, rinse carefully, and allow them to drip dry for a minute.

13 Weigh the eggs again and record the mass. Be sure to keep track of which solution each egg was in.

RESULTS

Record your results in a table like the one below.

Table 1 Example of a raw data table

Solution	Distilled water	5% NaCl	10% NaCl
Initial mass (g)			
Final mass (g)			
Mass gain/loss (g)			
Percentage mass gain/loss (g)			

DISCUSSION QUESTIONS

1 Describe the process of osmosis.

2 Compare and contrast osmosis, diffusion, and facilitated diffusion.

3 Explain any changes that you observed in the mass of the eggs based on your understanding of osmosis.

4 Estimate the solute concentration of the egg's cytoplasm. Explain how you arrived at your estimation.

5 Given your results, explain what would happen to a microscopic animal cell if you placed it in each of these solutions.

6 Identify the independent, dependent, and controlled variable/s in this investigation.

7 It is difficult to dry all the eggs in exactly the same way/exactly the same amount. Identify the type of error that this might introduce, and explain how this might affect the precision and accuracy of your results.

8 There are many different variables that influence the rate of transport across membranes. Select one of these variables, and design a method to test the effect this variable has on the rate of transport across cell membranes. Provide details of the following aspects of your experiment:

- **a** How will you address replication?
- **b** What are the independent and dependent variables?
- **c** What is the control group?
- **d** What is the hypothesis?
- **e** How will errors be minimised?

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- whether the hypothesis was supported by referring to the results
- limitations in the experiment
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

4.1 OBSERVING MITOSIS IN ONION ROOT CELLS

Scientific investigation type: Correlational study

This experiment relates to Chapter 4: The cell cycle

INTRODUCTION

Eukaryotic cells are constantly replicating through a process known as the eukaryotic cell cycle, which is a complex sequence of events involving growth and development, maintenance and repair, and reproduction. There are three main stages of the eukaryotic cell cycle: interphase, mitosis, and cytokinesis. Interphase involves the replication of DNA and the preparation of cells for division, mitosis involves the separation of sister chromatids into two new nuclei, and cytokinesis involves the division of the cytoplasm and organelles into two identical daughter cells.

This investigation focuses primarily on mitosis, which is composed of prophase, metaphase, anaphase, and telophase. Because onion root cells are constantly replicating, it is possible to observe each of these stages occurring when they are observed under a light microscope. By counting the number of cells at each stage, we can determine the relative duration of each stage of mitosis. During preparation, it is important that the onion root cells are treated with HCl solution and incubated at high temperatures to break down DNA so it can be stained.

Resources

Risk assessments, lab tech notes, and answers are available online.

AIM

To observe the various stages of mitosis in onion root cells and determine the relative duration of each stage.

MATERIALS

- onion root cells
- 1 M HCl
- pipettes
- 1 × Petri dish
- 1 × water bath
- 1 × plastic microtube
- Feulgen stain
- forceps
- 1 × scalpel or knife
- 1 × light microscope
- microscope slides and coverslips
- lab coat
- safety glasses
- gloves

METHOD

Part A: Specimen preparation

1 Use the scalpel/knife to cut two onion root tips approximately 1 cm in length and transfer them into a plastic microtube.

2 Fill 2/3 of the plastic microtube with 1 M of HCl.

3 Incubate the plastic microtube in a 60 °C water bath for 15 minutes.

4 After incubation, remove the plastic microtube and transfer the root tips onto a small Petri dish with forceps.

Part B: Slide preparation

5 Carefully rinse the root tips with distilled water three times.

6. After rinsing, add three drops of Feulgen stain and allow the root tips to rest for another 15 minutes.
7. After staining, remove the stain with a pipette and rinse the root tips three times with distilled water.
8. Using a scalpel/knife, remove any unstained portions of the root tip.
9. Transfer the root tips onto a microscope slide and add a drop of water. Note: microscope slides must be handled only by their edges, otherwise you will end up observing your fingerprints under the microscope.
10. Carefully place a coverslip on top of the root tips. To do this, place one edge on the microscope slide, then using forceps or another similar object, gently lower the other side of the coverslip down. Be sure that no air bubbles form.
11. Mount the slide on the stage of the microscope and use the coarse and fine adjustment knobs to adjust the focus of the microscope.
12. Cover the root tip with a coverslip and while observing under a microscope at 400× magnification, record the number of cells at each stage of mitosis.

Image: Natalia_Arefieva/Shutterstock.com

Figure 1 A prepared microscope slide

Image: Darren Baker/Shutterstock.com

Figure 2 Viewing a microscope slide on a light microscope

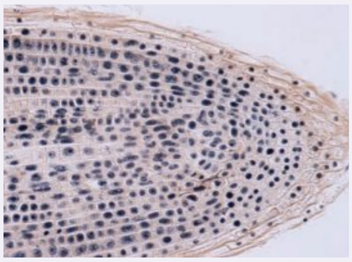


Image: Choksawatdikorn/Shutterstock.com

Figure 3 Observation of onion root cells at low magnification

RESULTS

If more cells are found at a particular stage, then we can conclude that the stage takes a longer duration to complete. Be careful not to record the same cell twice when completing Table 1. The percentage of total cells at a particular stage can be calculated with the following equation:

percentage of total cells = (number of cells at a particular stage)/(total number of cells) × 100

Table 1 The number and percentage of cells at each stage of the cell cycle

Phase	Number of cells	Percentage of total cells
Prophase		
Metaphase		
Anaphase		
Telophase		

DISCUSSION QUESTIONS

1. Describe the purpose of cell replication.
2. Briefly describe each stage of mitosis.
3. From your results, identify which stage is the longest and why.
4. Based on your observations, sketch a scientific diagram of a cell during each stage of mitosis (prophase, metaphase, anaphase, and telophase). Remember to label the key features of the cell.
5. Considering your method, what steps could you add in or modify to increase the accuracy and precision of your experiment?
6. Identify any possible errors that may have affected your results. Be sure to state whether it was a personal, systematic, or random error.

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- limitations in the experiment
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

5.1 CELERY SUCKS

Scientific investigation type: Controlled experiment

This experiment relates to Chapter 5: Biological systems

INTRODUCTION

We all know that plants need water – after all, it is an input for photosynthesis. But, in the scheme of things, most of the water that plants absorb from the soil is lost to the atmosphere via tiny pores in the leaves called stomata. This process is called transpiration, and it is vital for transportation of nutrients, cooling the plant, and prevention of cell damage and wilting. Transpiration works due to capillary action, cohesion of water molecules, and differences in pressure between different regions of the plant and the environment.

While transpiration is important, too much transpiration can lead to excessive water loss from the plant, and even plant death. Certain environmental factors such as high temperatures, wind, and low humidity can increase the rate of transpiration. Some plants have evolved mechanisms to help regulate transpiration and prevent water loss in these conditions.

In this investigation, you will measure the rate of transpiration in celery that is in humid or standard environments. By doing so, you will discover if celery can regulate its rate of transpiration, and identify how quickly celery transpires water. You will also be able to visualise the process of transpiration and observe the structures through which water moves. In Part B of the investigation, you have the opportunity to improve on the original method outlined in Part A, and test if other factors influence the rate of transpiration in celery.

> ***Resources***
>
> Risk assessments, lab tech notes, and answers are available online.

AIM

To observe and record the movement of water through a celery stalk in a humid, closed environment compared to a stalk that is exposed to a less humid, open environment.

MATERIALS

Part A

- 4 × celery stalks with leaves attached
- 2 × beakers (or glasses or cups)
- red or blue food colouring
- single-edge razor blades or scalpels
- cling wrap
- clear, sealable plastic container that is large enough to fit an upright celery stalk
- 1 × ruler

Part B

- student-directed. Materials may include petroleum jelly, fans, incubators/heaters, refrigerators, or spray bottles

METHOD

Part A

1 Fill two beakers with 150 mL of water and add 2-3 drops of food colouring to each.

2 Select four celery stalks of similar size and with a similar number of leaves (you can break the stalks off the celery bunch if necessary). Carefully use a scalpel to make a clean cut to remove the base of each stalk. After removing the base, the four stalks should be of a similar height.

3 Set two stalks into each beaker. Use the cling wrap to ensure that the stalks are upright and that the beaker is sealed (you could also pour a layer of oil over the top of the water to prevent evaporation). Be sure to support all stalks in the same fashion.

4 Add 50–100 mL of room temperature water to the bottom of the plastic container. Place one of the celery beakers into the container and seal the lid to create a humid, closed environment.

5 Place the two celery apparatuses next to each other. Make sure that both are exposed to the same amount of sunlight and temperatures.

6 Write a hypothesis for this investigation. How do you expect the independent variable to affect the dependent variable, and why?

7 Return to the beakers 30–60 minutes later. Remove one celery stalk from each beaker, and cut it longitudinally with a scalpel. Then, use a ruler to measure the distance that the dyed water has travelled in each stalk. Record your results.

8 Take a very thin transect cut of each of the cut celery stalks. You should be able to see that the dye has travelled through certain parts of the stem, and avoided other parts. Prepare a scientific drawing of the transects and label all key structures.

9 Set up the apparatus again (but with only one, un-tampered celery stalk in each beaker) and leave overnight.

10 The next day, remove the last two celery stalks and cling wrap and record the volume of solution in each beaker. Carefully use a scalpel to slice the stalks open longitudinally. Once more, measure the distance that the dyed water has travelled from the base of the celery. Make observations about the colours of the leaves.

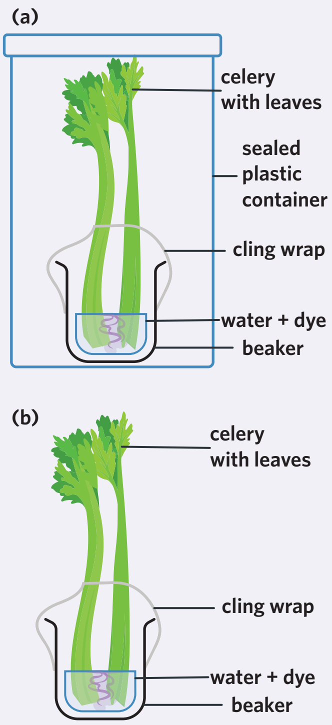


Image: HappyPictures/Shutterstock.com

Figure 1 **(a)** The set up for the celery in a beaker that is not exposed to air, and **(b)** the setup that is exposed to air.

Part B (optional extension)

11 Analyse the method you undertook in Part A, and identify ways to improve the reliability and repeatability of the experiment. For instance, perhaps weighing the celery and beaker would improve the accuracy of the data? Alternatively, the cling wrap may have been difficult to work with – is there a better way of both supporting the celery and preventing evaporation? Perhaps there was little difference between your celery stalks, as the laboratory wasn't warm enough to create a humid environment for your experimental group. Find at least two realistic ways to improve the accuracy, precision, or validity of the method, and record these in your results section.

12 There are a number of other factors that affect the rate of transpiration besides humidity. Design and undertake a variation of Part A (that includes the method upgrades you identified in step 1 of Part B) that tests how one or more of these factors influence the rate of transpiration. Aim to include appropriate controlled variables, replication, and a control or comparison group.

RESULTS

Part A

Table 1 Results for Part A

	Beaker without container			Beaker in container		
	Initial	**After 30 mins**	**Final**	**Initial**	**After 30 mins**	**Final**
Volume of water and food colouring solution (mL)						
Length of stalk where food colouring is visible (cm)						
Observations						

Scientific drawing of the transect sections

Part B

- Two ways to improve the method:

  1 ____

  ____

  2 ____

  ____

- Plan and design the full experiment and method in your logbook. Here, identify the:
  - independent variable/s
  - dependent variable/s
    - › how will you measure change in the dependent variable/s?
  - controlled variable/s
  - uncontrolled variable/s
  - experimental group/s
  - control/comparison group
  - level of replication.

DISCUSSION QUESTIONS

These questions refer to Part A of the investigation.

1 Describe transpiration, including its purpose and mechanism.

2 Compare and contrast phloem and xylem.

3 Identify the independent and dependent variables in this investigation.

4 Identify any controlled variables in this experiment.

5 Identify any possible errors that may have affected your results. Be sure to state whether it was a personal, systematic, or random error.

6 State what this investigation tested, and describe your main results.

7 Using your understanding of transpiration, explain your results.

8 Explain the role of the cling wrap in this experiment.

9 Explain the importance of using similarly sized celery stalks in this experiment.

CONCLUSION

Summarise the findings of this experiment. Be sure to:

- state whether the hypothesis was supported or refuted, and justify your choice
- identify limitations in the experiment
- identify potential ways to improve the experiment.

6.1 FACTORS AFFECTING HEART RATE AND RESPIRATORY RATE

Scientific investigation type: Controlled experiment

This experiment relates to Chapter 6: Homeostasis

INTRODUCTION

Cells require a stable environment to function properly. Our bodies, however, are constantly experiencing different environments and conditions. In order to keep our internal environment as stable as possible, our bodies undergo a variety of processes to maintain homeostasis.

One factor that influences the environment of our cells is the amount of exercise we do. When exercising, our muscle cells undergo increased amounts of cellular respiration. As a result of this, they use more oxygen than they normally do, and produce more carbon dioxide than they do when resting. In order to maintain homeostasis during exercise and ensure normal cellular function, our bodies have to correct these changes as quickly as possible.

Two internal systems that are incredibly important to the maintenance of homeostasis during and after exercise are the circulatory and respiratory systems. The circulatory system delivers oxygen and nutrients to cells in the body and removes the waste products they create. The respiratory system, on the other hand, is responsible for oxygenating blood and removing carbon dioxide from the body. As exercise results in increased oxygen consumption by cells, both the respiratory and circulatory systems must work to compensate for these increased demands and for the increased production of waste products. Is there a way we can measure this process? And how quickly are our circulatory and respiratory systems able to compensate for exercise?

Resources

Risk assessments, lab tech notes, and answers are available online.

AIM

To observe and record the effect of exercise on heart rate and respiratory rate.

MATERIALS

- 1 × stopwatch

METHOD

Part A: resting rates

1 Form groups of three or four. Select one volunteer. Have them sit quietly, breathing calmly. While they are doing so, find their pulse in one of two ways:

- Radial pulse – place two fingers on the groove in the wrist below the thumb. Move your fingers around until you feel a slight pulsation – this is their radial artery! (Figure 1)
- Carotid pulse – place two fingers on the neck, roughly near the trachea which can be found near your volunteer's Adam's apple (if they have one). Move your fingers around until you feel a slight pulsation – this is the carotid artery! (Figure 2)

Note: It's important that you only do this on one side of the neck at a time!

Image: VGstockstudio/Shutterstock.com

Figure 1 Location of the radial pulse

Image: Ilya Andriyanov/Shutterstock.com

Figure 2 Location of the carotid pulse

2 Using the stopwatch, have one group member count how many pulsations they feel in the space of 15 seconds. Multiply this number by four to calculate your participant's heart rate in beats per minute. Write this number in the appropriate place in Table 1.

3 Whilst one group member is counting your subject's pulse rate, have another group member count how many breaths your subject takes in the same 15-second time frame. Write this number in the appropriate place in Table 1.

Part B: Low-intensity exercise

4 Get your volunteer to perform as many push-ups or sit-ups as they can in 20 seconds. This is Exercise A.

5 Immediately after they have finished, use the stopwatch again to repeat steps 2 and 3, measuring your volunteer's pulse in the same location as earlier. Record your results in Table 1.

6 Repeat these measurements after allowing your volunteer to rest for one minute. Record your results in Table 1.

7 Continue to record your volunteer's pulse and respiratory rates for 15 seconds in one-minute intervals for a total of five minutes.

8 Allow your volunteer to rest for another five minutes.

Part C: High-intensity exercise

9 Once they've recovered, get your volunteer to jog on the spot as fast as they can for two minutes. This is Exercise B.

10 Immediately after they have finished, use the stopwatch again to repeat steps 2 and 3, measuring your volunteer's pulse in the same location as earlier. Record your results in Table 1.

11 Repeat these measurements after allowing your volunteer to rest for one minute.

12 Continue to record your volunteer's pulse and respiratory rates for 15 seconds in one-minute intervals for a total of five minutes.

13 Go get your volunteer a drink of water and pat them on the back for putting their body on the line to advance scientific knowledge.

RESULTS

Table 1 Heart rate and respiratory rate recordings

	Heart rate (beats per minute)	Respiratory rate (breaths per minute)
Resting		
Immediately post- Exercise A		
1-minute post-Exercise A		
2-minute post-Exercise A		
3-minute post-Exercise A		
4-minute post-Exercise A		
5-minute post-Exercise A		
Immediately post- Exercise B		
1-minute post-Exercise B		
2-minute post-Exercise B		
3-minute post-Exercise B		
4-minute post-Exercise B		
5-minute post-Exercise B		

Use the data from Table 1 to create a graph of your results.

DISCUSSION QUESTIONS

1 Describe the components of the stimulus-response model.

2 Homeostasis occurs largely via negative feedback loops. Describe what the term 'negative feedback loop' means in the context of homeostasis.

3 Using your knowledge of the respiratory system, describe how the changes in respiratory rate that you noticed would alter oxygen concentrations in the blood.

4 Oxygen is required for the process of aerobic cellular respiration. Write out the chemical formula for aerobic cellular respiration.
5 Identify the independent and dependent variables in this experiment.
6 Did one type of exercise affect your subject's heart/respiratory rate more? Explain.
7 Which variable (heart rate or respiratory rate) was affected more by exercise? Justify your results using the data you obtained during this experiment.
8 Did you notice any other physiological changes in your volunteer as they exercised? Describe them and explain why they may be occurring.
9 Identify a limitation of this method and explain how it could be addressed in a future repetition of this experiment.
10 There are many different variables that influence a person's heart rate. Select one of these variables, and design a method to test the effect this variable has on a person's heart rate. Provide details of the following aspects of your experiment:
   - **a** How will you address replication?
   - **b** What are the independent and dependent variables?
   - **c** What is the control group?
   - **d** What is the hypothesis?
   - **e** How will errors be minimised?
   - **f** How will you ensure the sample is large and randomly collected?

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- whether the aim was achieved by referring to the results
- limitations in the experiment
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

6.2 ALLEN'S RULE

Scientific investigation type: Case study

This experiment relates to Chapter 6: Homeostasis

INTRODUCTION

The beak of a bird comes in many different shapes and sizes. Take a look at Figure 1, for instance. How many of these birds do you recognise? Can you think of some reasons why these birds might have evolved such different beaks?

Some of the main contributors to the shape and size of a particular bird species' beak include their main food sources (do they need to reach deep into the ground, for example), and the way they attract mates (some species prioritise longer beaks when selecting a mate). However, what if I were to tell you that the beaks of some birds often serve a homeostatic purpose? The basis of this idea comes from what is known as 'Allen's rule' (Joel Allen, 1877), which suggests that animals in colder climates will have shorter appendages (beaks included) than similar animals in warmer climates.

The reason for this is simple, and relates to the SA:V ratio of the animal's body. Assuming you are a bird in a cold climate, it makes sense to have as small a beak as possible, as this reduces the amount of heat that is lost through that part of the body (due to the reduced exposed surface area). When the temperature is cold, the bird will limit the amount of blood that is sent to its beak which minimises heat loss. The opposite is also true for birds in warmer climates. For example, the toucan, which has one of the largest beaks per body size of any bird, can attribute around 60 percent of its heat loss to its beak. In this investigation, you will review the work of Greenberg et al. (2012), who used infrared imaging to demonstrate the heat loss differences between Atlantic Song Sparrows (*Melospiza melodia atlantica*) and Eastern Song Sparrows (*Melospiza melodia melodia*).

Resources

Risk assessments, lab tech notes, and answers are available online.

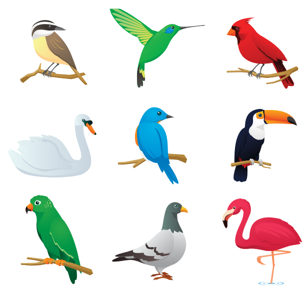


Image: Tomacco/Shutterstock.com

Figure 1 Different birds and their beaks

AIM

To visualise the effect of Allen's rule in two separate species of song sparrow.

MATERIALS

- Figures 2–6
- Table 1

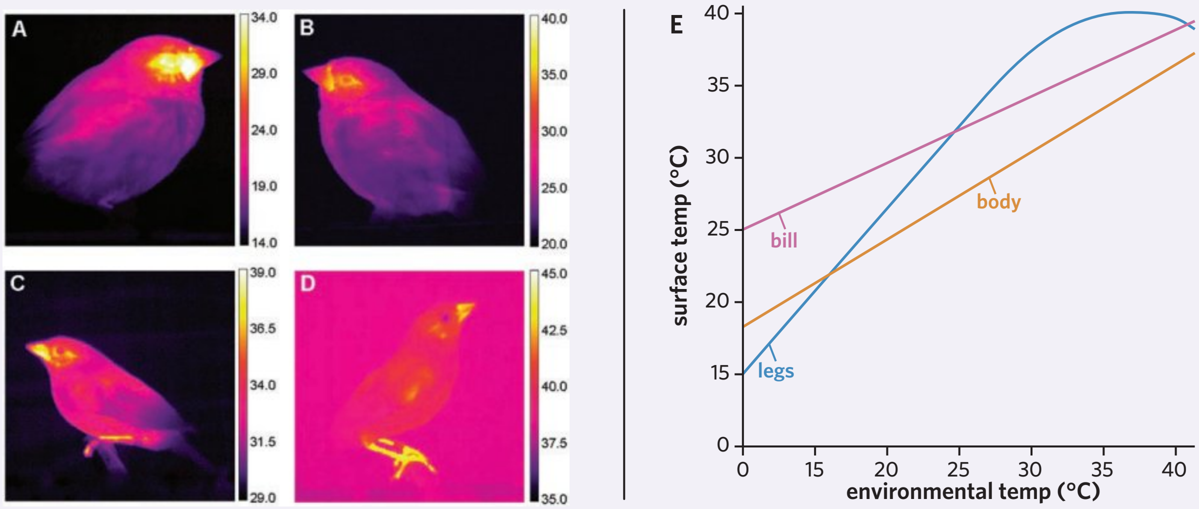


Image: Greenberg et al. (2012)

Figure 2 Infrared imaging showing the body temperatures of **(A)** Eastern and **(B-D)** Atlantic Song Sparrows when exposed to different environmental temperatures. Note that **(A)** is exposed to 15 °C, **(B)** 21 °C, **(C)**, 29 °C, and **(D)** 37 °C. **(E)** represents the average surface temperatures of different body parts of both subspecies compared to the environmental temperature.

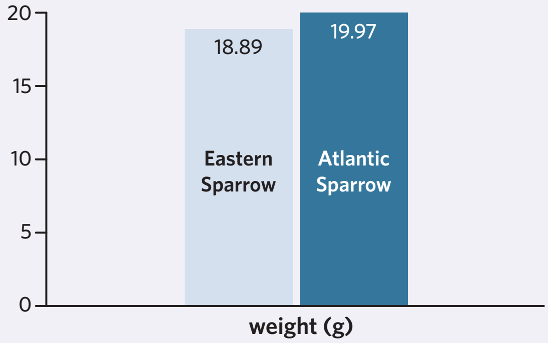


Figure 3 Mean weight (g) of birds used in study

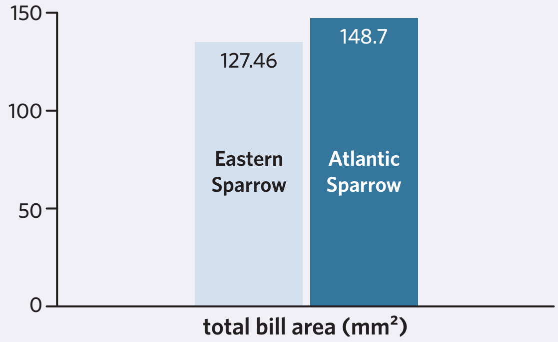


Figure 4 Mean total bill area (mm^2) of birds used in study

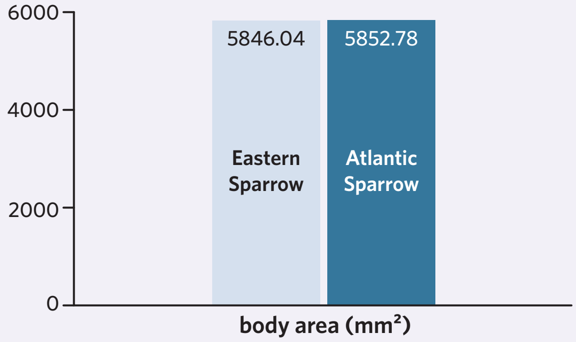


Figure 5 Mean body area (mm^2) of birds used in study

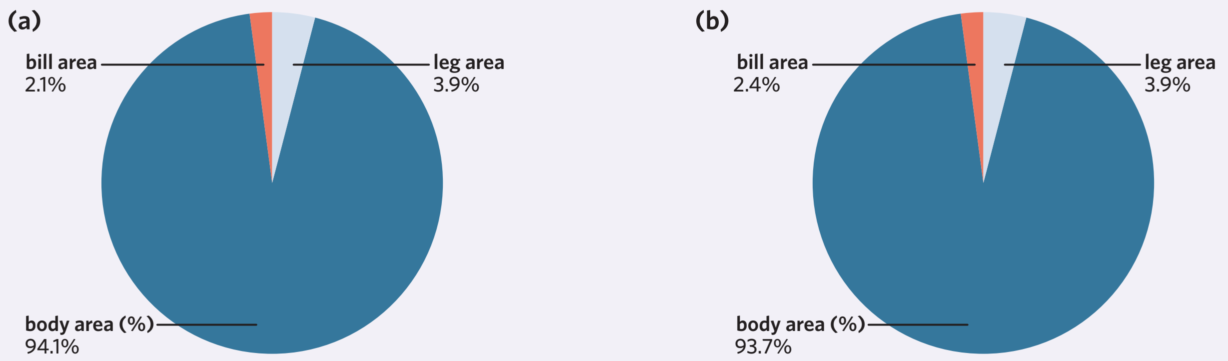


Figure 6 Comparative pie charts showing the breakdown between bill area, leg area, and body area as well as the percentage of total surface area of the **(a)** the Eastern Song Sparrow, and **(b)** Atlantic Song Sparrow

Table 1 Findings summary

- The bill of the Atlantic Song Sparrow has 17% more surface area than that of the Eastern Song Sparrow.
- The bill of the Atlantic Song Sparrow dissipated up to 33% more heat compared to that of the Eastern Song Sparrow.
- The Atlantic Song Sparrow lives in hot dune/salt marsh environments with high exposure to heat.
- The Eastern Song Sparrow lives in mesic habitats, which are green and exhibit a well-balanced supply of moisture.
- The heat loss in both birds was measured independently of evaporative water loss.

METHOD

1 Examine Figures 2–6.

2 Read Table 1.

3 Complete Table 2 to convert the data in Figures 2–6 from graphical form into tabular form. This is an example of transforming data depending on your needs, and will allow you to better answer the discussion questions.

RESULTS

Table 2 Mean measurements for sparrows used in the thermal imaging studies

Measurement	Eastern Song Sparrow	Atlantic Song Sparrow
Weight (g)		
Total bill area (mm^2)		
Body area (mm^2)		
Total bill area as a % of entire area		

DISCUSSION QUESTIONS

1 Define what is meant by 'SA:V ratio'. In your answer, explain the impact of a small SA:V ratio on temperature regulation.

2 Referring only to Figure 1, does this evidence support or reject 'Allen's rule' in the sample of song sparrows that were examined?

3 Referring only to Table 2, does this evidence support or reject 'Allen's rule' in the sample of song sparrows that were examined?

4 Other than the fact that they are furthest from a bird's centre, the extremities of many animals are typically very small compared to the rest of their bodies. Human hands, for example, are thought to constitute as little as 1.5% of our total body surface area. With this in mind, how might we use Figure 6 to define both the bill and the legs of the birds as 'extremities'? Justify your response with reference to the measurements of the Eastern song sparrow.

5 With reference to the environment of the Atlantic Song Sparrow, suggest one reason why it may have evolved a larger bill size than its Eastern counterpart.

6 The body loses heat through evaporation. According to the findings summary in Table 1, heat loss was measured independently of evaporative water loss. Identify what type of variable 'evaporative water loss' is in this study. Justify your response.

7 Imagine that you are asked to repeat this experiment. When asked to measure the leg length of each song sparrow, you are not sure whether to measure to the tip of the toe, or to the end of the foreleg (excluding the feet). You guess and choose to measure the entire leg (inclusive of the feet and toes), while other members of your class measure only to the start of the foot. Explain what type of error this uncertainty is likely to cause.

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- limitations of the study
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

7.1 EXTRACTING DNA FROM STRAWBERRIES

Scientific investigation type: Controlled experiment

This experiment relates to Chapter 7: Genetics

INTRODUCTION

Every living organism contains DNA – the molecule which tells an organism how to function, develop, and survive. Since DNA is so critical, it is found in nearly every cell. Each cell contains a copy of the entire set of genetic instructions, which is referred to as the genome. Scientists study an organism's genome for many reasons, including solving forensic investigations, developing novel therapies, genetically modifying crops, or establishing the evolutionary history of different species.

In order to obtain and visualise DNA, scientists have established a method to extract, isolate, and observe DNA from thousands of cells at a time. The first DNA extraction experiment was performed in 1869 by Friedrich Miescher.

In this investigation, you will extract, isolate, and observe DNA for yourself. You will be using strawberries because they possess eight copies of each chromosome (octoploid) and therefore yield more DNA than any other fruit! In addition, strawberries are easy to mash and contain pectinases and cellulases (types of enzymes) which help to break down the cell wall when acted upon by mechanical force.

Resources

Risk assessments, lab tech notes, and answers are available online.

Image: Ian Cruz/Shutterstock.com

AIM

To extract, isolate, and observe DNA from strawberries.

MATERIALS

- 25 mL of isopropyl alcohol (rubbing alcohol)
- personal protective equipment (gloves, lab coat, and goggles)
- 1 × 50 mL lysis buffer falcon tube
- 1 × 25 mL measuring cylinder
- 1 × 5 mL disposable pipette
- 1 × sealable plastic bag
- 1 × glass beaker
- filter paper
- 1 × funnel
- 1 × electronic balance
- 1 × plastic weighing tray
- 5 g of table salt (NaCl)
- 45 mL water
- 5 mL of liquid detergent
- 1 × one ripe strawberry
- 25 mL of isopropyl alcohol (rubbing alcohol)

METHOD

Part A: Making the lysis buffers

1. Weigh out 5 g of table salt using the electronic balance
2. Add 5 g of table salt to the lysis buffer falcon tube.
3. Add 45 mL water and 5 mL liquid detergent to the lysis buffer falcon tube.
4. Place the cap securely on the tube and mix by gently inverting the tube several times. This is the lysis buffer you will be using in Part B.

Part B: Making the strawberry lysate

5. Place the ripe strawberry in a sealable plastic bag. Remove all the air from the bag before sealing it.
6. Mash the strawberry through the bag with your fingers. Be careful not to break the bag. Record what you observe in Table 1.
7. Unseal the bag and add the lysis buffer to the bag.
8. Once again, remove the air, seal the bag and continue to mash the strawberry with your fingers. The mixture at this stage is referred to as strawberry lysate.
9. Record what you observe in Table 1.

Part C: Filtering the lysate

10 Place the funnel over the glass beaker and insert the filter paper into the funnel.

11 Carefully pour the strawberry lysate from the plastic bag into the funnel and wait until all the liquid has dripped from the funnel into the glass beaker. The liquid in the beaker is called the filtrate.

Part D: Precipitating and observing DNA

12 Remove the funnel from the glass beaker, and record what you observe in table 2.

13 Measure out and slowly add 25 mL isopropyl alcohol into the glass beaker.

14 Observe the boundary between the isopropyl alcohol and strawberry filtrate layer. Record your observations in Table 2.

RESULTS

Table 1 Appearance of strawberry lysate before and after the addition of lysis buffer

	Lysis buffer	
	Before	**After**
Lysate		

Table 2 Appearance of DNA before and after the addition of isopropyl alcohol

	Isopropyl alcohol	
	Before	**After**
DNA		

DISCUSSION QUESTIONS

1 List three real-life applications that show why it is important for scientists to be able to extract and examine DNA.

2 Describe the main steps involved in DNA extraction.

3 Identify three factors that could affect the outcome of DNA extraction in other fruit or vegetables.

4 Draw and describe the appearance of the precipitated DNA in your test tube at the conclusion of the experiment.

5 Identify the cellular components of the strawberry filtrate and identify where the filtrate is located in your test tube.

6 The following table shows the steps you performed in this DNA extraction experiment. Identify the purpose of each step.

Procedure	Purpose
Mash the strawberry in the sealable plastic bag	
Add the DNA lysis buffer to the mashed strawberry	
Pour the strawberry lysate through the funnel which contains filter paper	
Add isopropyl alcohol to the strawberry filtrate	

7 Imagine someone is standing 100 meters away from a single cotton thread which is not visible. If the person winds thousands of threads together in a rope however, the threads become visible. Is this statement comparable to what occured when you performed DNA extraction in this investigation? Justify your answer.

8 Explain the role of detergent and isopropyl alcohol in this investigation.

9 Identify an appropriate control for this investigation and explain your answer.

10 Imagine a student obtained 127 mg of DNA from 1.25 g strawberry lysate. Calculate the percentage yield of extracted DNA. Note that 1 g = 1000 mg

11 Identify whether cells are broken before or after the lysis buffer is added. Justify your response.

12 Considering your method, what steps could you add in or modify to increase the yield of extracted DNA?

13 Identify any possible errors that may have affected your results. Be sure to state whether they were personal, systematic, or random errors.

14 There are many different variables that influence whether DNA is successfully extracted from fruit or vegetables. Select one of these variables, and design a method to test the effect this variable has on DNA extraction. Provide details of the following aspects of your experiment:

- **a** What is the hypothesis?
- **b** What are the independent and dependent variables?
- **c** What is the control group?
- **d** How will errors be minimised?
- **e** How will you maximise accuracy and precision?
- **f** How will you address replication?

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- whether the aim was achieved by referring to your results
- limitations in the experiment
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

7.2 MODELLING MEIOSIS USING LEGO BRICKS

Scientific investigation type: Modelling

This experiment relates to Chapter 7: Genetics

INTRODUCTION

Meiosis involves a single, diploid parent cell dividing twice to produce genetically unique, haploid gametes. Each gamete contains half the genetic information of the original parent cell and each is genetically unique from one another.

Two stages of meiosis in particular help increase the genetic diversity in the resulting gametes. These are:

- crossing over in prophase 1, whereby genetic material is exchanged between homologous chromosomes which results in recombinant chromatids
- independent assortment during metaphase 1, which allows homologous chromosomes to arrange randomly along the equator of the cell and results in the random splitting of chromosomes into different daughter cells.

Of course, these important processes occur at a molecular level, making it difficult for us to visualise how recombination takes place and what it means for the genetic composition of resulting gametes. Over the course of this investigation, we will use Lego bricks to model the stages of meiosis, paying particular attention to how recombination occurs.

Resources

Risk assessments, lab tech notes, and answers are available online.

AIM

To simulate the importance of crossing over and independent assortment using Lego bricks of different colours.

MATERIALS

- 4 × rubber bands
- 40 × red Lego bricks
- 40 × yellow Lego bricks
- 2 × black Lego bricks
- 2 × white Lego bricks
- 2 × blue Lego bricks
- 2 × pink Lego bricks

(Note: specific colours are not important. Use whatever colour bricks you have available, but ensure that there are six different colours.)

METHOD

Assume we are looking at meiosis in an organism that is diploid (2*n*) and has two pairs of homologous chromosomes. Each step is pictured.

1 Using half of your red and yellow Lego bricks, create two sets of chromosomes of different lengths (Figure 1).

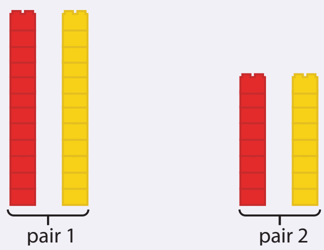


Figure 1 Two sets of chromosomes – red bricks represent the maternal copy, while yellow bricks represent the paternal copy.

2 Using the remaining colours, decide on the genetic composition of your chromosomes at two separate gene loci. To do this, simply insert an allele (coloured brick) into each chromosome (Figure 2). In this case, we are looking at two genes:

Table 1 The possible alleles at each gene loci

Gene	Dominant allele	Recessive allele
Hitchhiker's thumb	Regular thumb – represented by a black Lego brick	Hitchhiker's thumb – represented by a white Lego brick
Hairline shape	Widow's peak – represented by a pink Lego brick	Straight hairline – represented by a blue Lego brick

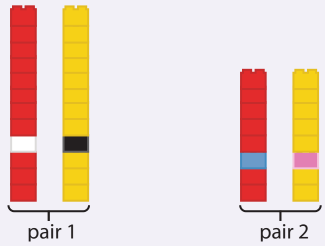


Figure 2 Our chromosomes now show the genotype of the individual at two separate gene loci. Note: not all combinations are shown – only heterozygotes are pictured.

3 Using the remaining red and yellow bricks, replicate each chromosome and bind the sister chromatids together using the rubber bands (which act as the centromere).

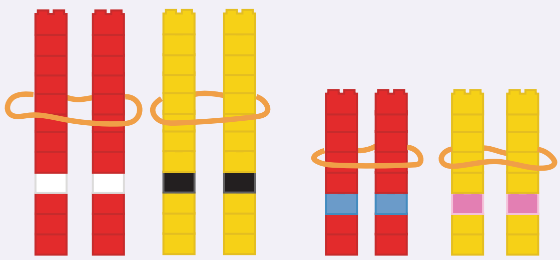


Figure 3 Each of our chromosomes have now been replicated and joined at a centromere.

4 Simulate the process of crossing over by forming a chiasma between each pair of homologous chromosomes.

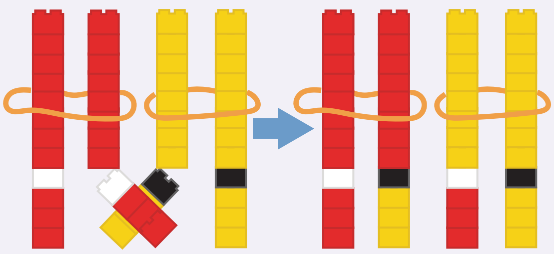


Figure 4 Our chromosomes have exchanged genetic material at a chiasma and are now recombinants.

5 Simulate the process of independent assortment by demonstrating all of the different ways that the homologous chromosomes could line up at the metaphase plate.

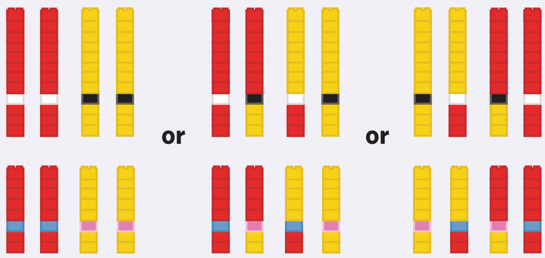


Figure 5 Our chromosomes can line up in multiple different combinations according to the principle of independent assortment. Note: not all combinations are shown, nor is crossing over.

6 Choose one combination from step 5 and demonstrate each possible gamete that could result from that configuration of homologous chromosomes.

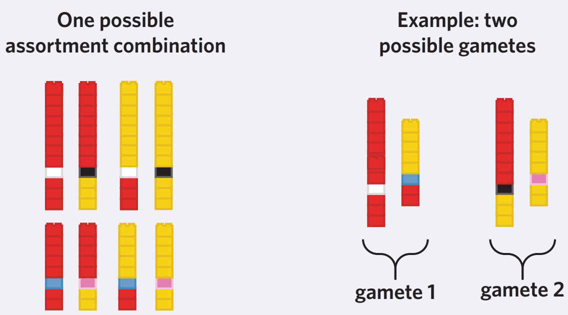


Figure 6 Depending on the combination chosen in step 5, our chromosomes can produce different allelic combinations in individual gametes. Note: not all combinations are shown, nor is crossing over.

DISCUSSION QUESTIONS

1 Outline the inputs and outputs of meiosis in humans.
2 Explain how the process of independent assortment increases the genetic diversity in resulting gametes.
3 Settle the following disagreement: Tom argues that homologous chromosomes are represented as early as step 1, while Jerry argues that homologous chromosomes are not present in the simulation until step 3. Who is correct, and why?
4 Describe the genotypes and phenotypes of the gametes you created.
5 Compare the gametes that have resulted from your simulation with those of your classmates. What do you notice about their genetic diversity?
6 Choose one of the gametes that resulted from your simulation to cross with another gamete from your classmate's simulation. What would the resulting organism's genotype and phenotype be?
7 The scientific methodology employed in this investigation was a modelling exercise. Briefly describe what is meant by 'modelling' and distinguish this methodology from a controlled experiment.

CONCLUSION

Summarise the findings of this simulation. Be sure to:

- describe the importance of crossing over and independent assortment on your results
- identify potential ways to improve the simulation.

7.3 USING GENOMIC DATABASES

Scientific investigation type: Modelling

This experiment relates to Chapter 7: Genetics

INTRODUCTION

An organism's genome is the complete set of DNA contained within the haploid set of chromosomes found in the gametes and includes all of the genes that are needed to make and maintain them as a complex living organism. In eukaryotes, a copy of the organism's genome is contained within each of their cells, provided that cell has a nucleus to house the DNA.

The size of an organism's genome depends on its species. The human genome, for instance, is more than three billion base pairs in length, while the fruit fly (*Drosophila melanogaster*) has a much smaller genome of approximately 165 million base pairs in length. However, size isn't the only way in which we can compare and contrast the genomics of different species. For instance, we can also look at the level of similarity between different gene sequences. Overall, the more differences that exist between the genomes of different organisms, the less related the two organisms are likely to be.

Modelling is an important type of scientific methodology that is often used in comparative genomics to observe these genomic differences. Thanks to the work of the Human Genome Project (HGP) and the genetic data that it has generated, we as researchers are now able to use extensive databases to model the genetic similarities between species. This can be done to a very high resolution using comparative software programs that analyse genomic sequences across different organisms. In this investigation, you will be using a free online software program to compare a particular gene sequence in humans with that of the mouse, chimp, and cow. Specifically, you will look at a gene called *TYR*, which is responsible for the production of the enzyme tyrosinase.

Resources

Risk assessments, lab tech notes, and answers are available online.

AIM

To observe the genomic similarities between four species for the *TYR* gene using the comparative genomics program VISTA.

MATERIALS

- Laptop/web browser/access to internet
- Website: pipeline.lbl.gov/cgi-bin/gateway2

METHOD

1. Visit the following website: pipeline.lbl.gov/cgi-bin/gateway2
2. Change position reference to: chr11: 89,177,565 – 89,295,759 (as pictured)

   This refers to the specific molecular location of the *TYR* gene, which is located on the human chromosome 11 between base pairs 89 177 565 and 89 295 759.

Figure 1 Screenshot of step 2

3 Click submit and you will be redirected to this page, which shows genomic alignment between the human *TYR* gene and the equivalent sequence in a mouse genome (as pictured).

Figure 2 Screenshot of step 3

4 It is now time to add more species into your alignment model. This can be done by adding alignments in the top right of your drop down menu (as pictured). For this model, let's add both a chimp and a cow genome into our comparison.

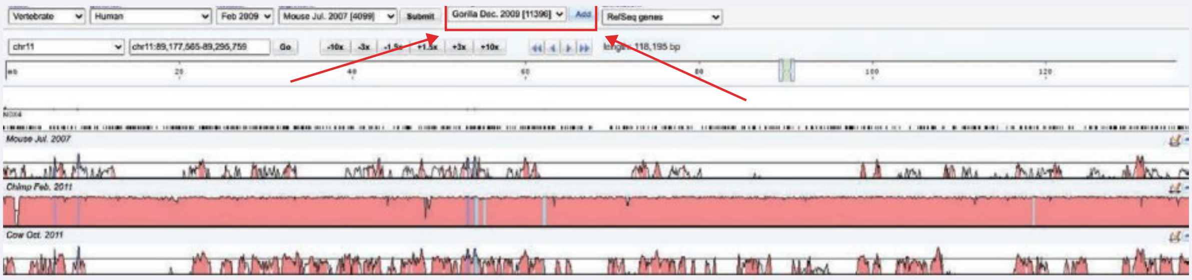


Figure 3 Screenshot of step 4

5 Once your model is complete with the gene sequences of the mouse, chimp, and cow, it is now possible to compare the similarities between the four species at this specific gene locus. For this exercise we will look at two specific points of comparison:

a the visual graph data (Figure 4)

b the molecular location (Figure 5)

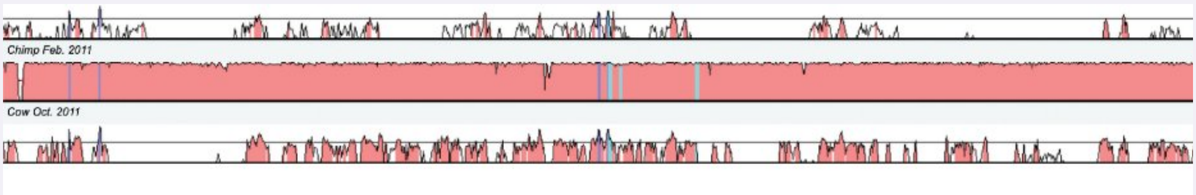


Figure 4 Visual representation of similarities between genomes

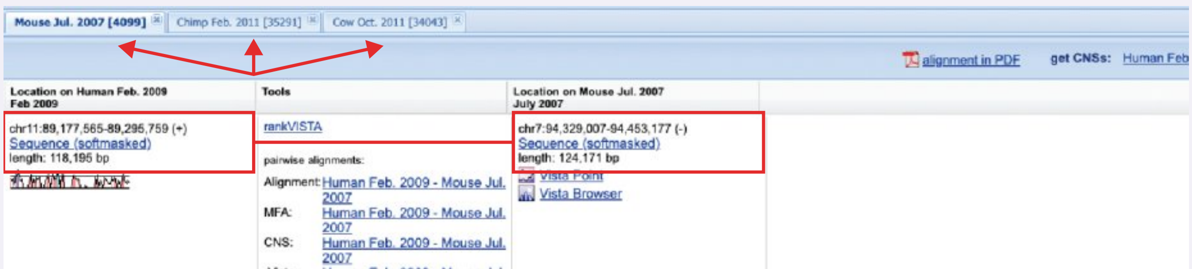


Figure 5 Comparison of the molecular location for the *TYR* gene locus in each species

RESULTS

Fill in Table 1 using the results of your investigation to list the species from most similar to least similar to humans at this locus.

Table 1 The order of genomic similarity between each test species and humans at this locus

Similarity	Species

Using the results from Figure 5, which show the molecular locations of this gene across each species, complete Table 2.

Table 2 The molecular location of the *TYR* gene across separate species

Species	Chromosomal location	Length (bp)

DISCUSSION QUESTIONS

1. Describe the Human Genome Project (HGP) and why it was important for the field of comparative genomics.
2. Referring to your results, summarise the findings of this investigation.
3. Using the alignment details (shown in Figure 5), identify the length and location of the corresponding gene region in the cow genome.
4. Discuss whether this type of investigation is repeatable, reproducible, and valid. Why or why not?
5. Identify an advantage of using a model in this case.
6. Using visuals and diagrams are an important part of scientific communication. Compare and contrast the role of Figure 4 and Figure 5 in this investigation.
7. Transforming data is another important part of scientific communication. How else could you represent the data shown in Figure 4?

CONCLUSION

Summarise the findings of this investigation. Be sure to:

- address the aim of the investigation
- comment on the genomic similarities between the species
- identify any limitations in this investigation and suggest potential improvements.

8.1 DESIGN A BIRD

Scientific investigation type: Simulation

This experiment relates to Chapter 8: Inheritance

INTRODUCTION

We inherit one copy of each gene from each of our parents. Variants of these genes are known as alleles. Each individual possesses two alleles for each gene. These alleles can be represented by a genotype, which encodes for our phenotype. When studying genetics and inheritance, monohybrid and dihybrid crosses are effective ways to track the possible phenotypes inherited from two parents to their offspring for one or two traits respectively.

In this investigation, you are going to flip coins to build a bird then breed it with one of your classmate's birds and predict the potential genotypes of your offspring.

Resources

Risk assessments, lab tech notes, and answers are available online.

AIM

To simulate inheritance patterns of genes across generations.

MATERIALS

- white paper or a printed copy of the results section (included)
- coloured pencils
- 2 × coins
- 1 × dice

METHOD

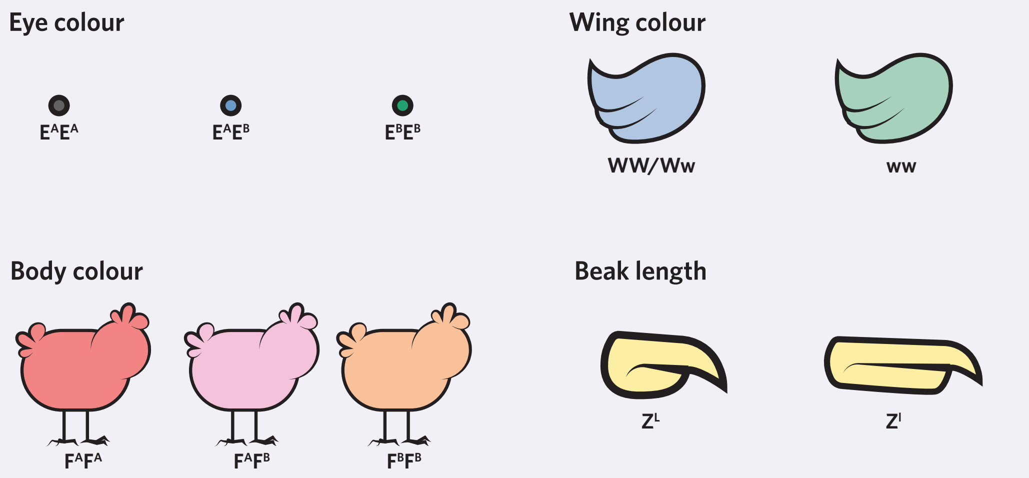


Figure 1 Possible phenotypes of the bird and their respective genotypes

Part A: Determine the characteristics of your bird

1. To determine the genotype of your bird's eye colour, flip the two coins at once. Heads represent the first allele (E^A), whilst tails represents the second allele (E^B). This means that if you flip one head and one tail, your bird would be heterozygous in incomplete dominance and have the genotype E^AE^B, which codes for blue eyes.
2. Write your bird's genotype for eye colour in Table 1, then use Figure 1 to determine the phenotype.
3. Repeat steps 1 and 2 for wing colour and body colour. Be sure to notice that some phenotypes are incompletely dominant.
4. Using the data collected in Table 1, colour in the eyes, wings, and body of your bird in Figure 2.

5 Flip one coin to determine the sex of your bird. Heads means it is male, tails means it is female. Circle the result on the top left of your bird picture. Birds do not have X and Y chromosomes like humans. Instead, they have Z and W sex chromosomes. Male birds are ZZ and female birds are ZW. Beak length genes are found on the Z-chromosome. To determine the genotype for beak length, flip two coins for a male (heads is Z^L and tails is Z^l), but flip only one coin for a female. Write the genotype for beak length in Table 1 and draw on the beak in Figure 2.

6 Pair up with a classmate that has created a bird of the opposite sex.

Part B: Determine your offspring's eye colour

7 Eye colour is found on an autosome and is unlinked to any of the other traits. Complete the Punnett square in Figure 3, then complete the sentence explaining the phenotypic percentage frequency.

8 Using the code in the top left corner of each box in the Punnett square, flip one coin twice. Note your two results down – H means heads, and T means tails. The order in which you flipped the coins is reflected in Figure 3 – for example, if you flipped a heads and then a tails, then your offspring will have the genotype shown in the top-right box. Once it is determined, complete Table 2 and colour in the eye of your offspring bird in Figure 6.

Part C: Determine your offspring's wing and body colour

9 Wing and body colour genes are found on different autosomes. These genes assort independently. Complete the dihybrid cross in Figure 4, then complete the sentence explaining the phenotypic percentage frequency.

10 Again, using the code in the top left corner of each box in the Punnett square, flip one coin four times. Once the offspring's wing and body colours are determined, complete Table 3 and colour in the wing and body of your bird in Figure 6.

Part D: Determine your offspring's beak length

11 Beak length genes are found on the Z-chromosome of the bird. Complete the monohybrid cross in Figure 5, then complete the sentence explaining the phenotypic percentage frequency.

12 Using the code in the top left corner of each box in the Punnett square, flip one coin two times. Once the offspring's beak length is determined, complete Table 4 and draw the beak on your bird in Figure 6.

RESULTS

Part A: your bird

Table 1 Your birds' genotypes and phenotypes, determined by the coin tosses

Trait	Genotype	Phenotype
Eye colour (E^A/E^B)		
Wing colour (W/w)		
Body colour (F^A/F^B)		
Beak length (Z^L/Z^l)		

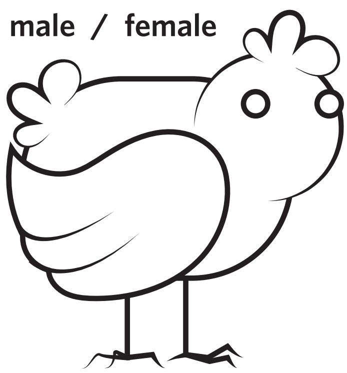


Figure 2 Your bird

Part B: offspring eye colour

- There is a __________% chance that our offspring will have black eyes.
- There is a __________% chance that our offspring will have blue eyes.
- There is a __________% chance that our offspring will have green eyes.

Table 2 Determine offspring eye colour

Offspring genotype	
Offspring phenotype	

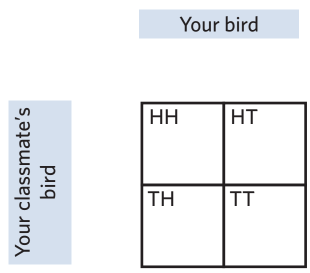


Figure 3 Eye colour monohybrid cross

Part C: offspring wing and body colour

- There is a _____% chance that our offspring will have blue wings and a pink body.
- There is a ______% chance that our offspring will have blue wings and a red body.
- There is a ______% chance that our offspring will have blue wings and an orange body.
- There is a _____% chance that our offspring will have green wings and a pink body.
- There is a ______% chance that our offspring will have green wings and a red body.
- There is a ______% chance that our offspring will have green wings and an orange body.

Table 3 Determine offspring wing and body colour

Offspring genotype	
Offspring phenotype	

Your bird

Your classmate's bird

HHHH	HHHT	HHTH	HTHH
THHH	HHTT	HTHT	HTTH
THHT	THTH	TTHH	HTTT
THTT	TTHT	TTTH	TTTT

Figure 4 Body and wing colour unlinked dihybrid cross

Part D: offspring beak length

- There is a _____% chance that our offspring will be male with a short beak length.
- There is a ______% chance that our offspring will be male with a long beak length.
- There is a ______% chance that our offspring will be female with a short beak length.
- There is a _____% chance that our offspring will be female with a long beak length.

Table 4 Determine offspring beak length

Offspring genotype	
Offspring phenotype	

Your bird

Your classmate's bird

HH	HT
TH	TT

Figure 5 Beak length monohybrid cross

Your completed offspring

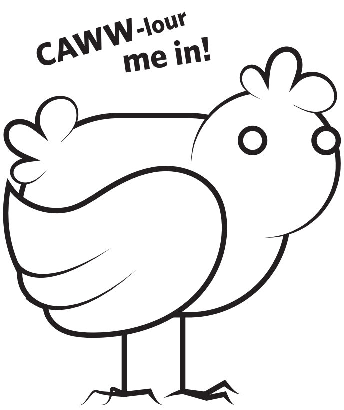


Figure 6 Your offspring

DISCUSSION QUESTIONS

1. What is meant by the term 'phenotype'?
2. Distinguish between incomplete dominance and codominance and identify which is relevant to the bird's eye colour.
3. In the class, which traits appeared most frequently and why?
4. If a pedigree chart were to be made for short beak length, explain some of the characteristics that would be seen on the chart.
5. What would happen to the frequency of recessive phenotypes if another generation of offspring were produced?

6 Explain whether your phenotypic ratios would be the same if offspring wing and body colour were linked genes.

7 Explain why a simulation is useful for an inheritance-based investigation.

8 Imagine all individuals with short beaks died due to an environmental selection pressure. Explain what would happen to the gene pool for beak size.

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- whether the aim was achieved by referring to your results and your class results
- limitations in the simulation
- potential ways to improve the simulation
- broader implications of your research or further areas of exploration that stem from your findings.

8.2 ARE YOU A SUPERTASTER?

Scientific investigation type: Classification and identification

This experiment relates to Chapter 8: Inheritance

INTRODUCTION

From your eye colour to establishing how likely you are to go bald, genetics can explain much about how our bodies function. Diploid organisms inherit a combination of two alleles of a gene from their parents – in homozygous individuals, these alleles are the same; in heterozygous individuals, these alleles are different. In a heterozygous individual, one allele might be expressed over the other – this allele is said to be dominant, whilst the other is said to be recessive. This pattern of inheritance and dominance explains much of how we look and behave – and even potentially how we taste!

Our tongues are covered in small bumps called papillae. On the surface of these are taste buds that contain gustatory cells. The tips of gustatory cells are coated in taste receptors and project onto the surface of the tongue (Figure 1). Molecules in food interact with these receptors, generating nerve signals that travel to our brains and allow us to perceive one of the five taste modalities – sweet, salty, sour, bitter, and umami. The shape of these receptors, however, and therefore their ability to interact with different molecules, differs between individuals according to their genetic makeup. This can be seen most clearly in the different flavours people experience when tasting a compound called phenylthiourea-phenylthiocarbamide, or PTC for short.

PTC is a non-toxic compound that chemically resembles alkaloid compounds found in some toxic plants. For some people, PTC tastes incredibly bitter. For others, however, they can place PTC directly on their tongues and taste nothing. It is thought that a single gene, *TAS2R38*, that codes for the TAS2R38 bitter taste receptor, is responsible for a person's ability to taste PTC and that this gene has two common alleles and at least five rarer alleles. Whilst PTC isn't found in nature, it is thought that the ability to taste it means that a person is far more sensitive to flavours in food than a person who can't taste it. These people are sometimes referred to as 'supertasters'! Are you a supertaster? Time to find out!

> **Resources**
>
> Risk assessments, lab tech notes, and answers are available online.

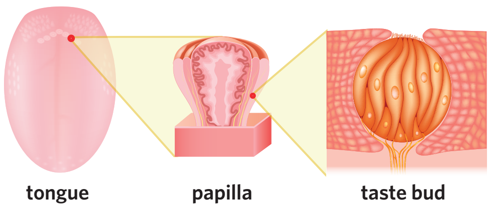


Image: Sakurra, Designua/Shutterstock.om

Figure 1 The structures involved in the sensation of taste

AIM

To calculate the frequency of PTC tasters and nontasters in a population and determine the pattern of inheritance of the *TAS2R38* gene.

MATERIALS

- PTC taste paper
- control taste paper
- paper towel
- 1 × cup of water

METHOD

1. Draw a line on your paper towel to divide it into two sections – label one 'Control' and the other 'PTC paper'.
2. Your teacher will put on a pair of gloves and will place one PTC taste paper and one control taste paper in their corresponding sections on your labelled paper towel.
3. Sip some water to rinse your mouth out.
4. Place the unhandled end of the control paper on your tongue. Move it around a little and make sure it mixes with your saliva. After 10 seconds, remove the paper and discard it.
5. Record in Table 1 what the control strip tasted like to you – rate it as either 'bitter' or 'no taste'.
6. Sip some water again to rinse your mouth out.

7 Place the unhandled end of the PTC taste paper on your tongue. Again, move it around a little and make sure it mixes with your saliva. After 10 seconds, remove the paper and discard it.
8 Record in Table 1 what the PTC strip tasted like to you – rate it as either ‘bitter’ or ‘no taste’.
9 Once your whole class has completed the activity, complete Table 1 with their results.

RESULTS

Table 1 PTC tasting results

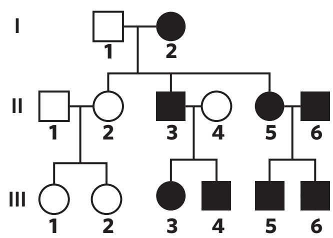
	Taste Rating	
	Bitter	**No taste**
Personal taste		
Class taste (total)		
Class taste (%)		

DISCUSSION QUESTIONS

1 Compare and contrast complete dominance, codominance, and incomplete dominance.
2 Describe why some people can taste PTC yet others cannot.
3 Explain how the presence of *TAS2R38* taste receptors might increase an individual’s chance of survival.
4 Examine your class data. What does it suggest about the pattern of gene expression for the *TAS2R38* gene?
5 Identify the genotypes of tasters and nontasters based on the pattern of gene expression suggested by your class data using the letters *T* for the dominant allele and *t* for the recessive allele.
6 Complete the Punnett square below and determine the genotypic ratio and phenotypic ratio of the offspring produced by the cross.

	T	***t***
T		
t		

7 Using your theory about the expression of the TAS2R38 receptor, examine the pedigree below, and determine the genotype of all the people in the family. If there is not enough information to determine their phenotype simply leave the corresponding allele blank (e.g. *T*_).



8 Amongst the people who could taste PTC, determine if some could taste it more strongly than others (e.g. some people may have found it so bitter they had to spit the PTC paper out). Explain these responses by referring to your predicted frequency of alleles/genotypes at the *TAS2R38* locus.
9 Identify a limitation of this method and explain how it could be addressed in a future repetition of this experiment.
10 In the method of the experiment you were instructed to put the ‘unhandled end’ of the paper in your mouth. What component of experimental design was this instruction addressing, and how could it be further incorporated into the experimental design?

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- whether the aim was achieved by referring to the results
- limitations in the experiment
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

9.1 CAULIFLOWER CLONING

Scientific investigation type: Case study

This experiment relates to Chapter 9: Reproduction

INTRODUCTION

Plant tissue culturing, or micropropagation, involves the cloning and regeneration of plants from a small segment of the original plant. These segments, which can be obtained from a leaf, shoot, or stem, are grown in a controlled sterile environment on a nutrient culture medium, where temperature, lighting, and hormone and nutrient availability are all closely regulated.

This practical involves the use of cauliflower florets, which are small flowering segments of the original cauliflower that are used to regenerate an entire cauliflower plant. Due to the importance of preventing the growth of unwanted microorganisms, careful aseptic technique must be practised. This includes cleaning relevant surfaces with disinfectant solution, sterilising equipment, and ensuring that exposure of the growth medium and floret to the outside world is kept to a minimum. If successful, the cauliflower floret should develop small shoots and leaves, which can be used to grow an entire cauliflower plant.

Resources

Risk assessments, lab tech notes, and answers are available online.

Image: Moving Moment/Shutterstock.com

Figure 1 Cauliflower florets

AIM

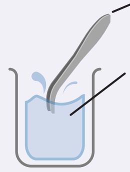
To produce a cloned cauliflower plant by using plant tissue culture.

MATERIALS

- 1 × forceps
- 1 × incubator
- test tubes
- cauliflower
- 1 × scalpel or knife
- disinfectant solution
- 1 × ruler or measuring tape
- 1 × Petri dish with an agar growth medium suited for plant tissue propagation (e.g. Murashige and Skoog medium)
- sodium dichloroisocyanurate (SDICN)
- safety glasses
- lab coat
- gloves

METHOD

1 Clean the bench with a disinfectant solution and the forceps and scalpel with SDICN.



1 Cut two 3–5 mm segments of cauliflower lengthways from a mini-floret with a scalpel/knife to produce micro-florets.

2 Using cleaned forceps, place the cut segments of cauliflower into a test-tube containing SDICN.

3 Thoroughly sterilise the micro-floret by swirling the test-tube for fifteen seconds every two minutes, for a total of ten minutes.

4 Carefully remove the micro-florets and slightly press their stalks into the growth medium of the Petri dish, closing the lid once complete.

5 Incubate the Petri dish near a window or light source for two weeks at approximately 21 °C.

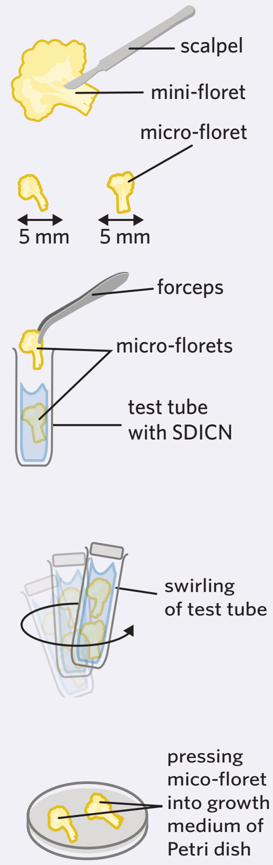


Figure 2 The method of cloning cauliflower florets

DISCUSSION QUESTIONS

1 Describe the conditions necessary for plant tissue culturing.

2 Describe the possible applications of plant tissue culturing.

3 Explain whether plant tissue culturing is biologically sustainable in the long-term if used on a large-scale.

4 Explain the importance of sterilising the equipment and cauliflower in this experiment.

5 Identify possible techniques that could improve aseptic technique in this experiment.

6 Explain how mini-florets are capable of regenerating an entire cauliflower plant.

7 Identify possible errors that may have affected the viability of the cauliflower plant. Be sure to state whether it was a personal, systematic, or random error.

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- limitations in the experiment
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

10.1 SURVEYING BIODIVERSITY

Scientific investigation type: Fieldwork

This experiment relates to Chapter 10: Adaptations and survival

INTRODUCTION

Biodiversity refers to the variety and variability of plant and animal life on Earth, or of a particular location. At an ecosystem level, biodiversity is measured by the number of different species inhabiting the area, and this can provide us with insight into the health of an ecosystem. Greater plant diversity typically supports a greater diversity of animal life as you move up the trophic levels, and in Chapter 10 you learned about the many reasons why biodiversity is integral for us and for the planet.

To understand and uncover the level of biodiversity within a particular habitat, scientists can survey and sample the area to quantify biodiversity. The information collected from a biodiversity survey provides people with the ability to assess conservation values, understand changes in land use, document heritage, and aid resource management. Some survey techniques are very complex and require vast expertise to undertake, but basic techniques are extremely simple and can be conducted by any aspiring scientist. For example, searching for and counting each individual organism within an ecosystem (the total count method) to discover the biodiversity is far too time-consuming. Instead, surveying a smaller part of the ecosystem can provide insights into the ecosystem as a whole and form the basis for decision making surrounding conservation.

In this activity, the focus of the survey is to examine the effects humans have on the biodiversity of habitats. You will propose a hypothesis about the impact humans have on biodiversity, and you will use sampling techniques to complete a series of investigations. The results you collect will either support or contradict your hypothesis. So, what do you think? How are the levels of biodiversity of an ecosystem, and the amount of human impact on that ecosystem, related?

Resources

Risk assessments, lab tech notes, and answers are available online.

AIM

To survey the biodiversity of multiple locations with varying degrees of human impact.

HYPOTHESIS

State your hypothesis in the following box. Be sure to include how you think the independent variable affects the dependent variable, then explain why you expect to see that relationship.

MATERIALS

- 10 m measuring tape
- 1 m measuring tape
- clipboard and paper/logbook for recording data

METHOD

Preparation – 24 hours prior to class

1 In this activity, you will survey pre-approved locations to find out about the variety of plants and animals that live within them. Prior to class, your teacher will choose suitable locations for the surveys. Three sites are needed for the practical.
   - The first site should show little or low human impact (e.g. a forested area, natural grasslands or any other area that appears mostly untouched by humans).
   - A second site should show moderate human impact (e.g. a grassland adjacent to buildings or a park).
   - The third location should show high human impact (e.g. a football oval or even a parking lot).

2 The three locations can be selected within or outside of school grounds, depending on the applicability. Importantly, the three sites should possess significantly different levels of human impact and need to be wide and open areas. Ideally, all three sites chosen will be similar in size. The sites should be accessible to all students and not be of great distance from one another. If locations are selected outside of school grounds, permission needs to be granted if necessary to pass through areas outside of school. The safety of each location is integral and a risk assessment should be performed which addresses any hazards.

3 It can also be useful to learn the surveying techniques within the class before implementing it on site.

Conducting the survey

4 Form groups of three. Assign roles within the group for the fieldwork. One student will be a recorder, and two students will be surveyors.

5 At the first location, a starting point is selected within the area. A 10 m line is then measured from the starting point to an endpoint. Half a meter is measured on either side of the 10 m line. You now have a 10 m long, 1 m wide strip that is 10 m^2 in area (Figure 1). This is your survey area and this surveying technique is known as strip transect sampling. Make sure that your strip does not interfere with the areas of your classmates.

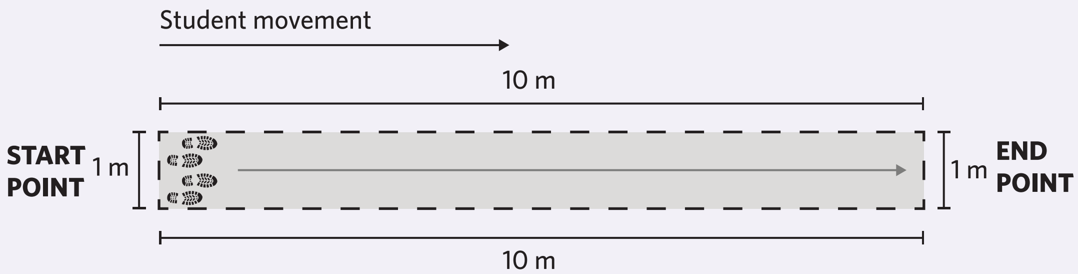


Figure 1 The strip transect survey area

6 Within your survey strip, begin searching for evidence of animal life. Side by side, the two surveyors will slowly walk along the survey area and call out every single sign, or trace of animal life they spot. The survey should be thorough; make sure you take your time to conduct it very slowly. A sign of animal life may include:
   - animals themselves that are present
   - footprints and trails
   - burrows and hollows
   - nests or eggs
   - faeces
   - feathers, fur, dead skin, and other remains
   - rubbish (a sign of humans)

7 Be sure to lift up all leaves, branches and rocks to look for insects and other small animals. Keep an eye out directly above your area for any birds flying over the area. If trees are present or overhang your area be sure to check them for signs of animals. We want all the different types of species to be recorded. It will be difficult to distinguish whether some signs are from different species or not, but do your best as a team to decide.

8 As the survey occurs the recorder notes the data. You do not need to identify what each species is, you just need to make a list of all the different species you think are present.

9 When the surveyors have made it to the end of the line, it is time to decide as a group whether the abundance (amount) of each species was relatively low (L), medium (M), or high (H) in the strip compared to the other species. An example of how your results could look can be seen in Table 1.

10 Repeat the surveying method for signs of plant species. Again, slowly search the strip for different species of plants, making sure to check directly above your strip area as well. You may see lots of different grass or plant species – look closely at the shape of seeds, flowers, and leaves to distinguish them from each other. If you have phones or cameras, your teacher may also ask you to photograph each species.

11 Repeat steps 2–7 at locations 2 and 3 and record your results.

RESULTS

Record your results for each site in three tables like the one seen below.

Table 1 Example of data collected at a single location

Animals		Plants	
Species list	**Abundance**	**Species list**	**Abundance**
Small ant	H	Short grass	H
Magpie	L	Tree 1	M
Humans	M	Tree 2	L
Larger ant	M	Small weedy plant	M
Millipede	L	Taller lush grass	M
Small spider	L	Tree 3	M
Brown bird	L	Large bush	M
Total animal species = 7		Flowering weed	M
		Prickly weed	L
		Total plant species = 9	

Using your results, produce a graph that displays the total number of plant species, animal species and overall species (both plants and animals) at each location.

DISCUSSION QUESTIONS

1 Identify and describe the major levels of biological systems organisation.

2 What are the four major values of biodiversity?

3 Identify the independent and dependent variables in this investigation.

4 Which location had the greatest number of species and which had the lowest?

5 Would you classify any of your counts of species as outliers? Explain your response.

6 Are these results consistent with your hypothesis? Justify your response.

7 When calculating the biodiversity of a habitat, ecologists will use two metrics rather than one – species richness and species evenness.

- Species richness is defined as the number of different species in a region – this is the total number of species (both plant and animal) that you counted for each location.
- Species evenness refers to how balanced the numbers of each species in a habit are. The more 'even' the species in a habitat are, the greater the biodiversity as there are not one or two species dominating over the rest. To quantify this, ecologists will count each individual member of each species in what can be a time-consuming process. Instead, you evaluated the abundance of the species as low, medium, or high.

a Which location do you think had the most even species and which had the least even?

b Considering the different habitat types you know, try to identify a habitat that has

i high species richness and high species evenness

ii high species richness but low species evenness

iii low species richness and low species evenness.

8 Are the species evenness and species richness consistent among the three locations?

9 How are the results for species evenness related to the level of human impact among the locations?

10 Considering the methodology, what steps could you add in or modify to increase the accuracy and precision of your experiment?

11 Other than human impact, there are many more variables that influence the biodiversity of an ecosystem. Select one of these variables, and design a method to test the effect this variable has on biodiversity. Provide details of the following aspects of your hypothetical experiment:

a How will you address replication?

b What are the independent variables?

c What is the control group?

d What is the hypothesis?

e How will errors be minimised?

CONCLUSION

Write a concluding paragraph to summarise your investigation. Be sure to include:

- whether the hypothesis was supported by referring to the results
- limitations in the experiment
- potential ways to improve the experiment
- broader implications of your research or further areas of exploration that stem from your findings.

ANSWERS

1A Key science skills

Theory review questions

1 A

2 A

3 C

4 B

5 I; II; III

6 random; systematic; accuracy; precision

7 D

8 III; IV; II; I

SAC skills questions

9 A	**10** A	**11** B	**12** A
13 B	**14** C	**15** D	

Exam-style questions

Within lesson

16 C	**17** D	**18** B	**19** B
20 A	**21** D	**22** D	**23** D

24 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 identified variables that need to be controlled.[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 key biological terminology such as: control group, treatment group, significant.

b Firstly, the welfare of the mice before and during the experiment should be considered. The scientists can address this issue by ensuring the mice are fed, kept in clean and low-stress cages, stimulated socially and physically, and are able to sleep.[1] Secondly, any pain or trauma experienced by the mice should be considered. This can be minimised by reducing the amount of handling, and by 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 could 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]

25 a [The independent variable is temperature and [1]][the dependent variable is the percentage of nutrient agar covered by bacteria.[2]]

- I have stated that temperature is the independent variable.[1]
- I have stated that the percentage of bacterial cover on the agar plates is the dependent variable.[2]

b [If temperature is increased, then more bacterial growth occurs.[1]]

Other acceptable responses include:

- If temperature increases, then bacterial growth occurs more quickly.

- I have stated a testable hypothesis that is supported by the results.[1]
- I have stated how the independent variable affects the dependent variables in my hypothesis.

c [The amount of bacteria initially added to the agar plates[1]][and the length of time kept at each temperature would need to stay constant across experimental groups.[2]]

Other acceptable responses include:

- the size of the nutrient agar plates
- the concentration of nutrient agar in the plates
- the light intensity to which the plates are exposed

- I have identified one possible variable to keep constant.[1]
- I have identified another possible variable to keep constant.[2]

d [Mimi is correct,[1]][because personal errors are fluctuations in data caused by human mistakes or imprecision. Averaging the percentage cover of bacteria will reduce the impact of poor estimates made by individual sets of human eyes.[2]][Including a control, however, will improve the reliability of the experiment but won't reduce the impact of personal error.[3]]

- I have stated that Mimi is correct.[1]
- I have explained why Mimi's suggestion reduces personal error.[2]
- I have explained why Diego's suggestion does not reduce personal error.[3]

1B Ethics in Biology

Theory review questions

1 I-applied ethics; II-bioethics; III-metathinking; IV-ethics

2 A

3 Consequences-based: II
Duty/rule-based: III, IV
Virtues-based: I

4 A

5 I-integrity; II-justice; III-beneficence; IV-respect; V-non-maleficence

SAC skills questions

6 B **7** D **8** C **9** A

10 C **11** C

Exam style questions

Within lesson

12 a [Victoria's euthanasia laws uphold the bioethical concept of respect by acknowledging the capacity of individuals to make their own decisions.[1]]

- I have made reference to the capability of individuals to make their own decisions.[1]

b [Having two separate doctors independently assessing the patient upholds the bioethical concept of integrity by demonstrating a commitment to accurately understanding the reality of the patient's situation.[1]]

- I have made reference to two doctors better understanding the patient's situation.[1]
- I have signposted connections to the bioethical concept of integrity using terms such as: independently, accurately, reality.

c i [A consequences-based approach to bioethics aims to maximise positive outcomes[1]][by working to minimise negative effects and focusing on the surrounding context of a given position, decision, or action.[2]]

Other acceptable responses include:

- Utilitarianism, or 'maximising the good for the most amount of people', or any other variation of maximising positive results or outcomes.

- I have correctly identified the aim of a consequences-approach to bioethics.[1]
- I have explained how this aim is achieved.[2]
- I have avoided reusing the word 'consequences' in my explanation of 'consequences-based approach'.
- I have signposted connections to a consequences-based approach using terms such as: positive outcomes, minimising negative effects.

ii [This argument is informed by a consequences-based approach by referencing the potential for unethical applications.[1]] [For example, the argument suggests that the possibility of involuntary euthanasia could outweigh the benefits associated with voluntary euthanasia.[2]]

- I have correctly identified the reference to unethical applications.[1]
- I have linked this to the principles of a consequences-based approach.[2]
- I have avoided reusing the word 'consequences' in my explanation of 'consequences-based approach'.
- I have signposted connections to a consequences-based approach using terms such as: unethical applications, outweigh benefits.

13 a [Integrity.[1]][Integrity is the commitment to knowledge and encourages individuals to act honestly and truthfully, especially when presenting their results.[2]][By failing to be honest with the doctors about the gene-edited embryos, He has transgressed their trust and failed to act honestly.[3]]

- I have identified integrity.[1]
- I have briefly explained integrity.[2]
- I have linked integrity to He's actions.[3]

b i [Heritable means that the trait is transmissible from parent to offspring, that is that it is encoded in genes.[1]]

- I have correctly defined the term heritable.[1]

ii [One potential bioethical issue relates to the heritability of *CCR5*, and the emergence of any unknown side effects that might occur as the gene is passed on and spread across generations.[1]]

Other acceptable responses include:

- Unknown consequences of the novel gene interacting with other genes/proteins in an unforeseen way
- How to fairly distribute and regulate the benefits of the study should *CCR5* be proven to effectively protect against HIV.

- I have identified a relevant bioethical issue.[1]

14 a [A bioethical issue is whether Mark had provided informed consent to being an organ donor or not.[1]]

- I have identified a bioethical issue.[1]

b [The bioethical concept of respect prioritises the consideration of the beliefs and wishes of those involved in a decision or course of action.[1]][In this case, the family are major stakeholders in Mark's care, and their wishes should therefore be honoured by the procurement team.[2]]

Other acceptable responses include:

- The family's wishes, while listened to, should be considered alongside Mark's wishes. While it is not known for sure what Mark wanted, his driver's licence indicates that he was a registered organ donor. If it was Mark's desire to be an organ donor, the procurement team should override the family and honour his wishes.

- I have explained the relevance of the bioethical concept of respect.[1]
- I have referenced respect in the suggested actions of the procurement team.[2]

c [A duty/rule-based approach places importance on the moral duty of the agent above all else.[1]][In this case, the organ procurement team has a responsibility to act in accordance with Mark's wishes and to determine his suitability for organ donation. This is their job, and as such, the life support should remain on while they follow Mark's wishes.[2]]

- I have explained the relevance of a duty/rule-based approach to bioethics.[1]
- I have referenced the responsibility of the procurement team to justify keeping life support on.[2]

Chapter 1 SAC practice

1 [Placebos are substances/interventions that have no therapeutic effect and are used as a type of control group.[1]]

- I have defined the term placebo.[1]

2 [The placebo problem occurs when the improvement from placebos is high enough to cause uncertainty regarding the efficacy of the proposed drug or treatment.[1]][This makes it difficult for psychopharmacological drug developers to be sure that improvements in a patient's symptoms are due to the action of their proposed treatment or medication.[2]]

- I have described what is meant by the placebo problem.[1]
- I have explained how this affects psychopharmacological drug development.[2]

3 [Integrity prioritises the accurate representation of the facts, whether favourable or unfavourable.[1]][In failing to publish negative findings as readily as positive findings, academic journals fail to accurately present the state of the research and risk misrepresenting the efficacy of certain treatments/medications.[2]]

Other acceptable responses include:

- Publishing negative findings could improve the rate at which new treatments are discovered. By withholding this information, academic journals risk affecting the rate of psychopharmacological drug development.

- I have explained that integrity prioritises the accurate representation of facts.[1]
- I have explained the potential impact of failing to publish negative findings.[2]

4 [Judgement sampling.[1]]

Other acceptable responses include:

- Selective sampling.

- I have identified the sampling technique used by Group 1.[1]

5 [A control group is a comparison group which shows the effect of the IV on the DV.[1]][Group 2 used Drug Y as their control.[2]]

- I have defined control group.[1]
- I have identified the control used by Group 2.[2]

6 [Group 2 had the highest level of replication with 20 replicates to Group 1's 15.[1]]

- I have identified Group 2 as having the higher replication rate.[1]

7 [One uncontrolled variable that could affect both groups' validity would be the varying severity of symptoms between participants.[1]][For instance, perhaps those with the most severe symptoms were randomly assigned mostly to the placebo group, meaning that the data might be skewed in favour of the treatment group/s.[2]]

Other acceptable responses include:

- Patient and clinician expectations regarding the trial.
- Changing levels of symptom severity due to the natural course of the illness.
- The effect of other non-therapeutic changes such as alterations to diet, fitness regime, and broader lifestyle.
- Patient related factors such as age, sex, and the presence of other medical or psychiatric illnesses.

I have identified a potential uncontrolled variable that affects both groups.[1]

I have explained how this uncontrolled variable could affect the accuracy and validity of the results.[2]

8 [Group 2.[1]][This was because neither the participants nor the researchers knew which arm of the study each participant was assigned.[2]]

I have correctly identified Group 2.[1]

I have explained this by describing a double-blind study.[2]

9 [By administering the tests at the start and end of participant exposure to Drug X, researchers are able to check for any decrease in cognitive ability that could be a result of exposure to the treatment.[1]][In so doing, Group 1 was able to minimise potential harm to future consumers by tracking a potential side effect of Drug X.[2]]

I have explained that the tests were likely administered to track cognitive decline in participants.[1]

I have related this to the concept of non-maleficence by referencing the minimisation of potential harm.[2]

10 [Due to the current lack of understanding between the placebo effect and its relationship to antidepressants, doctors are often forced to engage in trial and error when prescribing medication.[1]]

Other acceptable responses include:

- Prescribing certain antidepressants to some patients can potentially expose them to adverse side effects, such as insomnia and joint pain.

I have identified a bioethical issue relating to the trial and error of antidepressant prescriptions.[1]

11 [A consequences-based approach prioritises positive outcomes while aiming to minimize any unnecessary negative outcomes.[1]][An opponent of the current trial and error system might argue that the potential for error is too high, and that the potential side effects of administering the wrong type of antidepressant for a patient outweigh the benefits of getting it right.[2]]

I have outlined the priority of the consequences-based approach.[1]

I have explained how this relates to the current risks associated with the trial and error prescription method.[2]

12 [Beneficence prioritises maximising benefits and the personal wellbeing of the patient.[1]][A supporter of the current trial and error method might argue that the constant alteration and re-evaluation of prescriptions allows doctors to eventually prescribe the most effective medication for each patient on a case-by-case basis.[2]]

I have outlined the priority of the bioethical concept of beneficence.[1]

I have explained how this relates to the current strengths associated with the trial and error prescription method.[2]

Chapter 1 Exam practice

Section A

1 C **2** C **3** B **4** B

5 A

Section B

6 a [The independent variable is the concentration of antifungal medication,[1]][and the dependent variable is the mean diameter 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.

I have identified the independent variable.[1]

I have identified the dependent variable.[2]

b [Using sterile tools prevents contamination of the agar plates with environmental microorganisms or extra spores from other plates.[1]][This means that the results are less likely to be affected by these external variables and decreases the likelihood of random errors in Ibrahim's results, allowing him to more closely measure what he intended to measure.[2]]

I have explained that sterile instruments prevent contamination.[1]

I have explained how this increases the validity of the experiment.[2]

c [Ibrahim replicated each experimental group twice. This is because he had two agar plates with the same concentration of antifungal medication.[1]]

I have outlined how Ibrahim replicated his experiment.[1]

I have used key biological terminology such as: experimental group, concentration.

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 have a higher number of replicates.

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 [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 my answer with reference to the type of data presented.[2]

7 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 [These percentages were estimated as it would be unrealistic to sample the entire population.[1]] [Instead a random 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 that it would be unrealistic to sample the entire population.[1]

I have explained how the estimation would be calculated.[2]

c [It is one of the fundamental duties of government to protect the health and wellbeing of its citizens.[1]] [In raising the prices of cigarettes, the government discourages citizens from buying cigarettes, especially in large quantities.[2]]

I have stated that it is the duty of government to protect citizens.[1]

I have explained that in raising cigarette prices, the government discourages their purchase.[2]

2A Cells as the basis of life

Theory review questions

1 A

2 VI; IX

3 A

4 living things; smallest; pre-existing cells

5 Eukaryotes: II; III; IV; VIII
Prokaryotes: V; VI
Both: I; VII; IX

6 I; IV; V; VI

SAC skills questions

7 A **8** B **9** C **10** D

11 C **12** A

Exam-style questions

Within lesson

13 D **14** B **15** D **16** A

17 **a** [It must be capable of independent movement and be able to respire to produce energy for cellular functions.[1]]

Other acceptable responses include:

- Sensitivity – it must be able to sense and respond to stimuli.
- Growth – it must be able to grow in size and develop.
- Reproduction – it must be able to replicate and produce offspring.
- Equilibrium – it must be able to maintain a stable internal environment, which is known as maintaining homeostasis.
- Excretion – it must be able to remove toxic waste products.
- Nutrition – it must be able to obtain nutrition from the environment.

I have described two criteria of living things.[1]

b [Fungal cells are eukaryotic.[1]]

I have correctly classified fungal cells.[1]

c [Eukaryotes have membrane-bound organelles whereas prokaryotes do not.[1]]

Other acceptable responses include:

- Eukaryotes contain nuclei whereas prokaryotes do not.
- Eukaryotic cells generally divide by mitosis and meiosis whereas prokaryotic cells divide by binary fission.
- Eukaryotes have multiple strands of linear chromosomes whereas prokaryotes have one singular circular chromosome.
- Eukaryotes are generally larger than prokaryotes.
- Plasmids are only found in prokaryotes, not eukaryotes.

I have described one feature that distinguishes between prokaryotic and eukaryotic organisms.[1]

I have used comparative language such as: whereas.

d [All living things are made of cells.[1]][Cells are the smallest and most basic unit of life.[2]][All cells come from pre-existing cells.[3]]

I have stated the first principle of cell theory.[1]

I have stated the second principle of cell theory.[2]

I have stated the third principle of cell theory.[3]

Key science skills and ethical understanding

18 **a** [The kingdom Bacteria.[1]]

I have identified the kingdom as Bacteria.[1]

b **i** [Monthly.[1]]

I have identified that the recordings occurred monthly.[1]

ii [Four people per 100 000 people.[1]]

I have given the average monthly notification rate in November 2004.[1]

iii [Starting at two people per 100 000 in January,[1]][it peaks in February at five people per 100 000,[2]][then fluctuates from March until August between two and four people per 100 000.[3]][The average recorded cases is approximately zero in the month of September, then rises to one case per 100 000 for October and November, before receding back down to zero per 100 000 in December.[4]]

I have identified the initial reading in 2001.[1]

I have identified the maximal point in the data.[2]

I have described the mid-year fluctuating trend.[3]

I have described the end of year trend.[4]

I have used data in my response.

c [Integrity.[1]]

I have stated that they ignored the concept of integrity.[1]

2B Organelles

Theory review questions

1 C

2 chloroplasts/cell walls; chloroplasts/cell walls; mitochondria/nuclei; mitochondria/nuclei; vacuoles

3 S-cell wall; T-vacuole; U-chloroplast; V-Golgi body; W-mitochondrion; X-ribosome; Y-nucleus; Z-rough endoplasmic reticulum

4 I-ribosomes; II-plasma membrane; III-Golgi body; IV-nucleus; V-mitochondrion; VI-rough endoplasmic reticulum; VII-lysosome; VIII-smooth endoplasmic reticulum; IX-chloroplasts

5 chloroplast; photosynthesis; mitochondria; aerobic cellular respiration

6 B

SAC skills questions

7 B **8** A **9** B **10** A

11 A **12** D

Exam-style questions

Within lesson

13 C **14** D

15 **a** [Nucleus.[1]]

I have identified structure X to be the nucleus.[1]

b [A plant cell, as it contains one large vacuole, multiple chloroplasts, and a cell wall.[1]]

I have justified why the diagram shows a plant cell.[1]

c [Structure Y.[1]]

I have identified structure Y to be the primary site of aerobic cellular respiration.[1]

d [Structure Z is a vacuole,[1]][which stores the water and nutrients for the cell. It also plays a role in maintaining a plant cell's structural integrity.[2]]

I have stated structure Z is a vacuole.[1]

I have explained the function of the vacuole.[2]

e [The cytosol is the liquid component of the cell[1]][whereas the cytoplasm includes the cytosol and all the organelles in the cell, except the nucleus.[2]]

I have described the cytosol.[1]

I have described the cytoplasm.[2]

I have used comparative language in my response.

Multiple lessons

16 B

Key science skills and ethical understanding

17 **a**

	Beaker 1	Beaker 2	Beaker 3
Change in oxygen concentration	–	↓	↑

I have correctly filled out the table.

b **i** [Personal error.[1]]

I have identified that it is a personal error.[1]

ii [The percentage of oxygen in the beaker.[1]]

I have stated the dependent variable in the experiment.[1]

iii [Beakers 1 and 2 support my predictions as there is no change in oxygen concentration in beaker 1 and there is a decrease in oxygen concentration in beaker 2 as the mitochondria are undergoing aerobic cellular respiration.[1]][Beaker 3 contradicts my predictions, as the percentage of oxygen decreases, but it should increase as oxygen is produced by photosynthesis.[2]][A potential error could be that mitochondria were introduced into beaker 3 instead of chloroplasts, which is an example of a personal error.[3]]

Other acceptable responses include:

- The beaker was not sealed correctly.
- The chloroplasts were not exposed to sufficient amounts of light.

I have explained which beakers support my predictions.[1]

I have explained which beaker refutes my predictions.[2]

I have outlined a potential experimental error.[3]

iv [Respect.[1]]

I have stated that it is undermining respect.[1]

2C Cell size and shape

Theory review questions

1 A

2 size; shape; higher; lower

3 1 : 3; 3 : 4

4 D

5 C

6 A

7 C

SAC skills questions

8 B **9** C **10** B **11** A

12 A **13** A

Exam-style questions

Within lesson

14 C **15** C

Multiple lessons

16 A

17 **a** [Nucleus.[1]]

I have identified that red blood cells do not have a nucleus.[1]

b [Red blood cells are required to be small to facilitate quick transport of oxygen into and out of the cell,[1]][whereas the ovum does not require a large amount of transport and must contain half the genetic material of a new organism, organelles, and nutrients required for growth, so it is larger.[2]]

- I have explained why red blood cells must be so small.[1]
- I have explained why ova are larger.[2]
- I have used comparative language such as: whereas.
- I have used key biological terminology such as: transport, genetic material, organelles.

c [Red blood cells would have a higher SA:V.[1]][They have a much smaller volume compared to the ovum[2]][and they have a biconcave disk shape which has a larger surface area compared to an almost spherical ovum.[3]]

- I have stated which cell has a larger SA:V.[1]
- I have justified this by referring to cell size.[2]
- I have justified this by referring to cell shape.[3]
- I have used comparative terminology such as: smaller, compared to.
- I have used key biological terminology such as: SA:V, volume, biconcave, surface area.

Key science skills and ethical understanding

18 a [The independent variable is agar block size[1]][and the dependent variable is the rate of colour change.[2]]

- I have stated the independent variable.[1]
- I have stated the dependent variable.[2]

b [The percentage volume diffused by the sodium hydroxide solution would be greatest in the 1 cm cube, followed by 2 cm then 3 cm cubes, assuming the percentage volume diffused does not reach 100% in either of the 2 or 3 cm cubes.[1]]

- I have described what would happen in the experiment.[1]

c

Cubes	**1 cm × 1 cm × 1 cm**	**2 cm × 2 cm × 2 cm**	**3 cm × 3 cm × 3 cm**
Volume (cm^3)	1	8	27
Surface area (cm^2)	6	24	54
SA:V	6 : 1	3 : 1	2 : 1

- I have completed the table.

d [Object shape can increase SA:V if it is elongated.[1]]

- I have explained how the object shape can increase SA:V.[1]

e [Integrity.[1]]

- I have stated the bioethical concept that would be ignored.[1]

Chapter 2 SAC practice

1 [The inputs of aerobic cellular respiration are glucose and oxygen and the outputs are carbon dioxide, water, and energy.[1]]

- I have identified the inputs and outputs of aerobic cellular respiration.[1]

2 [Vomiting, difficulty swallowing, and diarrhoea[1]][would prevent weight gain as they are interfering with the patient's ability to digest food and gain nutrients required for normal growth and development.[2]]

- I have identified the symptoms that support the inability to gain weight.[1]
- I have explained how these symptoms lead to minimal weight gain.[2]
- I have used key biological terminology such as: digest.

3 [Weakness in limbs is due to insufficient aerobic cellular respiration as a result of limited enzyme function,[1]][meaning patients cannot produce enough energy for normal limb function.[2]]

- I have explained that the rate of aerobic cellular respiration is decreased.[1]
- I have explained the impact of a low rate of aerobic cellular respiration.[2]
- I have used key biological terminology such as: aerobic cellular respiration, energy, enzymes.

4 [Mitochondria are only found in eukaryotes.[1]]

- I have stated the location of the mitochondria.[1]

5 [Chloroplasts contain their own DNA[1]][and cannot be found in animal cells[2]][as they are the site of photosynthesis, a process that only occurs in plants.[3]]

- I have named another organelle that contains its own DNA.[1]
- I have stated that it cannot be found in animal cells.[2]
- I have explained why it is not found in animal cells with reference to photosynthesis.[3]
- I have used key biological terminology such as: chloroplasts, photosynthesis.

6 [Mitochondria and bacteria both contain their own circular DNA and their own ribosomes.[1]]

Other acceptable responses include:

- Mitochondria and bacteria both divide through binary fission.
- Mitochondria and bacteria can both produce specialised proteins for specific functions.
- Mitochondria contain a double membrane which suggests it was once a unicellular organism that was engulfed by a larger organism.

- I have stated two pieces of evidence to support the endosymbiosis theory.[1]
- I have used key biological terminology such as: mitochondria, bacteria, circular DNA, ribosomes, binary fission, specialised proteins, double membrane.

7 [The inner membrane is highly folded to increase the surface area to volume ratio,[1]] [which will maximise the efficiency of respiration.[2]]

I have stated that the inner membrane is folded to increase SA:V.[1]

I have explained the benefit of an increased SA:V.[2]

8 [mtDNA has a higher mutation rate.[1]]

I have stated that mtDNA has a higher mutation rate.[1]

9 [Mutations can be repaired in DNA as organisms have molecules that proofread DNA and correct mutations.[1]]

I have explained that DNA mutations can be repaired.[1]

10

Feeding/sucking difficulties	Struggle to consume food or milk.
Epileptic seizures	An electrical disturbance in the brain that causes a behavioural change and fluctuations in the level of consciousness and can be characterised by uncontrollable jerking of arms and legs.
Failure to thrive	A child who struggles to put on weight and is significantly underweight.
Abnormal motor function	Unusual function of muscles, tendons, and ligaments, affecting movement and coordination.
Abnormal ocular function	Atypical function of the eyes affecting vision.

I have completed the table.

11 [The median refers to the middle value in a data set.[1]] [In this case, it means that when examining the ages at which people were diagnosed with Leigh disease, seven months was the middle age of onset.[2]]

I have referred to the definition of median.[1]

I have referred to the scenario in my response.[2]

12 [Abnormal motor function.[1]]

I have identified the most common symptom at diagnosis.[1]

13 [Failure to thrive.[1]]

I have identified the symptom that affects the least number of patients as the disease progresses.[1]

14 [Abnormal ocular function[1]] [as its occurrence grew by 35.8%[2]] [during the course of the disease which is a greater increase than any other symptom.[3]]

I have stated the symptom that showed the most growth.[1]

I have included data in my response.[2]

I have explained the data in my response.[3]

I have used comparative language such as: greater.

15 [Beneficence and non-maleficence.[1]]

I have identified the two most relevant ethical concepts.[1]

16 [Ensuring the scientists do not lie or falsify their results.[1]]

Other acceptable responses include:

- Accurately cite all resources used in the study.
- Publish their findings, rather than bury or hide them.

I have outlined what integrity means.[1]

Chapter 2 Exam practice

Section A

1 B	**2** A	**3** C	**4** B
5 D	**6** D		

Section B

7 a [All living things are made of cells. Cells are the smallest and most basic unit of life. All cells come from pre-existing cells.[1]]

I have stated the three principles of cell theory.[1]

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]

d i [Structure Y is the vacuole[1]] [which is responsible for water and nutrient storage, and maintaining plant cell structure.[2]]

I have identified structure Y as the vacuole.[1]

I have outlined the function of the vacuole.[2]

ii [Structure X[1]] [as it is significantly smaller than structure Y.[2]]

I have identified the structure with a higher surface area to volume ratio.[1]

I have justified my response.[2]

8 **a** [The organism is motile as is has a flagellum,[1]] [it can respire as it contains mitochondria,[2]] [and it is capable of reproduction.[3]]

- I have referred to the criteria of movement.[1]
- I have referred to the criteria of respiration.[2]
- I have referred to the criteria of reproduction.[3]

b [This organism does contain membrane-bound organelles, as it has chloroplasts, mitochondria, and one large vacuole.[1]]

- I have stated whether the organism has membrane-bound organelles.[1]

c [Binary fission.[1]]

- I have named the process.[1]

3A Introduction to the plasma membrane

Theory review questions

1 A

2 X-phosphate head; Y-fatty acids tails; Z-phospholipid

3 polar/hydrophilic; nonpolar/hydrophobic

4 R-glycolipid; S-carbohydrate; T-glycoprotein; U-phospholipid bilayer; V-integral protein; W-peripheral protein; X-cholesterol; Y-protein channel; Z-transmembrane protein

5 B

6 I; II; III

7 I-peripheral; II-integral; III-transmembrane

8 A

SAC skills questions

9 A   10 C   11 C   12 B

13 A

Exam-style questions

Within lesson

14 D   15 C   16 B   17 D

18 a [Q is a phospholipid, R is cholesterol, S is a glycoprotein, and T is a channel protein.[1]][Molecules of Q make up the basic structure of the phospholipid bilayer in which other molecules are embedded. Molecules of R regulate the fluidity of the membrane. Molecules of S are involved in sending and receiving signals, or cell-cell adhesion. Molecules of T help transport molecules across the membrane.[2]]

- I have identified molecules Q, R, S, and T.[1]
- I have outlined the functions of molecules Q, R, S, and T.[2]

b [The phosphate head of Molecule Q is hydrophilic and polar, while the fatty acids are hydrophobic and nonpolar.[1]][This makes the overall molecule amphiphilic.[2]]

- I have identified that phosphate heads are polar and fatty acids are nonpolar.[1]
- I have stated the chemical nature of an individual phospholipid.[2]
- I have used key biological terminology such as: hydrophilic, polar, fatty acid, hydrophobic, nonpolar, amphiphilic.

c [The plasma membrane is fluid because the phospholipids and other molecules can move around – they are not stiff or held in one place.[1]] [The plasma membrane is mosaic because many different molecules are embedded in the membrane.[2]]

- I have explained why the membrane is fluid.[1]
- I have explained why the membrane is mosaic.[2]

Multiple lessons

19 A   20 A   21 A

Key science skills and ethical understanding

22 a [The cell membrane is a lipid bilayer, not a monolayer,[1]][so two layers of lipids are required to cover the surface area of a red blood cell.[2]]

- I have stated that the cell membrane is a bilayer.[1]
- I have explained why more lipids are required to form a bilayer.[2]
- I have used key biological terminology such as: lipid, bilayer, surface area, membrane.

b [Organelles and nuclei have lipid membranes too,[1]][so Gorter and Grendel would have accidentally extracted lipids from places other than the cell membrane if they hadn't used red blood cells.[2]]

- I have identified that organelles and the nucleus are membrane-bound.[1]
- I have explained the consequences of using cells with membrane-bound organelles.[2]
- I have used key biological terminology such as: membrane, lipid, membrane, organelle.

c [Being unable to accurately extract all lipid was a systematic error,[1]] [and making calculation errors was a personal error.[2]]

- I have identified the systematic error.[1]
- I have identified the personal error.[2]

d [The ethical concept of integrity.[1]]

- I have identified the ethical concept they have upheld.[1]

3B Passive transport

Theory review questions

1 A

2 J-simple diffusion; K-facilitated diffusion; L-osmosis

3 nonpolar/hydrophobic; down; facilitated diffusion; polar/hydrophilic; down; proteins

4 III; V

5 M-isotonic; N-hypotonic; O-hypertonic

6 I-diffusion; II-diffusion, osmosis, facilitated diffusion; III-facilitated diffusion; IV-diffusion, osmosis, facilitated diffusion; V-osmosis, facilitated diffusion

SAC skills questions

7 B   8 D   9 A   10 C

11 C   12 A

Exam-style questions

Within lesson

13 C   14 C   15 D

Multiple lessons

16 a i

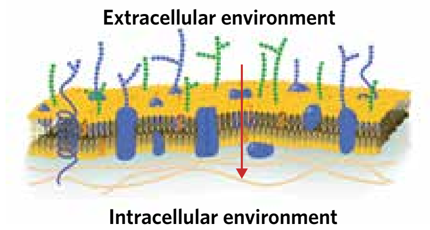


Image: J.Marini/Shutterstock.com

- 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]][Therefore, thanks to the 'like dissolves like' rule, other hydrophobic substances can pass straight through the membrane without the aid of transport proteins.[2]][The hydrophobic molecule moves down its concentration gradient, which is why it moves into the cell.[3]]

- I have described the nature of the plasma membrane.[1]
- I have explained the consequences of membrane structure on the movement of hydrophobic molecules.[2]
- I have explained why the molecule moves into the cell.[3]

b [J is a phospholipid. 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 to 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 molecule J.[1]
- I have identified and described the role of molecule K.[2]
- I have identified and described the role of molecule L.[3]

c [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 passive transport.[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.

Key science skills and ethical understanding

17 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 used comparative language such as: more, smaller, lighter.

b [The brand of corn syrup used and the amount the solutions were mixed.[1]]

Other acceptable responses include:

- The mass of the eggs at the start of the experiment.
- The volume of solution used.
- The hen the eggs were from.
- The place the circumference was measured from on the egg.
- Surface area of the egg.
- Temperature of the solution the egg is in.

- I have suggested two variables that are reasonable to control.[1]
- I have not suggested controlling variables that were already kept constant in the experiment such as: amount of corn syrup, time in solution, treatment beforehand.

c [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]

d [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 also be 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 a control 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]

e [The bioethical concept of integrity requires researchers to disclose results regardless of whether they are favourable or unfavourable.[1]][By deleting her previous results and not telling anyone, Kinji is not acting ethically.[2]]

- I have described the bioethical concept of integrity.[1]
- I have stated that Kinji is acting unethically.[2]

3C Active transport

Theory review questions

1 A

2 I; II; III; VI

3 A

4 C

5 B

6 I; II; III; IV

7 Exocytosis: I
Endocytosis: II
Active transport: III

SAC skills questions

8 A **9** B **10** B **11** A

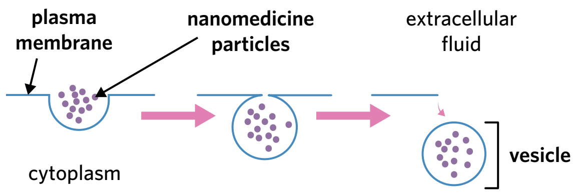
12 A

Exam-style questions

Within lesson

13 C **14** D

15 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 the 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]

Multiple lessons

16 C **17** C **18** C **19** C

20 C

21 a [Drug 2 is soluble in lipids,[1]][as it is found buried amongst the lipophilic/hydrophobic fatty acid tails of phospholipids.[2]] [Drug 1 is insoluble in lipids (lipophobic), as it is found inside the liposome in a hydrophilic environment.[3]]

- I have stated that Drug 2 is soluble in lipids.[1]
- I have justified why Drug 2 is soluble in lipids.[2]
- I have stated that Drug 1 is insoluble in lipids and justified why this is the case.[3]
- I have used key biological terminology such as: lipophilic, soluble, insoluble, lipophobic.

b [Medicines could also enter cells via simple diffusion.[1]][This would involve the hydrophobic drug moving down its concentration gradient across the plasma membrane and into the cell.[2]]

Other acceptable responses include:

- Medicines could also enter cells via protein-mediated active transport. This would involve the drug being moved against its concentration gradient, through a protein pump using ATP, and into the cell.
- Medicines could also enter cells via facilitated diffusion. This would involve the hydrophilic drug moving down its concentration gradient, through a protein channel, and into the cell.

- I have identified another drug transport mechanisms.[1]
- I have described the transport mechanism.[2]

Key science skills and ethical understanding

22 a [The age of the mouse neurons is the independent variables.[1]] [The amount of APP endocytosis and beta-amyloid in neurons are the dependent variables.[2]]

- I have identified the independent variable.[1]
- I have identified the dependent variables.[2]

b [*In vitro* experiments take place outside a living organism.[1]] [This maximises the ethical concept of non-maleficence,[2]] [as it minimises the risk of harm or pain to living things.[3]]

Other acceptable responses include:

- The ethical concept of beneficence is maximised, as the welfare of living things is optimised by avoiding *in vivo* experiments.
- The ethical concept of respect is maximised, as the inherent value of life is prioritised by avoiding *in vivo* experiments.

- I have described *in vitro* experiments.[1]
- I have identified a relevant ethical concept.[2]
- I have explained why the ethical concept influences the decision to undertake *in vitro* research.[3]

c [The results support the scientist's hypothesis.[1]][Older mouse neurons had double the amount of APP endocytosis and 50% more beta-amyloid. [2]]

- I have stated that the results support the hypothesis.[1]
- I have justified my response with data from the scenario that explains how the independent variable affects the dependent variable.[2]

Chapter 3 SAC practice

1 [Aquaculture refers to the farming of water-based species.[1]] [We can infer this because the paragraph states that Ronda studies how to sustainably farm aquatic and marine organisms for food.[2]]

- I have defined aquaculture in my own words.[1]
- I have used information from the scenario to justify my response.[2]

2 [Phospholipids, glycoproteins, glycolipids, proteins, and cholesterol.[1]]

- I have identified the core chemical components of plasma membranes.[1]

3

	Active or passive?	Direction	ATP required?	Protein required?	Type of molecules that move
Diffusion	passive	down concentration gradient	no	no	hydrophobic
Osmosis	passive	from hypotonic to hypertonic regions	no	sometimes	water
Facilitated diffusion	passive	down concentration gradient	no	yes	hydrophilic
Active transport	active	against concentration gradient	yes	yes	hydrophilic or very large/bulky

- I have correctly identified each transport type as active or passive.
- I have correctly identified the direction of movement of transport.
- I have correctly identified if ATP is required.
- I have correctly identified if a protein assists.
- I have correctly identified the types of molecules involved in each transport type.

4 [Ronda was most likely influenced by the concept of non-maleficence,[1]] [as she sought to avoid unnecessary harm to living things when there was an alternative available.[2]]

Other acceptable responses include:

- Ronda was most likely influenced by the concept of respect, and recognises that all living things have an inherent value and right to life.

- I have identified a bioethical concept.[1]
- I have explained how the bioethical concept may have influenced Ronda's decision.[2]

5 [Ida was most likely informed by a consequences-based approach,[1]] [and thought that the potential negative impacts of Ronda's presence, such as the likely disruption to her farm, outweighed the potential benefits.[2]]

Other acceptable responses include:

- Ida was most likely informed by a duty/rule-based approach and believes that she has a duty to protect her farm and ensure it runs effectively.
- Ida was most likely informed by a virtues-based approach, and believes that a good moral agent would prioritise the safety of those who work and use her farm.

- I have identified a bioethical approach.[1]
- I have explained how the approach may have informed Ida's decision.[2]
- I have avoided reusing the word 'consequences' in my explanation of a 'consequences-based approach'.

6 [Image A depicts the plasma membrane of the Norwegian Atlantic salmon.[1]] [We know this because the phospholipids are more loosely packed,[2]] [which is beneficial in colder environments like Tromsø where the lower temperatures reduce membrane fluidity and impair transport.[3]] [In hot environments, however, the increased kinetic energy makes membranes very fluid, so keeping phospholipids tightly packed increases membrane stability.[4]]

- I have identified that image A is of Norwegian salmon.[1]
- I have justified my choice.[2]
- I have explained why loosely packed phospholipids are beneficial in cold environments.[3]
- I have explained why tightly packed phospholipids are beneficial in hot environments.[4]
- I have used key biological terminology such as: membrane, phospholipid, fluidity, stability, transport, kinetic energy.

7 [Norwegian Atlantic salmon have unsaturated fatty acid tails in their phospholipids,[1]] [as there are kinks/bends in the hydrocarbon chain.[2]]

- I have identified that the Norwegian salmon have unsaturated fatty acids.[1]
- I have explained that the kinks in hydrocarbon chains are indicative of unsaturated fatty acids.[2]
- I have used key biological terminology such as: fatty acid, phospholipid, hydrocarbon.

8 [A biological consequence is that the fish produce waste products that could negatively affect nearby ecosystems.[1]] [A social consequence could be increased employment opportunities for locals.[2]]

Other acceptable biological consequences include:

- The fish may escape and become pests.
- The fish may compete with local fish for food.
- The native fish may be attracted to the fish farm to eat leftover fish food.
- Increased boat traffic near the farm could pollute or damage the environment.

Other acceptable social consequences include:

- People may no longer be able to use the area recreationally.
- People may get cheaper prices for salmon.

9 [Wei would grow colonies of *E. coli* on four different Petri dishes at 15 °C. She would also have four Petri dishes at 25 and 35 °C.[1]]

- I have stated that four Petri dishes would be used at each temperature.[1]

10 [If you can replicate your experiment and consistently get similar results, you know that your results are not just due to chance[1]] [and that your measurements are precise.[2]]

Other acceptable responses include:

- High replication reduces the effect that random errors, personal errors, and outliers have on your results.

- I have stated that replication tells scientists if their results are due to chance.[1]
- I have explained that replication tells scientists if their measurements are precise.[2]

11 [Wei's results do not support Hypothesis 1,[1]] [as there is no overall change in the ratio of saturated : unsaturated fatty acids over generations. For instance, generation 1 at 15 °C had a ratio of 1:4, as did generations 2, 3, and 4. [2]]

- I have stated that the results do not support Hypothesis 1.[1]
- I have used data from the table to support my response.[2]

12 [Generation 3 at 25 °C is unusual.[1]]

- I have identified that the third generation at 25 °C is unusual.[1]

13 [Wei could increase the number of replicates.[1]]

Other acceptable responses include:

- Wei could increase the sample size.
- Wei could refine the measurement process/method.

- I have identified an action that reduces random error.[1]

Chapter 3 Exam practice

Section A

1 D	**2** D	**3** D	**4** D
5 C	**6** B	**7** B	**8** B

Section B

9 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, 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]

10 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 key 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 to the blood plasma in terms of K^+.[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 diffuse across the membrane.[3]
- I have used key biological terminology such as: active transport, ATP, pump, concentration gradient, diffuse.

4A The prokaryotic cell cycle

Theory review questions

1 A

2 I; III; IV

3 A

4 A

5 binary fission; asexual reproduction; identical

6 P-plasmid; L-septum; M-cell wall and membrane; N-ribosome; O-circular chromosome

7 I-the uncoiling of the prokaryotic circular chromosome and the replication of DNA; II-the formation of a septum; III-a prokaryotic cell prior to binary fission; IV-the formation of a new cell membrane and cell wall

8 B

SAC skills questions

9	A	10	B	11	A	12	B
13	C	14	B				

Exam-style questions

Within lesson

15 B 16 B

Multiple lessons

17 B

18 a [Mitochondria.[1]]

I have identified the correct organelle.[1]

b [Bacterial chromosomes are circular.[1]]

I have described the shape of a bacterial chromosome.[1]

c [During stage Y, the cell is beginning cytokinesis and a septum is forming.[1]]

I have stated what is occurring at stage 'Y'.[1]

Key science skills and ethical understanding

19 a [Because bacteria have a short replication time, they can multiply rapidly thereby producing large quantities of insulin.[1]]

Other acceptable responses include:

- By using bacteria, scientists can avoid experimenting on living animals.

I have identified an advantage of using bacteria.[1]

b [By killing the bacterial cells which are not resistant to tetracycline, scientists will be left only with bacterial cells that have taken up the modified plasmid with the inserted foreign DNA.[1]]

I have identified the purpose of the Petri dish containing tetracycline.[1]

c [Scientists should use gloves and wash their hands thoroughly.[1]]

Other acceptable responses include:

- conducting the experiment in a controlled environment
- sterilising equipment before use
- wearing safety glasses
- wearing a lab coat

I have suggested two potential precautions scientists could take.[1]

d [Personal error.[1]]

I have identified the correct type of error.[1]

e i [The ethical principle of justice is being undermined.[1]][This is because pharmaceutical companies can charge whatever they wish for their products, which prevents everyone from being able to access medication.[2]]

I have identified the correct ethical principle.[1]

I have explained the relevance of the ethical principle to the scenario.[2]

ii [One solution is that governments can subsidise medication, making it more accessible.[1]]

Other acceptable responses include:

- Governments can impose limits on how much pharmaceutical companies can charge.
- Governments can limit the duration of patents, allowing manufacturers to produce cheaper, generic medication sooner.

I have identified one potential solution.[1]

4B The eukaryotic cell cycle

Theory review questions

1 A

2 interphase; mitosis; cytokinesis

3 A

4 I-G0; II-G1; III-S; IV-G2

5 A

6 C

7 I-anaphase; II-prophase; III-telophase; IV-metaphase

8 I-telophase; II-telophase; III-anaphase; IV-metaphase; V-prophase; VI-prophase; VII-metaphase; VIII-anaphase

9 B

10 A

SAC skills questions

11	A	12	B	13	B	14	C
15	A	16	A	17	B		

Exam-style questions

Within lesson

18 D **19** A **20** C **21** B

22 B **23** D **24** A

25 **a** [Q, P, J, M, L, G, H.[1]]

I have correctly ordered the events of mitosis.[1]

b [The step depicted in J is prophase.[1]][Prophase is the first stage of mitosis, within which the chromosomes condense into visible and discrete chromosomes[2]][and the centrioles form and migrate to opposite poles of the cell[3]][and spindle fibres begin to form.[4]]

I have correctly identified the step shown in diagram J.[1]

I have identified that the chromosomes condense.[2]

I have identified that the centrioles migrate to opposite ends of the cell.[3]

I have identified that the spindle fibres begin to form.[4]

Multiple lessons

26 **a** [The G1 phase of interphase during the eukaryotic cell cycle is primarily focused on preparing the cell for the replication of DNA during the next stage of the cycle, synthesis.[1]][As the structure of DNA requires large amounts of histone proteins, and the process of DNA replication requires proteins to proceed,[2]][the cell must synthesise or import the amino acids necessary for the construction of such proteins.[3]]

I have described the purpose of the G1 phase of the eukaryotic cell cycle.[1]

I have identified that DNA structure requires the use of proteins.[2]

I have explained why the cell must synthesise amino acids during the G1 phase.[3]

I have used key biological terminology such as: G1, histone proteins, amino acid.

b [The surface area to volume ratio would decrease[1]][and the rate of diffusion across the membrane would decrease.[2]]

I have recognised that this would decrease the surface area to volume ratio within the cell.[1]

I have explained the effect this would have on transport across the membrane.[2]

Key science skills and ethical understanding

27 **a** [One of the four plant hormones (auxin, cytokinins, abscisic acid, or ethylene) will cause cell growth by promoting cytokinesis.[1]]

I have correctly identified the hypothesis.[1]

b [The growth of the plant cell cultures.[1]]

I have correctly identified the dependent variable.[1]

c [The type of plant hormone.[1]]

I have correctly identified the independent variable.[1]

d [The plant culture with no hormone added acts as a control,[1]][and shows the base rate of plant culture growth when not exposed to any experimental treatment.[2]][This ensures that Charlie can tell whether any increase in plant culture growth is due to the presence of the plant hormones.[3]]

I have identified the correct control.[1]

I have explained the purpose of the control.[2]

I have related the purpose of the control to the experiment.[3]

e [In animals, cytokinesis begins with the membrane and cytoplasm 'pinching in on itself', the formation of a cleavage furrow, and the eventual split into two identical daughter cells.[1]][In contrast, cytokinesis in plants involves the formation of a cell plate, which separates and grows to eventually split the plant cell into two identical daughter cells.[2]]

I have explained the process of cytokinesis in animal cells.[1]

I have explained the process of cytokinesis in plant cells.[2]

I have used comparative language in my response such as: in contrast.

f [Social implication: could promote the creation of jobs in the business of creating cultured meat.[1]][Biological implication: could reduce humanity's reliance on beef farming, reducing any negative influences on the environment.[2]]

Other acceptable social implications include:

- Beef cells could be genetically engineered to be healthier to consume than naturally grown beef.
- Promoting business which grows cultured beef could negatively affect the profits of traditional commercial beef farmers.
- Consumers may not know what they are eating if companies are not transparent.

Other acceptable biological implications include:

- Reduce greenhouse gas emissions from beef farms.
- Potential harming of cows for experimental testing.

I have identified a social implication.[1]

I have identified a biological implication.[2]

4C Apoptosis

Theory review questions

1 B

2 X-death receptor pathway; Y-mitochondrial pathway

3 B

4 proteins; shrinks; apoptotic bodies

5 C

6 decrease; death signalling molecules; cancer

7 I; V; VI

8 B

9 I-increased survival; II-antigrowth deactivation; III-tissue invasion and metastasis; IV-self-sufficiency

SAC skills questions

10 B 11 B 12 A 13 B

14 C 15 D 16 A

Exam-style questions

Within lesson

17 B 18 B 19 A 20 C

Multiple lessons

21 a [No, apoptosis in this cell is caused by internal DNA damage and would be initiated via the mitochondrial pathway.[1]]

- I have justified that apoptosis is not initiated via the death receptor pathway.[1]
- I have used key biological terminology such as: mitochondrial pathway.

b [After apoptosis, phagocytes engulf and destroy apoptotic bodies through phagocytosis.[1]]

- I have correctly identified the role of phagocytes after apoptosis.[1]
- I have used key biological terminology such as: apoptotic bodies.

22 a [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 i [The primary function of the mitochondria is to produce energy in the form of ATP via aerobic cellular respiration.[1]]

- I have identified the function of the mitochondria.[1]

ii [The mitochondrial pathway of apoptosis is initiated when internal components of the cell are damaged.[1]] [First, mitochondria release cytochrome c which causes the activation of caspases.[2]][Then, the caspases cleave proteins and the cell shrinks as intracellular material is broken down.[3]] [This results in the blebbing and breakage of the cell into apoptotic bodies.[4]]

- I have described how the mitochondrial pathway is initiated.[1]
- I have identified the release of cytochrome c and activation of caspases.[2]
- I have identified that the cell shrinks.[3]
- I have identified that the cell blebs and breaks into apoptotic bodies.[4]
- I have used key biological terminology such as: cytochrome c, caspases, blebbing, apoptotic bodies.

iii [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 and ethical understanding

23 a [Cancer cells and senescent cells.[1]]

Other acceptable responses include:

- Malignant tumour cells.

- I have identified two types of 'apoptosis-resistant' cells.[1]

b [Yes, Chemotherapy drugs damage DNA in the cell which initiates apoptosis and senolytic drugs cause the release of cytochrome c.[1]] [Both of these actions are part of the mitochondrial pathway of apoptosis.[2]]

- I have described the effects of chemotherapy and senolytic drugs on the cell.[1]
- I have correctly identified the pathway(s) of apoptosis.[2]

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]
- I have used evidence from the text to justify my response.

d [Based on the ethical principle of respect,[1]] [as long as the patient and their family understand the consequences of their actions and have sufficient mental capacity to make the decision, then doctors should not be allowed to withhold treatment from patients.[2]]

Other acceptable responses include:

- Based on the ethical principle of non-maleficence, doctors should be allowed to withhold treatment from patients if they believe that by administering treatment they would be doing more harm than good.
- Based on the ethical principle of beneficence, doctors should be allowed to withhold treatment from patients if they believe that they are providing patients with the best quality of life by withholding treatment.
- Based on the ethical principle of justice, to ensure the fair consideration of all competing claims, both parties should nominate a third-party mediator to assess the claims and to choose whether treatment should be withheld or not.

I have identified a relevant ethical principle.[1]

I have explained the relevance of the ethical principle to the scenario.[2]

4D Stem cells

Theory review questions

1 C

2 A

3 A

4 I-totipotent; II-multipotent; III-pluripotent

5 P-totipotent stem cells; Q-pluripotent stem cells; R-multipotent stem cells; S-specialised cells

6 C

SAC skills questions

7 B   8 B   9 C   10 A

11 A   12 A

Exam-style questions

Within lesson

13 C   14 C

Multiple lessons

15 a [Scientists could observe the development of the cell. If the cell is capable of self-renewal and differentiation, then the cell must be a cancer stem cell.[1]] [If the cell does not show either of these properties, then it must be a normal cancer cell.[2]]

I have described the observations which would suggest the cell is a cancer stem cell.[1]

I have described the results which would suggest the cell is a normal cancer cell.[2]

I have used key biological terminology such as: self-renewal, differentiation.

b [This process is apoptosis, which is initiated by either the mitochondrial or death receptor pathway. Caspase enzymes are then activated, and they cleave particular proteins, leading to the digestion of intracellular contents and organelles.[1]] [Following this, the cell shrinks and parts of the plasma membrane bleb, forming apoptotic bodies.[2]]

I have described the initiation of apoptosis.[1]

I have described the formation of apoptotic bodies.[2]

I have used key biological terminology such as: apoptosis, caspase enzymes, blebbing, apoptotic bodies.

c [A cancerous stem cell may evade death signalling molecules by producing non-functional death receptor proteins so that the death signalling molecules cannot initiate apoptosis.[1]]

Other acceptable responses include:

- The signalling pathway between receptor activation and apoptosis initiation in cancerous cells may be interrupted by internal cell processes, preventing apoptosis.

I have suggested how cancerous stem cells may evade death signalling molecules.[1]

d [As the number of cancerous stem cells increases, the level of oxygen and nutrients required to maintain their growth also increases, as does the amount of waste products they produce. Therefore, new blood vessels need to be formed to deliver oxygen and nutrients to the cells and to remove waste products.[1]]

I have explained why new blood vessels need to be formed.[1]

Key science skills and ethical understanding

16 a [Totipotent stem cells can differentiate into any specialised cell, pluripotent into many different cell types, and multipotent into a handful of different cell types within an organ or tissue.[1]]

I have described each of the three stem cell potencies.[1]

I have used key biological terminology such as: differentiate, specialised cells.

b i [Based on the ethical principle of beneficence researchers should be focused on maximising benefit to all parties.[1]] [Because the extraction of embryonic stem cells is required for research into treating many currently untreatable diseases, scientists should continue with the procedure.[2]]

Other acceptable responses include:

- Because the extraction of embryonic stem cells leads to the destruction of embryos, scientists should not continue with the procedure.

I have described the ethical principle of beneficence.[1]

I have explained the relevance of beneficence to the scenario.[2]

ii [Based on the ethical principle of non-maleficence, researchers should be focused on ensuring that the benefits of a course of action always outweigh the harm.[1]] [Therefore, the scientists should continue extracting embryonic stem cells as long as the benefits of stem cell research outweigh the harm associated with the death of an embryo.[2]]

- I have described the ethical principle of non-maleficence.[1]
- I have explained the relevance of non-maleficence to the scenario.[2]

c i [The injection of stem cells into the muscle will yield greater muscle regeneration than the control.[1]]

- I have identified the hypothesis.[1]

ii [The independent variable is injection with the stem cell treatment or the 0.9% saline.[1]] [The dependent variable is the growth of muscle tissue after treatment.[2]]

- I have identified the independent variable.[1]
- I have identified the dependent variable.[2]

iii [In this experiment, the 0.9% saline solution served as a control.[1]] [This control group is a comparison to the experimental group, allowing scientists to decide whether the growth in muscle tissue was due to the stem cell treatment or something else such as the placebo effect.[2]]

- I have identified this group as the control.[1]
- I have explained the purpose of a control in this scenario.[2]

iv [Scientists could improve the accuracy of this experiment by using a larger, more representative sample size.[1]]

Other acceptable responses include:

- Calibrating measuring instruments to ensure they are providing accurate measurements.

- I have suggested how scientists could improve the accuracy of this experiment.[1]

d i [Differentiation is the process by which a cell becomes more specialised.[1]]

- I have described the process of differentiation.[1]

ii [Induced pluripotent stem cells are advantageous as they avoid many ethical issues such as the destruction of an embryo which is associated with embryonic stem cells.[1]]

- I have suggested an advantage of induced pluripotent stem cells compared with embryonic stem cells.[1]

Chapter 4 SAC practice

1 [As myeloid stem cells differentiate into specialised blood cells, the potency is multipotent.[1]] [Multipotent stem cells are those with the ability to differentiate into multiple, but limited, specialised cells.[2]]

- I have named the potency of the myeloid stem cells.[1]
- I have described the potency of the myeloid stem cells.[2]

2 [Apoptosis.[1]]

- I have identified the correct regulatory process.[1]

3 [DNA damage often occurs during the S phase because errors can arise during DNA replication.[1]]

- I have explained why DNA damage often occurs during the S phase.[1]

4 [Because AML affects the production of red blood cells, oxygen circulation around the body decreases.[1]] [This leads to lower levels of energy (ATP) being produced, thereby causing fatigue.[2]]

- I have identified that AML affects oxygen circulation.[1]
- I have explained that low oxygen levels decrease energy in the body, leading to fatigue.[2]

5 [Males aged 75–79.[1]]

- I have identified the group with the greatest number of cases.[1]

6 [In both females and males aged 0–4 years old, the average number of new cases is initially approximately 20 before decreasing in 5–9 year-olds.[1]] [Then, both groups gradually increase until the 75–79 year-old group for males and the 80–84 year-old group for females.[2]] [The number of males affected is far greater compared to females. While females reach approximately 200 average cases in the 80–84 year-old group, males nearly reach 280 average cases in the 75–79 year-old group.[3]] [After the 75–79 year-old group for males and the 80–84 year-old group for females the average number of cases decreases.[4]]

- I have described the increased incidence in 0–4 year-olds.[1]
- I have described the gradual increase up until the 75–79 year-old group for males and the 80–84 year-old group for females.[2]
- I have identified that the number of males diagnosed is higher than females.[3]
- I have described the decline after the 75–79 year-old group for men and the 80–84 year-old group for females.[4]
- I have used data to support the general trend.
- I have used comparative language such as: both, compared to.

7 Doctors can take a biopsy of the patient's bone marrow to assess whether the number of leukaemia cells is increasing or decreasing.[1]

Other acceptable responses include:

- Doctors can do blood tests to assess whether the number of leukaemia cells is increasing or decreasing.
- Doctors can do imaging tests such as CT and PET scans to assess whether the number of leukaemia cells is increasing or decreasing.

I have identified one diagnostic method doctors can use.[1]

8 Because the chemotherapy drug is a large hydrophilic molecule that cannot cross the plasma membrane,[1] it could induce apoptosis by binding to an extracellular receptor on cells such as a death receptor.[2]

I have referred to the solubility of the chemotherapy drug.[1]

I have identified how the chemotherapy drug could induce apoptosis.[2]

9 The death receptors of the leukaemia cells may be non-functional,[1] meaning chemotherapy drugs will be unable to bind to them and induce apoptosis.[2]

Other acceptable responses include:

- The signalling pathway between receptor activation and apoptosis initiation in leukemia cells may be interrupted by internal cell processes, preventing apoptosis.

I have identified that the death receptors could be non-functional.[1]

I have related non-functional receptors to a failure in apoptosis.[2]

10 Terminally differentiated cells remain in the G0 phase of the eukaryotic cell cycle indefinitely.[1] Therefore, because they can no longer replicate, they will not naturally regrow.[2]

I have identified that terminally differentiated cells remain in the G0 phase.[1]

I have concluded that they will not naturally regrow.[2]

11 Treated stem cells do not initiate an immune response within volunteers.[1]

I have stated an appropriate hypothesis.[1]

12 The independent variable is whether the volunteers are given converted stem cells.[1] The dependent variable is whether the volunteers develop an immune response.[2]

I have identified the independent variable.[1]

I have identified the dependent variable.[2]

13 Based on the ethical principle of non-maleficence, scientists should not proceed with the release because their focus should be on doing no harm.[1] If they did release the treatment, then they would be causing harm to 1% of all patients who receive the treatment.[2]

Other acceptable responses include:

- Based on the ethical principle of beneficence, scientists should proceed with the release because their focus should be on maximising the amount of good they can provide. If they did not release the treatment, then they would not be able to help 99% of patients who seek treatment.
- Based on the ethical principle of respect, scientists should not proceed with the release because their focus should be on the welfare and health of their patients. Therefore, they should maximise their efforts to maintain the health of patients instead of risking their lives.

I have identified a relevant ethical principle.[1]

I have explained the relevance of the ethical principle to the scenario.[2]

14 *S. pneumoniae* would replicate through binary fission.[1] In binary fission, the cell would replicate its DNA, elongate, and then pinch into two new bacterial cells.[2]

I have identified that *S. pneumoniae* would replicate through binary fission.[1]

I have described the process of binary fission.[2]

15 The replication of *S. pneumoniae* differs from human cells because *S. pneumoniae* undergoes binary fission while human cells undergo mitosis.[1] They differ as spindle fibres do not form in binary fission and chromosomes do not separate at the centromere.[2]

Other acceptable responses include:

- Binary fission is faster than mitosis.
- Chromosomes do not line up at the equator during binary fission.
- Mitosis is composed of distinct phases, whereas binary fission is not.

I have named how human cells and bacterial cells replicate.[1]

I have described two differences between how bacteria and human cells replicate.[2]

16 1999.[1]

I have identified the correct year.[1]

17 The death rate from pneumonia of under five-year-olds has gradually decreased from approximately 360 per 100 000 in 1990 to approximately 110 per 100 000 in 2017.[1] This decrease can be explained by advances in sanitation[2] leading to better methods of preventing bacterial infections.[3]

Other acceptable responses include:

- This decrease can be explained by advances in technology, leading to better methods of detection and treatment of bacterial infections.
- This decrease can be explained by advances in medicine, leading to better treatment in early life care.

I have described the trend.[1]

I have identified one contributing factor to the trend.[2]

I have explained how this factor led to a change in the death rate.[3]

Chapter 4 Exam practice

Section A

1 B **2** A **3** B **4** C
5 C

Section B

6 a [During metaphase, spindle fibres attach to the centromere of each chromosome.[1]][The spindle fibres then help to line up the chromosomes along the equator of the cell.[2]]

- I have described the attachment of spindle fibres.[1]
- I have described the arrangement of chromosomes in the cell.[2]
- I have used key biological terminology such as: spindle fibres, centromere, equator.

b [The cell would undergo apoptosis at metaphase if the cell detects that the spindle fibres have not attached correctly or if the chromosomes are incorrectly aligned.[1]][By initiating apoptosis, the formation of malfunctioning cells is prevented.[2]]

- I have described the scenarios in which the metaphase checkpoint would initiate apoptosis.[1]
- I have explained why the metaphase checkpoint would initiate apoptosis.[2]

7 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 unnecessary cells and removes damaged or non-functioning cells.[1]]

Other acceptable responses include:

- Prevent the formation of tumours within mice.
- Apoptosis ensures that the total number of cells in an organism remains constant.

- I have stated two benefits of apoptosis in mice.[1]
- I have not just stated that apoptosis assists in paw formation.

c [Caspases cleave specific proteins in the cell as part of a chain of reactions.[1]]

- I have stated the role of caspases in apoptosis.[1]

8 a [Every chromosome is initially composed of a single strand.[1]] [After replication, each chromosome is composed of genetically identical sister chromatids joined by a centromere.[2]]

- I have described the initial structure of chromosomes.[1]
- I have described the structure of chromosome following replication.[2]

b [John is correct.[1]][This is because even though at both stages A and B the cells are diploid, each chromosome at stage A will be comprised of two identical sister chromatids formed by DNA replication, whist each chromosome at stage B will have chromosomes composed of a single chromatid. Therefore, the cell at stage A will have twice as much DNA as the cell at stage B.[2]]

- I have identified which student is correct.[1]
- I have explained why this student is correct.[2]

9 a [*C. perfringens* replicates via binary fission.[1]]

Other acceptable responses include:

- *C. perfringens* is a bacterium.

- I have identified a feature of *C. perfringens* that makes it a prokaryote.[1]

b [*C. perfringens* would contain one circular chromosome and would not contain a nucleus.[1]]

Other acceptable responses include:

- *C. perfringens* may contain many plasmids.
- *C. perfringens* would not contain membrane-bound organelles.
- *C. perfringens* may contain a cell wall.
- *C. perfringens* may have flagella.

- I have identified two cellular characteristics.[1]

c [A nuclear membrane is not broken up in binary fission, whereas a nuclear membrane is broken up during prophase of mitosis.[1]] [Chromosomes do not line up across the equator in binary fission, whereas as chromosomes line up during metaphase of mitosis.[2]]

Other acceptable responses include:

- Centrioles do not separate chromosomes during binary fission.
- Chromosomes do not condense during binary fission.
- There are no sister chromatids to separate during binary fission.

- I have identified one difference between binary fission and mitosis.[1]
- I have identified another difference between binary fission and mitosis.[2]

5A From cells to systems

Theory review questions

1 A

2 B

3 I-flowers; II-fruit; III-roots; IV-leaves; V-stems

4 epithelial tissue; nervous tissue; muscle tissue; connective tissue

5 I; II; IV

6 I-excretory system; II-immune system; III-respiratory system; IV-blood circulatory system; V-endocrine system

7 digestive; fruit; roots; stems; skeletal

SAC skills questions

8 A **9** A **10** A **11** A

12 B **13** B

Exam-style questions

Within lesson

14 B **15** C **16** A **17** D

18 B **19** C

Multiple lessons

20 a [Surface area to volume ratio is a comparison between the total surface area of an object, and its total volume.[1]]

I have defined the surface area to volume ratio.[1]

b [As a cell increases in size, its surface area to volume ratio will decrease.[1]]

I have described the relationship between cell size and surface area to volume ratio.[1]

c [A high surface area to volume ratio increases the rate of diffusion across a cell surface.[1]]

I have explained that a higher surface area to volume ratio increases the rate of diffusion.[1]

d [These cells are arranged to maximise their surface area to volume ratio[1]][which allows for greater absorption of nutrients from food into the cells.[2]]

I have identified that these cells have a high surface area to volume ratio.[1]

I have explained that this is beneficial for nutrient absoprtion.[2]

Key science skills and ethical understanding

21 a [The number of deceased organ donors remained somewhat constant from 2000–2009 at approximately 200 individuals per year before rising to reach approximately 550 individuals in 2019.[1]] [Similarly, the number of transplant recipients was approximately 600–700 individuals per year from 2000–2009 before rising to approximately 1 400 individuals in 2019.[2]]

I have described the changes in deceased organ donor numbers over the 20 years.[1]

I have also described the changes in transplant recipient numbers over the 20 years.[2]

I have used data from the graph to support my answer.

b [Approximately 320.[1]]

I have identified the number of donors as between 300–350.[1]

c [Approximately 1 500.[1]]

I have identified the number of recipients as between 1 450–1 550.[1]

d i [The doctor should be following the bioethical concept of integrity[1]][as it is their responsibility to report to the potential donor the risks and complications that can be associated with the procedure, regardless of how unlikely they are.[2]]

I have identified the bioethical concept of integrity.[1]

I have justified my response by referring to the doctor's responsibility to report all information.[2]

ii [The bioethical concept of non-maleficence should be followed[1]] [to ensure the surgeon does not undertake any action which would place undue risk on either the donor or the recipient.[2]]

I have identified the bioethical concept of non-maleficence.[1]

I have justified by response by referring to the minimisation of unnecessary risk.[2]

5B Plant vascular tissues

Theory review questions

1 B

2 L-xylem; M-phloem; N-vascular bundle; O-xylem; P-phloem

3 phloem; glucose/nutrients/minerals; source and sink; xylem; roots/root system

4 III; V; VI; VII; VIII

5 large; guard cells; stoma; turgid; transpiration

SAC skills questions

6 A **7** A **8** C **9** B

10 C **11** A **12** B **13** B

Exam style questions

Within lesson

14 C **15** D **16** A **17** C

18 D

Multiple lessons

19 A **20** A **21** A

22 **a** **i** [The cytoplasmic pathway.[1]]

I have correctly identified the pathway of nutrient absorption taken by solutes.[1]

ii [Cells below the ring-barking would be deprived of glucose and other nutrients, and slowly die.[1]] [Ring-barking removes the phloem tissue, impeding the transportation of essential nutrients such as glucose.[2]] [Following girdling, the cells above the girdling would be deprived of water, while cells below would be deprived of nutrients. In this case, the plant would likely rapidly wilt and die.[3]] [This is because girdling is the removal of the phloem and xylem, impeding the translocation of nutrients by the phloem, and preventing transpiration in the xylem.[4]]

I have predicted the impact of ring-barking on the oak tree.[1]

I have justified the impact of ring-barking on the oak tree.[2]

I have predicted the impact of girdling on the oak tree.[3]

I have justified the impact of girdling on the oak tree.[4]

b [The two major components of the xylem are the vessel elements and tracheids. The vessel elements are large hollow tubes that stack end-to-end, allowing water to flow vertically through the xylem.[1]] [The tracheids are much smaller hollow tubes that have overlapping ends, requiring the water to flow horizontally through perforations in the cell wall before travelling up the plant.[2]]

I have described the structure and purpose of the vessel elements.[1]

I have described the structure and purpose of the tracheids.[2]

Key science skills and ethical understanding

23 **a** [The independent variable is the soil-water content, and the dependent variable is the transpiration rate of the bean plants.[1]]

I have correctly identified the independent and dependent variables.[1]

b [The graph displays quantitative data, as quantitative data is represented numerically, whilst qualitative data refers to the descriptions of observations and results.[1]]

I have described the difference between quantitative and qualitative data.[1]

c **i** [The results do not support the commonly held theory governing the rate of transpiration in plants as the theory suggests that plants exposed to a greater water availability should transpire the most.[1]] [This is not supported by this experiment, which shows that Group Y, that had high access to water availability, had a lower rate of transpiration than Group X, which only had medium access to water availability.[2]]

I have suggested what should occur according to the theory of transpiration.[1]

I have explained how the results from the experiment contradict this theory.[2]

ii [Group X and Group Y may have been mislabelled.[1]]

Other acceptable responses include:

- The theory of transpiration may be incorrect or incomplete.
- *Phaseolus vulgaris* health may be damaged by high soil-water contents.

I have suggested a reasonable explanation.[1]

d [Glucose is produced in photosynthesising cells (the sources) before it is taken up by companion cells surrounding the phloem. Glucose then passively diffuses into the sieve cells[1]] [of the phloem, and the higher solute concentration in this location causes water to diffuse in from the xylem.[2]] [The diffusion of water increases the turgor pressure in these sieve cells, pushing the liquid through the phloem and around the rest of the plant.[3]] [Cells which require glucose (the sinks) pump the glucose into their cytoplasm which decreases the solute concentration in the phloem, causing water to diffuse back into the xylem.[4]]

I have described how glucose moves from source cells to companion cells and then sieve cells.[1]

I have explained that increased concentration causes water to diffuse into the phloem from the xylem.[2]

I have explained how the liquids in the phloem are moved.[3]

I have described how glucose is pumped into sink cells and water diffuses back to the xylem.[4]

I have used key biological terminology such as: photosynthesising cells, companion cells, phloem, passive diffusion, sieve cells, xylem.

5C The digestive system

Theory review questions

1 B

2 I; II; III; VI

3 W-liver; X-gallbladder; Y-pancreas; Z-rectum

4 A

5 large intestine; small intestine; large intestine; large intestine

6 A

7 B

8 A

SAC skills questions

9 B **10** A **11** B **12** A

13 A **14** B

Exam-style questions

Within lesson

15 C **16** B **17** C

18 a [Stomach.[1]]

I have identified organ X.[1]

b [Within the stomach, both chemical and physical digestion of food is occurring whilst the food is temporarily stored there.[1]] [Digestive juices and protease enzymes are secreted by the stomach to chemically break down food.[2]] [Peristaltic movements of the stomach muscles mix the juices and food together in a process called churning to physically break down food into smaller pieces.[3]]

I have stated that both chemical and physical digestion occurs in the stomach.[1]

I have described the process of chemical digestion in the stomach.[2]

I have described the process of physical digestion in the stomach.[3]

I have used key biological terminology such as: stomach, chemical, physical, digestive juices, protease enzymes, acidic, peristalsis, churning.

c [Chyme.[1]]

I have given the name for partially digested food that leaves the stomach.[1]

d i [Duodenum, jejunum, and ileum.[1]]

I have named the three parts of the small intestine.[1]

ii [Cells of the small intestine are specialised to aid digestion as they are arranged into villi and have microvilli on their surface.[1]] [The villi and microvilli greatly increase the surface area of the small intestine, allowing for greater absorption of organic molecules along the digestive tract.[2]]

I have stated that cells in the small intestine form villi and have microvilli.[1]

I have explained that an increased surface area increases absorption.[2]

I have used key biological terminology such as: villi, microvilli, surface area, absorption.

iii [After leaving the small intestine, undigested food enters the large intestine where the last absorption of water and nutrients takes place.[1]] [Food that remains undigested here is pushed along the large intestine and turned into faeces, which travels through the rectum to the anus.[2]]

I have stated that further digestion takes place in the large intestine.[1]

I have explained that undigested food is pushed along and turned into faeces.[2]

I have used key biological terminology such as: large intestine, absorption, faeces, rectum, anus.

Multiple lessons

19 C

20 a [Dogs are carnivores, so their digestive systems are relatively simple.[1]] [They have canine teeth to rip the flesh off their prey, their intestines are shorter as meat is dense and relatively easy to digest, and they feed occasionally rather than grazing.[2]]

I have identified that dogs are carnivorous.[1]

I have described how their digestive system is specialised for their diet.[2]

I have used key biological terminology such as: carnivores, canine teeth.

b i [The small intestine.[1]]

I have identified the small intestine.[1]

ii [Generally, cells that are longer in length and shorter in depth and width have larger surface area to volume ratios.[1]] [Cells lining the small intestine arrange into long, skinny projections to increase their surface area to volume ratio and allow for greater nutrient absorption.[2]]

I have explained that cells with long lengths and short depth and width typically have larger surface area to volume ratios.[1]

I have identified that the cellular projections have a high surface area to volume ratio and greater nutrient absorption ability.[2]

c [Herbivores have longer, more complex digestive systems than carnivores which allows for the continued breakdown of cellulose.[1]]

Other acceptable responses include:

- Carnivores have one stomach, herbivores can have multiple stomachs.
- Carnivores have sharp teeth that rip apart their prey whereas herbivores have flat teeth that grind food side to side

I have identified one difference between herbivore and carnivore digestive systems.[1]

Key science skills and ethical understanding

21 a [Meal A.[1]]

I have identified which meal has the larger total energy.[1]

b [Meal B.[1]]

I have identified which meal has a greater sugar content per 100 grams.[1]

c [50.0 g.[1]]

I have calculated the recommended average daily intake of protein.[1]

d Ingestion of the meal occurs through the oral cavity, where the food then travels through the oesophagus to the stomach where it is temporarily stored.[1] After leaving the stomach, the chyme enters the small intestine followed by the large intestine,[2] where the undigested food is turned into faeces in the rectum and eliminated out of the anus.[3]

- I have outlined that food travels from the oral cavity to the stomach through the oesophagus.[1]
- I have stated that chyme travels from the stomach to the intestines.[2]
- I have described how faeces is produced and eliminated.[3]
- I have used key biological terminology such as: oral cavity, oesophagus, stomach, chyme, small intestine, large intestine, faeces, anus.

e The ethical concept of integrity is not being followed by these companies,[1] as there is dishonest reporting of information that could be considered unfavourable by the public.[2]

- I have identified that the companies are not adhering to the concept of integrity.[1]
- I have justified my answer by referring to the dishonest reporting of information.[2]

5D The excretory system

Theory review questions

1 A

2 III; IV; V

3 W-kidney; X-ureter; Y-bladder; Z-urethra

4 bladder; kidneys

5 A

6 B

7 III; IV; V; I; II

8 skin; lungs; liver

SAC skills questions

9 A **10** B **11** A **12** B

13 B **14** A **15** C

Exam-style questions

Within lesson

16 D **17** B **18** A **19** A

20 B **21** A

22 a The renal artery delivers blood to the kidney for filtration, which occurs across the glomerulus into the Bowman's capsule of the nephrons. During filtration a primary filtrate consisting of only small molecules is produced.[1] The filtrate is then passed along the proximal convoluted tubule where the majority of the ions, glucose, amino acids, and water are reabsorbed back into the blood.[2] At the loop of Henle, more water is reabsorbed.[3] Then, at the distal convoluted tubule, water and specific substances may be reabsorbed or secreted depending on the body's needs.[4] At the end of the nephron, the urine is delivered to the collecting duct, where more water reabsorption and ion secretion may occur, and urine is formed.[5]

- I have described what occurs in the Bowman's capsule.[1]
- I have described what occurs in the proximal convoluted tubule.[2]
- I have described what occurs in the loop of Henle.[3]
- I have described what occurs in the distal convoluted tubule.[4]
- I have described what occurs in the collecting duct.[5]
- I have used key biological terminology such as: renal artery, kidney, filtration, glomerulus, Bowman's capsule, nephrons, filtrate, renal tubule, reabsorbed, urine, collecting duct, urine, secretion.

b After being produced in the kidneys, urine travels within the ureters to the bladder.[1] At the bladder, urine is stored until it is ready to be excreted.[2] Urine then leaves the bladder and is expelled from the body through the urethra.[3]

- I have stated that ureters carry urine from the kidneys to the bladder.[1]
- I have explained the function of the bladder.[2]
- I have stated how urine leaves the bladder and body.[3]
- I have used key biological terminology such as: kidneys, urine, ureter, bladder, urethra.

Multiple lessons

23 C

Key science skills and ethical understanding

24 a Student A's urine was a dark 6.5 value at approximately 7:00 AM, before becoming a lighter shade throughout the day until it was a darker value of 6 at 9:00 PM.[1] Student B's urine was a 6 value at 3:00 AM and became slightly lighter as the day progressed.[2] In both students, the general trend was that the shade of urine became lighter throughout the day, resulting in lower values on the graph.[3]

- I have described Student A's results on the graph.[1]
- I have also described Student B's results.[2]
- I have identified a general trend in both students' results.[3]
- I have used data from the graph to support my response.

b [Student A.[1]]

I have identified which student had a lower solute concentration.[1]

c [Student A,[1]][as from approximately 7:30 PM to 9:00 PM their shade of urine rose from approximately 2.1 to 6.1. During exercise, water is lost meaning that the urine is a darker shade as the body tries to conserve as much water as possible. This can explain the drastic rise on the graph.[2]]

I have identified which student likely exercised after dinner.[1]

I have explained that this is because of the drastic rise on the graph.[2]

I have used data from the graph to support my response.

d [The students did not record the shades of their urine at the same time during the day.[1]][This means that the time between urinations for the two students varies, making it difficult to compare the differences in the shade changes throughout the day.[2]]

Other acceptable responses include:

- The number of urinations of each student differs. This makes comparing the changes in shade of the two students urine challenging as one student is urinating more frequently, providing less time for a change in shade.
- Using shades of colour as an indicator could be an inaccurate measurement as individuals have their own perceptions of shades.

I have identified a potential flaw in the students' experiment.[1]

I have explained why the flaw makes it difficult to compare the two students' results.[2]

e [Non-maleficence.[1]][This ethical concept may be undermined because the students could be harmed by not drinking water for a whole day, or by drinking too much water.[2]]

Other acceptable responses include:

- Respect, because Student B is hesitant and their perspective should be considered when designing the new experiment.

I have identified an ethical concept.[1]

I have explained why this ethical concept may be undermined.[2]

5E The endocrine system

Theory review questions

1 B

2 I; II; V

3 W-pituitary gland; X-parathyroid glands; Y-adrenal glands; Z-testes (male)

4 pancreas; hypothalamus

5 A

6 B

7 II; V; III; I; IV

SAC skills questions

8 A **9** B **10** A **11** B

12 B **13** B

Exam-style questions

Within lesson

14 A **15** D **16** A **17** D

Multiple lessons

18 A **19** D **20** B **21** D

22 a [ADH is released from the pituitary gland into the bloodstream, where the blood circulatory system transports it to the kidneys.[1]][Once at the kidney, ADH molecules bind to specific receptors on kidney cells causing the insertion of aquaporins.[2]]

I have outlined that ADH is transported in the bloodstream.[1]

I have stated that ADH binds to specific receptors on kidney cells.[2]

I have used key biological terminology such as: pituitary gland, bloodstream, blood circulatory system, kidneys, aquaporins.

b [Blood is pushed through the glomerulus into the Bowman's capsule of a nephron to produce a primary filtrate.[1]][The filtrate moves through the proximal convoluted tubule, loop of Henle and distal convoluted tubule where materials such as water, ions and glucose are reabsorbed.[2]][The filtrate left forms urine which moves to the collecting duct and is released out of the kidneys via the ureters.[3]]

I have stated that blood filtration occurs across the glomerulus into the Bowman's capsule.[1]

I have explained that reabsorption occurs in the proximal convoluted tubule, loop of Henle, and distal convoluted tubule.[2]

I have stated that urine is collected at the collecting duct.[3]

I have used key biological terminology such as: glomerulus, Bowman's capsule, nephron, filtrate, proximal convoluted tubule, ions, loop of Henle, distal convoluted tubule, urine, collecting duct, ureters.

c [If a person were overhydrated, the hypothalamus would produce less ADH.[1]][This would result in lower stimulation of nephron cells and less aquaporin insertion into membranes,[2]][resulting in a decrease in water permeability and less water reabsorption from urine.[3]]

I have stated that ADH levels would be lower.[1]

I have related the lower levels of ADH to aquaporin insertion.[2]

I have explained how less aquaporin insertion decreases water permeability.[3]

I have used key biological terminology such as: hypothalamus, ADH, aquaporin, permeability, reabsorption, urine.

Key science skills and ethical understanding

23 **a** [Insulin glargine.[1]]

I have stated which form of insulin is the slowest acting.[1]

b [Insulin lispro.[1]]

I have stated which form of insulin has the shortest duration.[1]

c [The pancreas plays a role in the body's digestive system where it secretes digestive juices into the small intestine to aid digestion.[1]] [The pancreas also plays a role in the endocrine system as it produces and releases the hormones insulin and glucagon, responsible for controlling blood glucose levels.[2]]

I have described the role of the pancreas in the digestive system.[1]

I have described the role of the pancreas in the endocrine system.[2]

I have used key biological terminology such as: digestive system, digestive juices, small intestine, endocrine system, hormone, insulin, blood glucose levels.

d [People of low-socioeconomic status may be unable to access the fastest acting or longest-lasting forms of insulin, and so they may be unable to select the most appropriate form for their situation.[1]]

I have identified a concern of the different insulin prices that relates to justice.[1]

Chapter 5 SAC practice

1 [The kidneys filter blood to remove excess and unwanted materials from the bloodstream, producing a kidney filtrate which is excreted as urine.[1]]

I have described the function of kidneys in the body.[1]

I have used key biological terminology such as: filter, blood, excess, filtrate, urine.

2 [The excretory system in humans consists of the kidneys, ureters, bladder, and urethra.[1]] [Additionally, the skin, lungs, liver, and gastrointestinal tract also play a role in excreting substances from the body.[2]]

I have stated the organs of the urinary tract of the excretory system.[1]

I have listed the additional organs that play a role in excreting certain substances.[2]

I have used key biological terminology such as: kidneys, ureters, bladder, urethra, skin, lungs, liver, gastrointestinal tract.

3 [Bonnie's blood uric acid level is 33 mg/L[1]] [and Bill's blood uric acid level is 124 mg/L.[2]]

I have calculated Bonnie's level as 33 mg/L by multiplying 0.033 by 1000.[1]

I have also calculated Bill's level as 124 mg/L by multiplying 0.124 by 1000.[2]

4 [Bonnie's level of 33 mg/L falls within the regular range of 24–60 mg/L for females, so she would not be diagnosed with hyperuricemia.[1]] [However, because Bill's level of 124 mg/L significantly exceeds the regular range for males and is above 86 mg/L, he would be diagnosed with hyperuricemia.[2]]

I have stated that Bonnie's level is within the regular range.[1]

I have stated that Bill's level is outside the regular range and he would be diagnosed with hyperuricemia.[2]

I have used data in my response.

5 [The mouth begins the process of digestion by breaking food into smaller pieces and exposing it to digestive amylase enzymes contained within the saliva.[1]] [Food travels down the oesophagus to the stomach.[2]] [In the stomach, food is churned and protease enzymes and digestive juices are released.[3]] [In the small intestine, bile from the liver and gallbladder is secreted, as well as digestive enzymes from the pancreas.[4]] [In the small intestine, the majority of the fat breakdown and continued breakdown of proteins and carbohydrates occurs, before they are all absorbed into the bloodstream.[5]] [In the large intestine, the final water and vitamin absorption occurs before undigested food is turned into faeces and eliminated out the anus.[6]]

I have described the role of the mouth in the digestive system.[1]

I have stated food travels along the oesophagus to the stomach.[2]

I have explained that enzymes and juices are released in the stomach, and churning occurs in the stomach.[3]

I have outlined the role of the liver, gallbladder, and pancreas.[4]

I have described the breakdown and absorption of organic molecules in the small intestine.[5]

I have described the final absorption and elimination of substances in the large intestine and out the anus.[6]

I have used key biological terminology such as: mouth, amylase, oesophagus, stomach, protease, small intestine, bile, liver, gallbladder, pancreas, large intestine.

6 [Bill's diet consists of food and drinks that are high in nitrogen-containing compounds, resulting in increased blood uric acid levels.[1]]

I have related Bill's diet to certain nitrogen-containing compound consumption and uric acid levels.[1]

7 [Hormone X is produced in the parathyroid glands and is released into the bloodstream of the blood circulatory system.[1]] [The bloodstream transports hormone X from the parathyroid glands to the kidneys, where it exits the bloodstream.[2]] [Upon arriving at the kidney cells, hormone X binds to specific receptors on the cell surface, causing a cellular response.[3]]

- I have stated that the parathyroid glands releases hormones into the bloodstream.[1]
- I have stated that hormones travel in the bloodstream to their destination.[2]
- I have explained how hormones cause responses in cells by binding to receptors.[3]
- I have used key biological terminology such as: parathyroid glands, bloodstream, blood circulatory system, kidneys, receptors.

8 [Within the *L. billium* plant there are two major organ systems, the root and shoot system.[1]] [The root system is typically underground and provides structure to the plant and absorbs water and nutrients from soil.[2]] [The shoot system contains flowers, fruits, leaves, and stems and is responsible for reproduction and photosynthesis.[3]]

- I have identified the two major organ systems of plants.[1]
- I have described the structure and function of the root system.[2]
- I have described the structure and function of the shoot system.[3]

9 [The vascular tissue is the xylem tissue[1]] [which only contains lignified, hollow, dead cells and transports water in one direction from the roots to the leaves.[2]] [The phloem is the other vascular tissue, which contains live cells and transports dissolved sugars and nutrients around the entire plant.[3]]

- I have identified the correct vascular tissue type.[1]
- I have described the structure and function of the xylem.[2]
- I have described the structure and function of the phloem.[3]

10 [Beneficence involves a commitment to maximising benefits and minimising risks.[1]] [Therefore, the scientists should not only ensure that the risks of the new drug are minimised so that Bill is not harmed, but they should also act to maximise the effect of the drug so that Bill is receiving the most benefit.[2]]

- I have described the bioethical principle of beneficence.[1]
- I have described the relevance of beneficence to the scenario.[2]

11 [Cells are organised into collections of cells to form tissues and organs to carry out shared functions that cannot be completed by a single cell.[1]]

- I have explained that greater organisation of cells allows for functions that cannot be carried out by single cells.[1]

12 [Day 4.[1]]

- I have identified the day when Bill's blood uric acid levels are predicted to return to normal.[1]

13 [The predicted results would support the hypothesis[1]] [as it can be seen that after five days the blood uric acid level is approximately 70 mg/L, which is significantly lower than the starting value of 124 mg/L and is within the regular range for males.[2]]

- I have stated that these results would support the hypothesis.[1]
- I have used data from the graph to support my answer.[2]

14 [Bill's blood uric acid level begins at approximately 124 mg/L and remains relatively constant until day eight, where it begins to gradually decrease, reading 80 mg/L at day 14.[1]]

- I have described the general trend.[1]
- I have used data from the graph in my response.

Chapter 5 Exam practice

Section A

1 D	**2** B	**3** C	**4** C
5 B	**6** D		

Section B

7 a [The root system is spread out into many projections to increase the overall surface area and the root hair cells have projections on their exterior to further increase the surface area.[1]]

- I have described how roots are specialised to have a high surface area.[1]

b [Water (and some dissolved nutrients) diffuses into the gaps/cell walls between root cells.[1]] [The water then reaches the Casparian strip where it enters the xylem via osmosis.[2]]

- I have identified that water and nutrients enter the roots between the gaps in root cells.[1]
- I have described that at the Casparian strip water enters the xylem via osmosis.[2]
- I have used key biological terminology such as: root cells, Casparian strip, xylem, osmosis.

c [Mineral ions and a small amount of water enter the cytoplasm of root hair cells by either passive diffusion or active transport.[1]] [The minerals then pass through root cells before entering the xylem.[2]]

- I have identified how minerals and some water enters through the cytoplasm of root hair cells.[1]
- I have described that the minerals and water enter the xylem.[2]
- I have used key biological terminology such as: root hair cells, diffusion, active transport, xylem.

8 a [Physical digestion refers to the mechanical movement of muscles and organs causing the breakdown of food into smaller pieces.[1]] [On the other hand, chemical digestion can be carried out by digestive enzymes which chemically break down food molecules, often in an acidic (low pH) environment.[2]]

I have described physical digestion.[1]

I have described chemical digestion.[2]

I have used key biological terminology such as: mechanical, acidic, digestive enzymes.

b [The churning of the stomach, which is created by muscular movements, physically breaks down food facilitating physical digestion.[1]][Chemical digestion is aided by proteases and acidic (low pH) digestive juices which chemically break down food.[2]]

I have described physical digestion in the stomach.[1]

I have described chemical digestion in the stomach.[2]

I have used key biological terminology such as: churning, proteases, digestive juices.

c [A high surface area to volume ratio is required to maximise the amount of nutrients absorbed.[1]]

I have outlined why a high surface area to volume ratio is required.[1]

9 a [Hormones only bind to and cause responses in cells that contain receptors specific to that hormone.[1]]

I have identified that specific receptors allow hormones to act on cells.[1]

b [Blood circulatory system.[1]]

I have identified the blood circulatory system.[1]

c [In the digestive system, the pancreas is responsible for secreting digestive enzymes into the small intestine to aid digestion and the secretion of bicarbonate which neutralises acidic chyme.[1]][In the endocrine system, the pancreas is responsible for producing and releasing hormones that instruct cells of the body to release or take in glucose.[2]]

I have explained the pancreas' role in the digestive system.[1]

I have explained the pancreas' role in the endocrine system.[2]

I have used key biological terminology such as: digestive enzymes, small intestine, bicarbonate, chyme, glucose.

6A Introducing homeostasis

Theory review questions

1 A

2 B

3 D

4 A

5 V-stimulus; W-receptor; X-modulator; Y-effector; Z-response

6 I-a glass of water; II-retinal cells in an individual's eye; III-the brain; IV-extending the muscles of the arm and hand to pick up the glass of water; V-picking up the glass of water to drink it

7 stimulus-response model; negative; response; stimulus; internal

SAC skills questions

8 B **9** B **10** A **11** B

12 B **13** C **14** A

Exam-style questions

Within lesson

15 D **16** A

17 a [Homeostasis.[1]]

I have correctly identified the process.[1]

b i [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 response.[2]

ii [Moving her arm to catch the ball.[1]]

I have correctly identified the response.[1]

iii [Negative feedback systems are stimulus-response systems where the original stimulus is reduced by the response.[1]] [In this system, an example of a negative feedback loop would be the inhibition of the electrical impulses causing a constriction of the pupils, reducing the original stimulus and reception of light hitting rhodopsin.[2]]

I have explained what a negative feedback system is.[1]

I have stated what a negative feedback system would be in the given example.[2]

I have referred to the scenario in my response.

Multiple lessons

18 B **19** B

Key science skills and ethical understanding

20 a [The effector is cortisol.[1]]

I have identified the effector.[1]

b [The independent variable is the living conditions of the cheetahs (i.e. free-range vs captive).[1]][The dependent variable is the concentration of the glucocorticoid and sex hormones.[2]]

I have identified the independent variable.[1]

I have identified the dependent variables.[2]

c [One limitation is that the scientists used a small sample size – having four cheetahs in one group does not provide enough evidence to prove their hypothesis.[1]][This limitation could be avoided in the future by increasing the sample size used in the experiment.[2]]

Other acceptable responses include:

- There are unequal sample sizes used in this experiment. This could be avoided by using groups of equal size.
- Capturing the cheetahs may have inadvertently altered their stress hormone level, giving inaccurate results. This could be avoided by using another method to gain the desired results.

I have identified a limitation of the experiment.[1]

I have stated how this limitation could be avoided.[2]

d [Non-maleficence.[1]][Whilst cheetahs will potentially experience stress as a result of this experiment, this stress is a necessary component of the variables under investigation. However, the scientists should ensure that they do all they can to avoid other harm coming to the cheetahs, and that the stress the cheetahs experience does not go beyond what they would normally experience in captivity.[2]]

Other acceptable responses include:

- Integrity. The scientists should report their findings honestly and clearly.
- Justice. The scientists should enable fair access to their findings.
- Beneficence. The scientists should commit to minimising the harm experienced by the cheetahs during the experiment.
- Respect. The scientists should give due regard to the welfare of the cheetahs in the experiment and ensure they are protected from further harm whilst participating.

I have identified a relevant ethical principle.[1]

I have explained the relevance of the ethical principle to the scenario.[2]

6B Regulation of body temperature

Theory review questions

1 A

2 B

3 A

4 W-conduction; X-convection; Y-evaporation; Z-radiation

5 I-reduction in surface blood flow; II-burning of triglycerides; III-behavioural changes; IV-shivering; V-raising of hair follicles

6 I-skin arterioles; II-sweat glands; III-cells; IV-arrector pili muscles; V-cerebral cortex

7 thermoreceptors; hypothalamus; arrector pili; convection

SAC skills questions

8 B **9** B **10** A **11** B

12 A **13** A **14** B

Exam-style questions

Within lesson

15 A **16** D **17** B **18** C

19 **a** [The sensor is the receptor for changes in the environment[1]] [and sends information to the modulator.[2]]

- I have stated the sensor monitors environmental changes.[1]
- I have stated the sensor interacts with the modulator.[2]

b [Skeletal muscles[1]] [are stimulated to cause shivering[2]] [and arterioles[3]] [are stimulated to constrict.[4]]

Other acceptable responses include:

- Cerebral cortex causes changes in behaviour.
- Arrector pili muscles in the skin constrict, lifting body hair.
- Cells in the body are stimulated to increase energy production.
- Brown fat cells are stimulated to burn triglycerides.

- I have stated one effector that is stimulated when the temperature is low.[1]
- I have stated the corresponding response of this effector.[2]
- I have stated a second effector that is stimulated when the temperature is low.[3]
- I have stated the corresponding response of this effector.[4]

c [Sweating reduces internal body temperature by secreting water onto the surface of the skin.[1]] [This water is evaporated[2]] [and takes heat energy with it as it is converted from a liquid to a gas.[3]]

- I have stated that sweat involves the secretion of water.[1]
- I have stated that this water is evaporated.[2]
- I have explained how evaporation reduces heat energy.[3]

Multiple lessons

20 D

21 **a** [Mitochondria[1]] [as these are the organelles responsible for energy production via the process of aerobic cellular respiration.[2]]

- I have stated the correct organelle.[1]
- I have explained that mitochondria produce energy via cellular respiration.[2]
- I have used key biological terminology such as: cellular respiration.

b [Negative feedback.[1]] [Negative feedback maintains homeostasis by detecting changes in the temperature of the external environment[2]] [and producing a response in the organism that counters this change.[3]]

- I have stated the correct type of feedback.[1]
- I have stated that a stimulus is detected.[2]
- I have stated that the response counters the stimulus.[3]
- I have referred to thermoregulation in my response.
- I have used key biological terminology such as: homeostasis, external environment.

Key science skills and ethical understanding

22 **a** [No, a control was not used.[1]] [A control would have been a subject who completed the exercise but who wasn't wrapped in cling wrap.[2]]

- I have stated that no control was used.[1]
- I have explained what the conditions of a control group would have been in this experiment.[2]

b [Beneficence is not being adhered to[1]] [because preventing the subjects from cooling naturally might cause their body temperature to increase to a dangerous level.[2]]

Other acceptable responses include:

- Non-maleficence, because preventing the subjects from cooling naturally might harm them.
- Respect, because the experimental design doesn't give due regard to the welfare of the subjects involved.

- I have identified a relevant ethical principle.[1]
- I have stated how this principle is not being adhered to in this experiment.[2]

c **i** [The fact the average resting body temperature measured by the students is well above the normal maximum human body temperature of 37.5 °C.[1]]

- I have stated evidence that supports the student's claim.[1]

ii [The students could avoid this error by using a properly calibrated thermometer.[1]]

Other acceptable responses include:

- The students could recalibrate their thermometer.
- The students could use a digital thermometer.

- I have stated how students could avoid a systematic error.[1]

6C Regulation of blood glucose

Theory review questions

1 A

2 A

3 B

4 blood glucose levels; hyperglycaemia; hypoglycaemia; homeostatic

5 beta cells; insulin; alpha cells; glucagon; glycogen

6 insulin secretion: II; III; V
glucagon secretion: I; IV

SAC skills questions

7 A	**8** B	**9** A	**10** A
11 A	**12** A	**13** C	**14** B

Exam-style questions

Within lesson

15 C **16** B **17** B

Multiple lessons

18 A **19** B

20 **a** [These rises most likely occurred shortly after and as a result of eating meals.[1]]

I have identified a reason for the rises in blood glucose.[1]

b [The rise was due to the student's body converting glycogen to glucose.[1]]

Other acceptable responses include:

- There are corrections of small overshoots.
- The body begins breaking down the low GI components of meals, increasing blood glucose levels.

I have suggested a reason for the rise in blood glucose at 10:00 AM.[1]

c **i** [A hormone.[1]]

I have stated the correct type of molecule.[1]

ii [Insulin targets skeletal muscle cells, fat cells, and liver cells.[1]]

I have identified the target cells of insulin.[1]

iii [Insulin promotes the uptake of glucose into skeletal muscle and fat cells by increasing the amount of glucose transporters in their plasma membranes[1]][and increases the production of glycogen in the liver by liver cells.[2]]

I have stated that insulin promotes uptake of glucose into skeletal muscle and fat cells.[1]

I have stated that insulin increases the production of glycogen by liver cells.[2]

I have used key biological terminology such as: glucose transporter, plasma membrane, glycogen.

Key science skills and ethical understanding

21 **a** [Group X.[1]][After 60 minutes their blood glucose concentration is 13.0 mmol/L which is outside the healthy blood glucose range and is higher than the other group.[2]][This indicates that people within group X are unable to lower their blood glucose concentration via homeostatic mechanisms including the production of insulin.[3]]

I have suggested the group which appears to have the disease.[1]

I have used data from the table to support my group choice.[2]

I have explained why this data suggests my group has the disease.[3]

I have used comparative language such as: higher.

b [A control group shows what a normal plasma glucose reading after 60 minutes is, allowing scientists to determine if blood glucose concentrations in the diseased group were due to the disease, or some other factor.[1]]

I have stated the importance of a control group in this experiment.[1]

c [Glucagon increases blood glucose concentration by facilitating the breakdown of glycogen into glucose.[1]]

I have stated how glucagon increases blood glucose concentration.[1]

d [The ethical concept of beneficence applies as altering the blood glucose levels of this group might have negative health consequences for them.[1]][It could be addressed by ensuring that medical support is present in case these participants become unwell.[2]]

Other acceptable responses include:

- Non-maleficence, as altering the blood glucose levels of this group might have negative health consequences for them. It could be addressed by ensuring that medical support is present to minimise the harm they experience as a result of participating in the experiment.

I have identified a relevant ethical concept.[1]

I have explained how this ethical concern could be addressed by the scientists.[2]

6D Regulation of water balance

Theory review questions

1 A

2 A

3 II; V

4 osmoreceptors; antidiuretic hormone; aquaporins; distal convoluted tubule and collecting duct; thirst centre

5 III; V; II; I; IV

6 decrease; suppresses; decrease; less

SAC skills questions

7 A	**8** B	**9** A	**10** A
11 C	**12** A	**13** A	

Exam-style questions

Within lesson

14 B **15** D

Multiple lessons

16 D

17 **a** [Negative feedback[1]][is a process in which a change in a variable is detected and a response occurs within the body to reverse the direction of change.[2]]

I have identified the correct type of feedback.[1]

I have explained how this type of feedback maintains homeostasis.[2]

b **i** [This increases the amount of sodium reabsorbed from the kidney filtrate, which increases the amount of water reabsorbed as water diffuses out of the kidney filtrate via osmosis.[1]]

I have described how sodium pumps increase the reabsorption of water.[1]

ii [Cells of the thirst centre.[1]]

Other acceptable responses include:

- Insertion of aquaporins in the distal convoluted tubule and the collecting duct of the kidneys.

I have provided an example of another effector.[1]

Key science skills and ethical understanding

18 **a** [ADH decreases blood plasma solute concentration by increasing the amount of water reabsorbed from the kidney filtrate.[1]][It does this by increasing the number of aquaporins in the cells of the distal convoluted tubule and collecting duct which increases the amount of water which diffuses out of the kidney filtrate.[2]][Additionally, ADH also stimulates the thirst centre to generate feelings of thirst, causing a person to drink more water.[3]]

I have stated the effect of ADH on plasma solute concentration.[1]

I have explained how ADH alters the reabsorption of water from filtrate in the kidneys.[2]

I have explained that ADH stimulates the thirst centre.[3]

I have used key biological terminology such as: ADH, solute concentration, filtrate, aquaporins, distal convoluted tubule, collecting duct, thirst centre.

b [Below plasma solute concentrations of 285 mOs/kg, ADH levels remain constant.[1]][After this, plasma ADH levels increased steadily.[2]][This means that at blood plasma solute concentrations above 285 mOs/kg, the participants were reabsorbing more water from the kidney filtrate.[3]]

I have stated that ADH levels initially remained constant.[1]

I have stated that at a blood plasma concentration of 285 mOs/kg, ADH levels began to rise.[2]

I have described the effect increased ADH levels would have on the reabsorption of water from the kidney filtrate.[3]

c [Beneficence.[1]][The committee may have been concerned about the risk of harm to participants since they were not allowed to eat or drink for an extended period of time.[2]]

Other acceptable responses include:

- Non-maleficence, as participating in the experiment may have caused harm to the participants due to them not being allowed to eat or drink for an extended period of time.

I have identified a relevant ethical principle.[1]

I have explained how this principle was not adhered to by the experimental design.[2]

d [The dependent variable was the plasma concentration of ADH.[1]]

I have correctly identified the dependent variable.[1]

6E Malfunctions in homeostasis

Theory review questions

1 B

2 B

3 hyperglycaemia; hypoglycaemia; long-acting; short-acting

4 I; V

5 A

6 W-hypothalamus; X-thyrotropin-releasing hormone (TRH); Y-anterior pituitary gland; Z-thyroid-stimulating hormone (TSH)

7 II; IV; V

8 B

SAC skills questions

9 B **10** A **11** A **12** B

13 A **14** B **15** C

Exam-style questions

Within lesson

16 B **17** B

18 **a** [Insulin.[1]]

I have identified the correct molecule.[1]

b [A decrease in blood glucose concentration below the homeostatic setpoint.[1]]

I have identified what would signal the pump to switch off.[1]

c [Hypoglycaemia occurs when blood glucose levels drop[1]][below 4 mmol/L.[2]]

I have outlined what is meant by the term hypoglycaemia.[1]

I have stated the specific point at which blood glucose is considered hypoglycaemic in units of mmol/L.[2]

Multiple lessons

19 **a** [Beta cell.[1]]

I have identified the correct cell type.[1]

b [Insulin regulates blood glucose levels by controlling the uptake of glucose into fat cells and skeletal muscle cells[1]] [and the conversion of glucose into glycogen in skeletal muscle cells and liver cells.[2]]

I have stated that insulin causes the uptake of glucose.[1]

I have stated that insulin causes the conversion of glucose to glycogen.[2]

c [In people with type 1 diabetes, beta cells have been destroyed and are no longer able to function.[1]] [As a result of this, insulin is no longer produced[2]] [and blood glucose levels become unregulated.[3]]

I have stated that in people with type 1 diabetes beta cells can no longer function.[1]

I have stated that insulin is not produced.[2]

I have stated the effect this has on the regulation of blood glucose levels.[3]

d [Hormones.[1]]

Other acceptable responses include:

- Proteins.

I have stated the correct type of molecule.[1]

20 **a** [Autoantibodies constantly stimulate the thyroid gland to release thyroid hormones.[1]] [This would normally result in a decrease in TRH and TSH secretion that would reduce the functioning of the thyroid gland via negative feedback.[2]] [However, the autoantibodies continue to stimulate the thyroid gland regardless of the negative feedback loop in place.[3]]

I have stated that antibodies stimulate the thyroid gland.[1]

I have stated that increased amounts of thyroid hormone normally results in decreased levels of TRH and TSH due to negative feedback.[2]

I have stated that antibodies are not affected by negative feedback and cause the ongoing secretion of thyroid hormones.[3]

b **i** [When the hypothalamus detects a drop in core body temperature, the thyroid gland is stimulated to secrete increased amounts of thyroid hormones.[1]] [These go on to raise the basal metabolic rate, increasing the amount of heat generated by cells[2]] [which lifts core body temperature.[3]]

I have stated how the thyroid gland is stimulated.[1]

I have explained what occurs as a result of stimulation by the hypothalamus.[2]

I have explained the result this has on the overall core body temperature.[3]

ii [Shivering.[1]]

Other acceptable responses include:

- Vasoconstriction of surface blood vessels.
- Changes in behaviour.
- Contraction of arrector pili muscles to raise body hair.
- Burning of triglycerides in brown fat cells.

I have identified another response.[1]

Key science skills and ethical understanding

21 A **22** D **23** C

Chapter 6 SAC practice

1 [In gestational diabetes it is thought that hormones related to pregnancy interfere with the normal functioning of insulin.[1]]

I have explained the cause of gestational diabetes.[1]

2 [Beta cells in the pancreas.[1]]

I have identified the correct cell type.[1]

3 [Increased urination and excessive thirst.[1]]

Other acceptable responses include:

- Excessive hunger.
- Lethargy/fatigue/tiredness.
- Weight loss.

I have identified two short-term symptoms of hyperglycaemia.[1]

4 [By interfering with insulin function, gestational diabetes will result in fewer glucose transporters being inserted into the membranes of cells in response to elevated blood glucose levels.[1]] [As a result of this, less glucose will be absorbed by cells[2]] [and therefore elevated amounts will remain in the blood, causing hyperglycaemia.[3]]

I have stated that fewer glucose transporters will be inserted into the membranes of cells.[1]

I have stated that less glucose will be absorbed by cells.[2]

I have stated that this causes hyperglycaemia.[3]

I have used key biological terminology such as: insulin, glucose transporters, hyperglycaemia.

5 [Yes because a glucose challenge test is a non-fasting test.[1]]

I have explained that the patient would be allowed to eat breakfast.[1]

6 [Compared to a non-fasting test, fasting before a test would decrease blood glucose levels, as no glucose from food would have been absorbed into the bloodstream.[1]]

I have explained that fasting would decrease blood glucose levels.[1]

7 [Patient 1's fasting blood glucose level was around 7.1 mmol/L which is abnormally high.[1]] [After two hours, their blood glucose level fell to 6.5 mmol/L, which is normal.[2]] [This suggests that Patient 1 does not have a condition, but rather didn't fast properly before their oral glucose tolerance test.[3]]

- I have described Patient 1's fasting result.[1]
- I have described Patient 1's two-hour post-glucose sample result.[2]
- I have stated what caused these results.[3]

8

Patient	Diagnosis
2	Normal
3	Gestational diabetes
4	Impaired fasting glycaemia

- I have correctly completed the table.

9 [Personal error.[1]]

- I have identified the type of error that has taken place.[1]

10 [Systematic error.[1]]

- I have identified the type of error that has taken place.[1]

11 [Small for gestational age.[1]]

- I have stated the correct size of the baby.[1]

12 [Between approximately 2 500 grams and 3 750 grams.[1]]

- I have stated the correct weight ranges.[1]

13 [Given that anti-diabetic medication can harm developing foetuses, the ethical concept of non-maleficence is important[1]] [because the doctor must choose the treatment option that reduces the likelihood of harm as much as possible.[2]]

- I have identified the relevance of non-maleficence in this case.[1]
- I have explained why this ethical concept is relevant with reference to minimising harm.[2]

14 [A consequences-based approach to bioethics places central importance on the outcomes of an action.[1]] [An opponent of this study might critique this experimental design on the basis that it unnecessarily exposes pregnant volunteers to an increased risk of developing gestational diabetes by assigning them to a control group that is not allowed to partake in exercise.[2]]

- I have explained what is meant by a consequences-based ethical approach.[1]
- I have stated why the experiment could be considered unethical.[2]
- I have avoided reusing the word 'consequences' in my explanation of 'consequences-based approach'.
- I have signposted connections to a consequences-based approach using terms such as: unnecessarily exposes, increased risk.

Chapter 6 Exam practice

Section A

1 C	**2** A	**3** A	**4** A
5 D	**6** C		

Section B

7 a [Homeostasis is the maintenance of a relatively stable internal environment within a narrow range of limits.[1]] [Negative feedback is a process in which a change in a variable outside this narrow range of limits is detected,[2]] [and a response occurs within the body to reverse the direction of change back to within homeostatic setpoints.[3]]

- I have explained the meaning of 'homeostasis.'[1]
- I have stated that negative feedback involves the detection of a change in a variable.[2]
- I have stated that negative feedback creates a response that reverses the change in variable.[3]

b i [Vasodilation of surface blood vessels and relaxation of arrector pili muscles in the skin.[1]]

Other acceptable responses include:

- Secretion of sweat.
- Changes in behaviour caused by the cerebral cortex.
- Slowing of metabolic processes.

- I have identified two correct responses.[1]

ii [Smooth muscle in the peripheral blood vessels contracts causing vasoconstriction.[1]] [This reduces the amount of heat lost to the environment via conduction and decreases blood flow to the skin surface, increasing body temperature.[2]]

- I have stated what occurs in smooth muscle.[1]
- I have stated how this change increases body temperature.[2]

c [Water balance.[1]]

Other acceptable responses include:

- Blood glucose level.
- Thyroid function.
- Oxygen concentrations.
- Carbon dioxide concentrations.
- Ion concentrations.

I have identified another variable under homeostatic control.[1]

---

8 **a** [Insulin.[1]] [It is produced and secreted by beta cells in the pancreas.[2]]

I have stated the name of the hormone.[1]

I have stated the cellular origin of the hormone.[2]

---

b [Insulin facilitates the insertion of a protein channel called a glucose transporter into the plasma membrane.[1]] [Glucose moves through these protein channels and along its concentration gradient into the cell.[2]]

I have stated that insulin facilitates the insertion of glucose transporters into the cell membrane.[1]

I have stated that these transporters allow for the facilitated diffusion of glucose into the cell.[2]

---

c **i** [Form A can be used to quickly reduce blood glucose levels when they rise above the normal physiological set point.[1]]

I have stated one advantage of Form A insulin.[1]

---

ii [It is normal in the body for glucose levels to vary throughout the day depending on when people eat and what they're consuming.[1]] [As such, people's insulin requirements also change.[2]] [People who don't produce insulin need to use long-acting insulin to ensure continued uptake of glucose into cells,[3]] [whereas they need to use fast-acting insulin after they have consumed food to quickly get the consumed glucose into their cells.[4]]

I have stated that glucose levels vary.[1]

I have stated that as a result of this insulin levels vary.[2]

I have explained why long-acting insulin is necessary.[3]

I have explained why short-acting insulin is necessary.[4]

7A Genes and chromosomes

Theory review questions

1 genome; gene; chromosome; genes; nucleotides

2 C

3 U-homologous chromosomes; V-centromere; W-replication; X-gene loci; Y-homologous chromosomes; Z-sister chromatids

4 I; II

5 C

6 B

7 I-$2n$-1; II-$3n$; III-$2n$+2; IV-$2n$+1

SAC skills questions

8 D **9** A **10** A **11** C

12 A

Exam-style questions

Within lesson

13 A **14** D **15** D

16 a [This woman's karyotype is not the same as a typical human karyotype.[1]] [Instead, this woman is missing a second X chromosome.[2]]

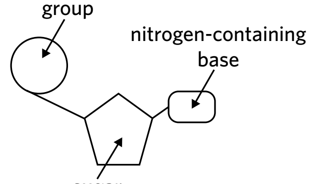
I have identified that this woman's karyotype is not the same as a typical human karyotype.[1]

I have identified the specific mutation shown in this karyotype.[2]

b [Nucleic acid and protein.[1]]

I have identified both macromolecules – nucleic acid and protein.[1]

c



I have correctly drawn the general structure of an individual nucleic acid monomer.

I have correctly labelled each of the three components of the monomer.

Multiple lessons

17 D **18** B

19 a [Vesicles.[1]]

I have identified vesicles as the other affected organelle.[1]

b [Mutation to the *TRIP11* gene results in an impaired Golgi complex, which in turn leads to impaired protein transport outside of the cell.[1]] [The proteins necessary for cell growth therefore won't be able to be transported to other cells and growth will be inhibited.[2]] [This results in bone shortening and stunted growth in patients with achondrogenesis 1A.[3]]

I have identified that the impact to the Golgi complex will lead to impaired protein transport.[1]

I have explained that this will lead to a lack of protein transport to regions outside of the cell.[2]

I have explained that this is likely a cause of the symptoms seen in patients with achondrogenesis 1A.[3]

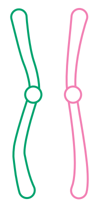
20 a [Synthesis.[1]]

Other acceptable responses include:

- S phase
- S1

I have identified the correct stage as being synthesis.[1]

b



I have correctly drawn a pair of homologous chromosomes that are not connected by a centromere.

Key science skills and ethical understanding

21 a [Suspect 2.[1]]

I have correctly identified suspect 2 as the murderer.[1]

b [The STR that Jessica possesses is $[TCACG]_6$, while the STR of her lab partner is $[TCACG]_2$.[1]] [Jessica's STR is four repeat units longer than her lab partner's.[2]]

I have correctly identified the two STRs of Jessica and her lab partner.[1]

I have described the difference between the two STRs based on the number of repeat units.[2]

c [This assumption is incorrect as the section of STR that is being examined is part of noncoding DNA,[1]] [meaning that it is not a gene sequence that codes for the production of proteins and therefore will not be responsible for *MAOA* activity.[2]]

I have identified that the STR sequence is part of noncoding DNA.[1]

I have explained that this means it is not a gene that codes for protein production and will therefore not be responsible for *MAOA* activity.[2]

d [A consequences-based approach to bioethics places importance on the outcomes of an action, and aims to maximise positive consequences while minimising negative effects.[1]] [Such an approach would likely support genetic sequencing of the children, so as to determine if they carry a similar genetic predisposition for violence, especially as they grow older.[2]]

I have briefly described a consequences-based approach to bioethics.[1]

I have linked this approach to the suggestion of Jessica's lab partner.[2]

e [A virtues-based approach to bioethics places importance on the moral character of each person, rather than on the actions of others.[1]] [Such an approach would likely believe that the murderer's children ought to be treated as their own moral agents, and that to sequence their DNA because of the actions of their father would be intrusive and ignorant of their own personal virtues.[2]]

I have briefly described a virtues-based approach to bioethics.[1]

I have linked this approach to Jessica's conclusion.[2]

7B Meiosis

Theory review questions

1 A

2 B

3 W-telophase I; X-prophase I; Y-metaphase I; Z-anaphase I

4 increases; crossing over; exchanging; chiasma; recombinant chromatids; independent assortment; metaphase plate

5 II; V; III; IV; I

6 III; IV

7 B

8 A

9 B

10 I-interphase; II-anaphase II; III-telophase I & II; IV-prophase I

SAC skills questions

11 C **12** B **13** A **14** B

15 A

Exam-style questions

Within lesson

16 C **17** A

18 **a** [6.[1]]

I have correctly identified that there would be 6 chromosomes.[1]

b [3.[1]]

I have correctly identified that there would be 3 chromosomes.[1]

19 **a** [Meiosis.[1]]

I have correctly identified which cycle is being shown.[1]

b **i** [Y represents the cell at the beginning of meiosis I, after its DNA has been duplicated during interphase.[1]]

I have identified the cell to be at the beginning of meiosis I.[1]

ii [The chromosome number would be 46,[1]] [while the chromatid number would be 92.[2]]

I have identified the chromosome number as 46.[1]

I have identified the chromatid number as 92.[2]

Multiple lessons

20 **a** [16.[1]]

I have correctly identified the diploid number of male honey bees as 16.[1]

b [16.[1]]

I have correctly stated that the wing cell would contain 16 pairs of homologous chromosomes.[1]

c [The male honey bee would produce gametes by mitosis.[1]] [If a fertilised egg is $2n = 32$, then it is reasonable to assume that each sperm must be $n = 16$.[2]]

I have identified mitosis as the means by which male bees would create gametes.[1]

I have explained my answer in further detail with reference to the diploid number of 32.[2]

Key science skills and ethical understanding

21 **a** [That the frequency of recombination increases when the concentration of Spo11 increases.[1]]

I have identified that the rate of recombination increases with a higher concentration of Spo11.[1]

b [Quantitative data.[1]]

I have correctly identified quantitative data.[1]

c [The independent variable was the concentration of Spo11 protein,[1]] [while the dependent variable was the rate of chiasma formation.[2]]

Other acceptable responses include:

- The dependent variable was the DSB frequency.

I have identified the independent variable.[1]

I have identified the dependent variable.[2]

d [Petri dish number 1.[1]]

I have identified Petri dish number 1 as the control.[1]

e [An opponent might argue that altering the crop in this way ignores the beliefs of those members of society who want to eat natural products free from artificial interventions.[1]] [They might argue that the natural crop has an intrinsic value and is healthier than a crop that has been stimulated with Spo11 protein.[2]]

- I have made mention of the beliefs of some people to eat natural products free from artificial alteration.[1]
- I have made mention of the intrinsic value of the natural crop yield.[2]

7C Genotypes and phenotypes

Theory review questions

1 A

2 homozygous; heterozygous

3 II; III

4 C

5 B

6 II; III

SAC skills questions

7 A **8** B **9** B **10** A

11 A **12** B

Exam-style questions

Within lesson

13 A **14** D **15** B

16 a [I^AI^B.[1]]

- I have correctly identified the genotype of child number 2 as I^AI^B.[1]

b [I^AI^A or I^Ai.[1]]

- I have correctly identified the two possible genotypes of child number 1 as either I^AI^A or I^Ai.[1]

c [Blood type A and blood type B.[1]]

- I have correctly identified the phenotypes of the parents as A and B.[1]

17 a [Hh.[1]]

- I have correctly identified the genotype of Princess Leia as Hh.[1]

b [It is possible for their offspring to have horns.[1]] [Such a child would be heterozygous, having inherited the dominant allele for horns from its mother, Princess Leia.[2]]

- I have correctly acknowledged that the pair could have a horned offspring.[1]
- I have explained this answer in further detail, linking to the inheritance of the dominant allele from the mother.[2]
- I have referred to the scenario in my response.

Multiple lessons

18 a [Father = Dd, Mother = Dd, Sibling = DD or Dd, Khmer = dd.[1]]

- I have correctly identified the possible genotypes of each member of Khmer's family.[1]

b [Based on this information, we can assume that Khmer's sibling was heterozygous for the condition and had the genotype Dd.[1]] [We know this because despite having a child with a partner who did not display the condition, their offspring was born with the condition and must have received a recessive allele from both parents.[2]]

- I have correctly identified Khmer's sibling's genotype as Dd.[1]
- I have explained that for the offspring to display the condition, Khmer's sibling must have passed on a recessive allele.[2]

c i [The hypothalamus is the processing centre involved in thermoregulation.[1]]

- I have identified the hypothalamus as the processing centre for thermoregulation.[1]

ii [Typically, a change in core body temperature is detected by thermoreceptors throughout the body and then communicated to the hypothalamus,[1]] [which will then send messages to effector cells in tissues throughout the body to stimulate a change in heat transfer.[2]]

- I have identified the change in core body temperature (the stimulus) as being detected by thermoreceptors (the receptors) and communicated to the hypothalamus (processing centre).[1]
- I have explained that the hypothalamus will then communicate to effector cells (effector) to stimulate a change in heat transfer (response).[2]

19 a [X^rY.[1]]

- I have correctly identified the genotype of this male as X^rY.[1]

b [We can assume that this fly is a female.[1]] [For a fly to have two different alleles for eye colour, they must have two X chromosomes.[2]]

- I have correctly identified the fly as female.[1]
- I have explained this answer with reference to having two X chromosomes.[2]

c [Genotype = X^RX^r.[1]] [Phenotype = Red-eyed, female fly.[2]]

- I have correctly identified the genotype of a heterozygote as X^RX^r.[1]
- I have correctly identified the phenotype of a heterozygote as red-eyed, female fly.[2]

d [Organisms with a larger surface-area-to-volume ratio will more readily exchange materials with their environment.[1]] [Therefore, flies with a proportionally higher SA:V ratio are likely to lose more of their water to their surroundings.[2]]

I have explained that cells with a larger SA:V ratio will more readily exchange materials with their environment.[1]

I have linked this to the case, showing that flies with a higher SA:V ratio are more likely to lose water via osmosis.[2]

Key science skills and ethical understanding

20 **a** [Heterozygosity is advantageous when low levels of herbicide are present.[1]][This is shown by the dramatic increase in the percentage of heterozygotes after 1986, when GCY spraying was reduced.[2]]

I have identified heterozygote advantage during low levels of herbicide spraying.[1]

I have linked directly to the information given to support my answer.[2]

b [Homozygous resistant weeds are least affected by the spraying of GCY.[1]][Therefore, after three years of GCY spraying (1983–86), large numbers of the homozygous sensitive and heterozygous weeds were killed by GCY, leaving the homozygous resistant weeds to flourish to high numbers.[2]]

I have explained that the homozygous resistant weeds are least affected by GCY.[1]

I have linked directly to the information given to support my answer.[2]

c [The botanist's assumption is incorrect.[1]][While homozygous sensitive individuals had reached zero percent in 1986, the GCY sensitive allele was still present in the population as it was carried by heterozygous individuals who were still around 10% of the population at that time.[2]]

I have identified that the botanist is incorrect.[1]

I have explained that the GCY sensitive allele was still carried by heterozygotes.[2]

d **i** [A farmer is likely to suggest that the benefits of using herbicides far outweigh the possible harms arising from its use.[1]][That is, while herbicide use may entail some small degree of possible harm, this harm is warranted to ensure the successful operation of the farm.[2]]

I have identified a relevant argument pertaining to a consequences-based approach in favour of using herbicides.[1]

I have explained this in further detail.[2]

ii [The leader of a herbicide protest group is likely to suggest that the possible damages to animal habitats as a result of herbicide use are more important than the possible benefits to the farmer.[1]][That is, that the harms of herbicide use outweigh the benefits and therefore the use of herbicide should be avoided.[2]]

I have explained that the leader of the protest group would suggest that the harms outweigh the potential benefits.[1]

I have explained this in further detail.[2]

iii [A duty/rule-based approach suggests that people have a specific duty to act in a way that is responsible and safe.[1]][As such, the farmer is required to follow ethical guidelines when using herbicides on his crops to guard against any unintended consequences to surrounding habitats.[2]]

I have briefly described a duty/rule-based approach to bioethics.[1]

I have explained that the farmer has a duty to use herbicides in a responsible and ethical manner.[2]

7D Nature vs nurture

Theory review questions

1 B

2 I; II

3 environmental; performance; phenotype

4 B

5 B

6 C

7 expression; activated; DNA methylation

8 C

SAC skills questions

9 B **10** A **11** A **12** A

13 D **14** A

Exam-style questions

Within lesson

15 D **16** C

17 **a** [Proportionate heritability suggests that not all variation in the phenotypes of a population can be explained by genetic factors alone. Instead, environmental factors such as diet and nutrition are said to also influence phenotype.[1]][In this case, populations exposed to high concentrations of genistein, such as Western countries, may be at greater risk of developing cancer.[2]]

I have explained proportionate heritability, including the impact of the environment on phenotype.[1]

I have linked proportionate heritability to the case, explaining that varying levels of dietary genistein between populations could be contributing to differences in cancer rates.[2]

I have used key biological terminology such as: variation, phenotypes, concentration.

b **i** [Methylation refers to the process by which small hydrocarbon molecules called methyl groups are attached to certain nucleotides in a DNA sequence so as to reduce the transcription of the gene.[1]]

I have correctly defined the process of DNA methylation.[1]

I have used key biological terminology such as: molecules, nucleotides, transcription.

ii [Yes they will.[1]] [This is because epigenetic changes are somatically heritable, meaning they are able to be passed on from somatic cell to somatic cell and are not erased during cell division.[2]]

- I have correctly identified that the offspring are likely to continually exhibit the epigenetic change throughout their life.[1]
- I have explained that this is because many epigenetic changes are somatically heritable, and are not erased during cell division.[2]
- I have used key biological terminology such as: somatic, heritable.

Multiple lessons

18 a [The findings suggest that both hereditary factors and environmental factors play a role in promoting muscle mass growth in elite athletes.[1]] [In this case, DNA hypomethylation is a hereditary genetic factor, and frequent and targeted physical exercise is an environmental factor.[2]]

- I have correctly mentioned that both factors play a role in promoting muscle mass growth.[1]
- I have identified each of the hereditary and environmental factors that are referenced in the extract.[2]
- I have used key biological terminology such as: hereditary, genetic, hypomethylation.

b i [Rough endoplasmic reticulum and ribosomes.[1]]

- I have correctly identified both the RER and ribosomes.[1]

ii [DNA methylation might inhibit the synthesis of myosin in skeletal muscle cells,[1]] [which could subsequently reduce muscle density and impact on muscle contraction in muscle tissues.[2]]

- I have stated that DNA methylation could inhibit the synthesis of myosin.[1]
- I have explained that this could impact on muscle contraction.[2]
- I have used key biological terminology such as: inhibit, synthesis.

Key science skills and ethical understanding

19 a [15 non-diabetic pancreatic cell samples.[1]]

- I have correctly named the non-diabetic pancreatic cells as the control in this experiment.[1]

b [The graph showing the amount of DNA methylation suggests that there are some methylated sites along the DNA sequence of regular pancreatic cells,[1]] [though much less methylation than what occurs at the same locus in type 2 diabetics.[2]]

- I have explained that DNA methylation occurs to some extent along the DNA sequence of regular pancreatic cells.[1]
- I have identified that this methylation is much less than that of the same locus in type 2 diabetics.[2]

c [There is a positive relationship between *PPARGC1A* expression and insulin secretion in pancreatic cells.[1]] [Individuals with type 2 diabetes experience a reduction in *PPARGC1A* expression resulting from DNA methylation, which in turn leads to a reduction in insulin secretion.[2]]

- I have described the relationship between *PPARGC1A* expression and insulin secretion in pancreatic cells.[1]
- I have explained this relationship in further detail, linking my answer to the findings of the study.[2]
- I have used key biological terminology such as: positive relationship, reduction, expression.

d [One possible limitation of Ted's study is that it seems to ignore other environmental factors that could play a role in insulin secretion, such as the age and weight of the donor.[1]]

Other acceptable responses include:

- The experiment is undertaken *in vitro*, which may not provide as accurate or relevant results as an *in vivo* experiment.

- I have stated one possible limitation.[1]

e [Ted would have needed to follow the ethical principle of respect when obtaining pancreatic cells from human donors.[1]] [Respect acknowledges the intrinsic value of research participants, and only allows the use of pancreatic cells from donors who have personally agreed to participate.[2]]

- I have identified the need for respect when using pancreatic cells given by human donors.[1]
- I have explained this in further detail with reference to ideas of personal value and consent.[2]
- I have used key biological terminology such as: respect, donor, participation.

Chapter 7 SAC practice

1 [Group 1, Trait B.[1]]

- I have correctly identified the set of data with the highest heritability value.[1]

2 [Group 2 used a much smaller sample size than Group 1.[1]]

- I have mentioned the smaller sample size as a possible limitation for Group 2.[1]

3 [This phenotypic variation is likely a result of the rearranging of alleles that occurs between parents and their offspring due to crossing over and independent assortment.[1]]

- I have referenced the rearrangement of alleles due to crossing over and independent assortment.[1]

4 [Using a consequences-based approach to bioethics, an intervention might focus on minimising damaging individual environmental influences, as these play a larger role in the differences in university success between young adults.[1]]

- I have explained how this research can be used to improve university success.[1]

5 [These findings are significant for the bioethical concept of justice, as they demonstrate a disproportionate disadvantage for students who grow up in low-socioeconomic areas and an unequal access to schooling success based on geographical location.[1]]

- I have explained the relevance of the findings to the bioethical concept of justice by reference to the disadvantage facing low-socioeconomic areas.[1]
- I have signposted connections to the bioethical concept of justice using terms such as: disproportionate, disadvantage, low-socioeconomic.

6 [Using the bioethical concept of non-maleficence, the government needs to consider the possible causes of harm that could result from reallocating resources.[1]][This could include unintended negative consequences resulting from the reallocation of resources from other groups.[2]]

- I have explained how the bioethical concept of non-maleficence applies to the scenario.[1]
- I have provided an example of the potential for unintended harms.[2]
- I have signposted connections to the bioethical concept of non-maleficence using terms such as: harm, unintended negative consequences.

7 [The independent variable is age,[1]][while the dependent variable is the heritability ratio for BMI.[2]]

- I have correctly identified the independent variable.[1]
- I have correctly identified the dependent variable.[2]

8 [Twin studies are useful in allowing researchers to more easily and accurately identify shared environmental influences, such as family environment.[1]][Additionally, the use of twins in this experiment reduces genetic variation between participants. Identical twins share 100% of DNA, while dizygotic twins share 50% of their DNA.[2]]

- I have identified one strength of using twin studies in this experiment.[1]
- I have identified another strength of using twins in this experiment.[2]

9 [The genetic heritability ratio increased from approximately 0.65 at age 7 to approximately 0.82 at age 10.[1]]

- I have correctly described the change in genetic heritability between ages 7–10.[1]

10 [The heritability ratio of shared environmental influences decreased from approximately 0.4 at age 4 to approximately 0.03 at age 7.[1]]

- I have correctly described the change in the heritability ratio of shared environmental influences between ages 4–7.[1]

11 [The information suggests that *FTO* expression and BMI levels are positively correlated.[1]]

- I have described the relationship between the *FTO* gene and BMI levels.[1]

Chapter 7 Exam practice

Section A

1 D **2** D **3** A **4** C

Section B

5 **a** [Recombination allows parents to produce offspring that are genetically distinct from themselves and from each other.[1]][This increases the genetic diversity of the offspring of a parent[2]][which in turn increases the genetic diversity of the population as a whole.[3]]

- I have explained that recombination allows individuals to create offspring that are genetically distinct from one another.[1]
- I have identified that the genetic diversity will increase in the gametes.[2]
- I have linked recombination to an increase in the genetic diversity of the population.[3]
- I have used key biological terminology such as: diversity, recombination.

b [Independent assortment ensures that the two alleles of every gene are separated from one another during meiosis,[1]][so as to produce new combinations of alleles during anaphase I and increase genetic variations within a population.[2]]

- I have explained the importance of independent assortment in ensuring that each gene assorts independently from one another.[1]
- I have linked this to the overall purpose of meiotic cell division.[2]
- I have used key biological terminology such as: anaphase, variations.

c **i** [46.[1]]

- I have correctly identified the diploid number of each twin.[1]

ii [The influence of environment and epigenetics on the phenotype of each twin.[1]]

- I have explained that environmental and epigenetic influences likely account for much of the differences seen.[1]

6 **a** [Homozygous dominant genotype = RR; Homozygous recessive genotype = rr.[1]]

- I have identified the genotypes of both homozygotes.[1]

b [Between Generations 1–15, we see an increase in the prevalence of recessive alleles and a decrease in the prevalence of dominant alleles.[1]] [One possible explanation is a potential heterozygote advantage, which confers some biological advantage due to being a carrier of both alleles and promotes the presence of the recessive allele across reproductive cycles.[2]]

I have identified the change in allele frequencies from Generation 1–15.[1]

I have attempted to explain this change with reference to a potential heterozygous advantage.[2]

7 a [Regular *MC1R* function, and inactivated/malfunctioning *MC1R*.[1]]

I have correctly identified both alleles with respect to the *MC1R* gene.[1]

b [Autosomal dominant.[1]]

I have correctly identified autosomal dominant as the likely type of dominance.[1]

c i [DNA methylation involves the adding of methyl (-CH_3) groups to particular nucleotides in a DNA segment so as to modify the expression of a gene.[1]] [Often, this results in the silencing of that gene and reduced gene expression, resulting in reduced production of a specific protein.[2]]

I have explained what is meant by DNA methylation.[1]

I have explained the relationship between DNA methylation, gene silencing, and protein production.[2]

ii [The protein p14(ARF) functions as a tumour suppressor, meaning that the higher an individual's levels of p14(ARF), the less likely they are to develop CMM.[1]]

I have described the relationship between p14(ARF) and an individual's likelihood of developing CMM.[1]

8A Monohybrid crosses

Theory review questions

1 A

2 Punnett square; top/side; top/side

3 III; II; V; I; IV

4

	H	H
H	HH	HH
h	Hh	Hh

5

	G	g
G	GG	Gg
g	Gg	gg

6

	I^A	I^B
I^A	I^AI^A	I^AI^B
i	I^Ai	I^Bi

7 D

8 B

SAC skills questions

9 C   10 B   11 B   12 C

13 C

Exam-style questions

Within lesson

14 A   15 A   16 D

Multiple lessons

17 a [The complete set of DNA contained within the haploid set of an organism's chromosomes.[1]]

I have defined genome.[1]

b i

	R	R
r	Rr	Rr
r	Rr	Rr

I have completed the Punnett square.

ii [100% of the potential offspring would be red.[1]]

I have stated the phenotypic percentage proportion.[1]

c i [This gene would be found on the X chromosome[1]][as the males are XY and only have one copy of the allele.[2]]

I have stated that the gene would be found on the X chromosome.[1]

I have explained my response.[2]

ii

	X^R	Y
X^r	X^RX^r	X^rY
X^r	X^RX^r	X^rY

I have completed a sex-linked Punnett square.

I have used correct allelic notation.

iii [100% of potential female offspring would be red[1]][and 100% of potential male offspring would be black.[2]]

I have stated the phenotypic percentage proportion for females.[1]

I have stated the phenotypic percentage proportion for males.[2]

d [In the autosomal cross, all offspring would be red, whereas only half the offspring in the sex-linked cross would be red.[1]][This is because the father only has one X-chromosome, therefore the allele on the X chromosome will always be expressed.[2]]

I have described the difference in the phenotypic proportions.[1]

I have explained how sex linkage changes the results.[2]

Key science skills and ethical understanding

18 a [Respect[1]]

I have identified that respect is being followed.[1]

b [Sandra can determine Martin's genotype as he only expresses recessive traits.[1]][Therefore, Martin is homozygous recessive for both the Rhesus factor and ABO groups.[2]][However, she cannot determine Payton's genotype,[3]][as she could be homozygous dominant or heterozygous for both blood type and the Rhesus factor.[4]]

I have stated that she can determine Martin's genotype.[1]

I have stated Martin's genotype.[2]

I have stated that she cannot determine Payton's genotype.[3]

I have explained the possible genotypes Payton could have.[4]

c **i** [The alleles for both traits would be found on autosomes[1]] [as Martin (a male) has two copies of each allele, therefore it is not on a sex chromosome.[2]]

- I have stated that the traits are autosomal.[1]
- I have justified why they are autosomal.[2]

ii

	D	D
d	Dd	Dd
d	Dd	Dd

- I have completed a Punnett square.

iii [The offspring will be positive for the Rhesus factor.[1]]

- I have stated that the offspring will be positive.[1]

d [In the top left square, Sandra has incorrectly crossed the alleles, the correct genotype is I^Bi.[1]] [This means that 50% of the potential offspring will be B blood type, and 50% would be O blood type.[2]]

- I have outlined the error in the Punnett square.[1]
- I have amended the percentage proportions.[2]

e [50%[1]]

- I have stated the percentage of potential offspring with the same phenotype as Payton.[1]

8B Dihybrid crosses

Theory review questions

1 A **2** A **3** B

4

	AB	Ab	AB	Ab
AB	AABB	AABb	AABB	AABb
Ab	AABb	AAbb	AABb	AAbb
aB	AaBB	AaBb	AaBB	AaBb
aB	AaBB	AaBb	AaBB	AaBb

5

	Ab	AB	ab	aB
ab	Ab/ab 48%	AB/ab 2%	ab/ab 2%	aB/ab 48%
	Parental	Recombinant	Recombinant	Parental

6 D

SAC skills questions

7 B **8** B **9** A **10** B

11 B

Exam-style questions

Within lesson

12 C

13 **a** [Linked genes are genes that are found on the same chromosome and are likely to be inherited together.[1]]

Other acceptable responses include:

- Are relatively close together.
- Low chance of crossing over to separate them.
- Are not separated by independent assortment.

- I have described linked genes.[1]

b [12[1]]

- I have stated the correct number of map units between the genes.[1]

c **i** [Both parents are red.[1]]

- I have stated that the parents are red.[1]

ii

	BE	Be	bE	be
Be	BBEe	BBee	BbEe	Bbee
be	BbEe	Bbee	bbEe	bbee
Be	BBEe	BBee	BbEe	Bbee
be	BbEe	Bbee	bbEe	bbee

- I have written the correct genotypic combinations for both parents.
- I have completed the cross correctly.

iii [50%[1]]

- I have stated the proportion of offspring with black eyes.[1]

iv [25%[1]]

- I have stated the proportion of offspring with a brown body.[1]

Multiple lessons

14 A **15** D **16** C

8B

Key science skills and ethical understanding

17 **a** [They are not linked genes because the proportions of the sample follow the ratio 9 : 3 : 3 : 1 which is the result of an unlinked dihybrid cross between two heterozygous individuals.[1]]

I have explained why they are not linked genes.[1]

b [If the sample only considers 30 seahorses, the results of the rest of the litter could alter the results.[1]]

I have provided a potential confounding variable.[1]

c [The researchers ought to have protected the infants and minimised any unnecessary harm that could cause death.[1]]

I have explained how beneficence must be considered.[1]

8C Pedigree analysis

Theory review questions

1 B

2 B

3 I; III; IV

4 must; may; may

5 must; must; must not; must not

6 C

SAC skills questions

7 C **8** B **9** A **10** B

11 B

Exam-style questions

Within lesson

12 C **13** C **14** B **15** A

Multiple lessons

16 **a** [Both individuals II-3 and II-4 display coat colours only encoded by dominant alleles at the R gene locus – red and black, respectively. Therefore, they each must contain at least one dominant allele at the R locus.[1]][Two of their children, individuals III-1 and III-4, display coat colours only encoded by a genotype homozygous for the recessive allele at the R gene locus indicating that both individuals II-3 and II-4 must contain at least one recessive allele at the R locus. Therefore, both individuals II-3 and II-4 must be heterozygous at the R gene locus.[2]]

I have explained that the offspring must have one dominant allele at the R locus.[1]

I have explained that the offspring must have one recessive allele at the R locus.[2]

I have used key biological terminology such as: heterozygous, dominant, recessive.

b [RrBb[1]]

I have stated the genotype of I-1.[1]

c

	Rb	rb	Rb	rb
RB	RRBb	RrBb	RRBb	RrBb
Rb	RRbb	Rrbb	RRbb	Rrbb
rB	RrBb	rrBb	RrBb	rrBb
rb	Rrbb	rrbb	Rrbb	rrbb

I have correctly identified the genotype of individual II-4.

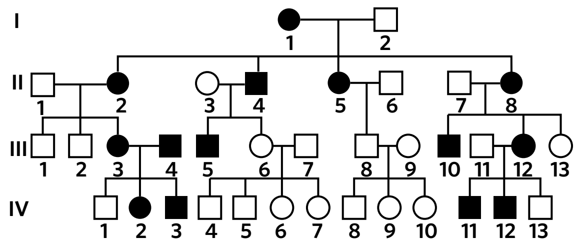
I have completed the dihybrid cross.

d [3/8 of offspring will have a red coat colour, the same as their mother.[1]]

I have stated the fraction of offspring with the same phenotype as their mother.[1]

Key science skills and ethical understanding

17 **a**



I have completed the pedigree.

b [Autosomal dominant because every affected individual has an affected parent and there appears to be no sex-linked pattern.[1]]

Other acceptable responses include:

- Widow's peak is autosomal dominant as IV-1 is unaffected despite both III-3 and III-4 being affected.
- I-1 has heterozygous children who are all affected.

I have explained the inheritance pattern of widow's peak.[1]

c [Primary data as it is raw data collected from the source, his great grandfather.[1]]

I have explained why the photograph is a form of primary data.[1]

d [Approach 2 would be a better example of a consequences-based approach as this approach justifies that the benefits of including Uncle Vernon in the chart outweigh any potential distress or embarrassment suffered by Uncle Vernon.[1]]

I have explained why approach 2 is a better example.[1]

Chapter 8 SAC practice

1 [Haemophilia is not contagious as it is a genetic disease.[1]]

I have explained why haemophilia is not a contagious disease.[1]

2 [The statement is false. Whilst haemophilia can be life-threatening in severe cases,[1]] [mild cases are barely noticeable and not fatal.[2]]

I have explained that it can be life-threatening.[1]

I have explained it is not always fatal.[2]

3 [Genetic tests could determine whether they possessed the alleles for haemophilia.[1]]

I have explained how mild haemophilia can be diagnosed.[1]

4 [Haemophilia must be a recessive disease[1]] [as one or both parents must be heterozygous but have their healthy dominant allele masking the expression of the diseased allele.[2]]

I have stated it is recessive.[1]

I have explained that a dominant allele can mask the expression of the recessive allele.[2]

5 [It cannot be Y-linked as not all affected fathers produce affected sons, as shown by II-14 being unaffected but having two affected sons, III-18 and III-19.[1]]

I have used evidence from the pedigree to justify why it is not Y-linked.[1]

6 [Males only have one X chromosome, which means they only require one recessive allele to express the disease,[1]] [unlike females who would need two copies of the recessive allele (which is less likely to occur).[2]]

I have explained why males are more likely to have the disease.[1]

I have compared my response to females.[2]

7 [I-1 is X^HY and I-2 is X^HX^h.[1]]

I have stated the genotype of I-1 and I-2.[1]

8

	X^h	Y
X^H	X^HX^h	X^HY
X^h	X^hX^h	X^hY

I have completed the monohybrid cross.

9 [50% of female offspring will have haemophilia, and 50% will be healthy.[1]] [50% of male offspring will have haemophilia, and 50% will be healthy.[2]]

I have stated the phenotypic percentages of females.[1]

I have stated the phenotypic percentages of males.[2]

10

	C	c
c	Cc	cc
c	Cc	cc

I have completed the monohybrid cross.

I have not used sex chromosome symbols to complete this autosomal cross.

11 [50% of offspring will have cystic fibrosis and 50% will be healthy.[1]]

I have stated the phenotypic percentages.[1]

12 [These genes are not linked genes as they are found on separate chromosomes and are unlikely to be inherited together.[1]]

I have explained why they are not linked genes.[1]

13

	CX^h	CY	cX^h	cY
CX^H	CCX^HX^h	CCX^HY	CcX^HX^h	CcX^HY
CX^h	CCX^hX^h	CCX^hY	CcX^hX^h	CcX^hY
cX^H	CcX^HX^h	CcX^HY	ccX^HX^h	ccX^HY
cX^h	CcX^hX^h	CcX^hY	ccX^hX^h	ccX^hY

I have completed the dihybrid cross.

14

	Females	Males
Neither cystic fibrosis nor haemophilia	3/8	3/8
Cystic fibrosis but not haemophilia	1/8	1/8
Haemophilia but not cystic fibrosis	3/8	3/8
Both cystic fibrosis and haemophilia	1/8	1/8

I have completed the table.

Chapter 8 Exam practice

Section A

1 A **2** C **3** B **4** C
5 C

Section B

6 a [X-linked dominant as an affected male produces all affected daughters, but not sons.[1]] [However, sex linkage cannot be confirmed without more evidence.[2]]

I have explained which mode of inheritance is shown.[1]

I have stated sex linkage cannot be confirmed.[2]

b [Only I-3 can be confirmed to have it[1]] [as to produce an affected male, the mother must also be affected.[2]]

I have stated I-3 is affected.[1]

I have explained why she is affected.[2]

c

	X^d	Y
X^D	X^DX^d	X^DY
X^d	X^dX^d	X^dY

I have completed the monohybrid cross correctly.

d [50% of females will be affected and 50% will not. 50% of males will be affected and 50% will not.[1]]

I have stated the phenotypical proportions for male and female offsprings.[1]

7 a [Linked genes are genes that are found close together on the same chromosome and are likely to be inherited together.[1]]

Other acceptable responses include:

- Low chance that crossing over will separate them.
- Are not separated by independent assortment.

I have defined linked genes.[1]

b [ab/ab[1]]

I have stated the genotype of these individuals.[1]

I have used the correct genotype conventions.

c [Autosomal as male individuals have two different alleles.[1]]

I have explained why the genes are autosomal.[1]

d

	AB	Ab	aB	ab
ab	AB/ab	Ab/ab	aB/ab	ab/ab
	46%	4%	4%	46%

I have correctly completed the linked dihybrid cross.

e [46% secrete the protein and produce protein X, 4% are non-secretors but do produce protein X, 4% are secretors but do not produce protein X, and 46% do not secrete proteins or produce protein X.[1]]

I have stated the phenotypic ratios.[1]

I have calculated phenotypic proportions based off the map units.

9A Sexual vs asexual reproduction

Theory review questions

1 B

2 B

3 A

4 Oviparity: II
Viviparity: I; III
Both: IV

5 II

6 A

7 C

8 A

SAC skills questions

9 B **10** C **11** B **12** A

13 A **14** C

Exam-style questions

Within lesson

15 A **16** B

17 a [Oviparity.[1]]

I have correctly identified the mode of embryonic development.[1]

b i [Mitosis.[1]]

I have correctly identified the type of cell division.[1]

ii [One advantage of asexual reproduction for the larvae inside the *Biomphalaria* is that it allows for rapid reproduction without the need for motility.[1]][This is important for the larvae that have shed their cilia, which were previously used for locomotion.[2]]

I have correctly identified that asexual reproduction does not require motility.[1]

I have explained why this is an advantage for the larvae inside the snail.[2]

Multiple lessons

18 C

19 a [Binary fission.[1]]

I have correctly identified the method of asexual reproduction.[1]

b [*G. intestinalis* is a eukaryotic organism[1]][as it has a nucleus.[2]]

I have correctly identified that *G. intestinalis* is eukaryotic.[1]

I have justified this by referring to the presence of a nucleus.[2]

c [Low genetic diversity is an advantage for *G. intestinalis*, which has developed a phenotype that is fine-tuned for success within the small intestine of humans.[1]]

I have mentioned the fine-tuning of *G. intestinalis* phenotype for success in its environment.[1]

I have used key biological terminology such as: phenotype.

d [One difference is that meiosis involves crossing over during prophase I,[1]][which increases genetic diversity by aiding the formation of recombinant gametes.[2]]

Other acceptable responses include:

- Independent assortment in metaphase I of meiosis.
- Formation of haploid gametes, as opposed to diploid daughter cells through mitosis.

I have identified one difference between meiosis and mitosis.[1]

I have explained how this difference influences genetic diversity.[2]

I have used key biological terminology such as: prophase, recombinant.

Key science skills and ethical understanding

20 a [35 °C.[1]]

I have correctly identified the optimal temperature.[1]

b [250 nm.[1]]

I have correctly identified the UV wavelength responsible for inactivation.[1]

c i [A temperature of 60 °C kills *Legionella*.[1]]

I have explained that this temperature likely kills the bacteria.[1]

ii [It is likely that *Legionella* would reach pool capacity in roughly half the time.[1]]

I have explained that *Legionella* would reproduce faster.[1]

d [A simulation allows for easier manipulation of environmental parameters, such as temperature and UV levels.[1]]

Other acceptable responses include:

- A simulation might have been more cost-effective than a controlled experiment or fieldwork.
- A simulation removes the need to obtain experimental materials, such as bacteria and pools.
- A simulation removes the interaction with living organisms, such as *Legionella*, therefore removing the potential for unnecessary experimental harm to living beings.

I have identified one advantage of using a simulation for this investigation.[1]

e **i** [Including these numerical models allows for other researchers in different locations to conduct similar simulations by using the same equations.[1]]

- I have outlined how this inclusion aids in reproducibility.[1]

ii [This inclusion satisfies the bioethical concept of integrity by ensuring that all sources of information for this study are fully reported,[1]][allowing public scrutiny and the reproduction of their investigation.[2]]

- I have identified how the inclusion satisfies integrity.[1]
- I have explained why the inclusion of this data is important.[2]
- I have used key biological terminology such as: reporting, scrutiny.

9B Cloning

Theory review questions

1 B

2 I-enucleation; II-extraction; III-insertion; IV-development

3 A

4 B

5 plant grafting; plant tissue culturing; plant cutting

6 A

7 P-scion; Q-rootstock

SAC skills questions

8 A **9** B **10** D **11** B

12 A **13** C

Exam-style questions

Within lesson

14 C **15** A **16** D

Multiple lessons

17 **a** [A genetically identical organism or section of DNA.[1]]

- I have correctly identified what a clone is.[1]

b [Somatic cell nuclear transfer.[1]]

- I have correctly named the technique.[1]

c [19.[1]][Because egg cells are gametes, they will contain half the number of chromosomes in somatic cells. In cats, somatic cells each contain 38 chromosomes.[2]]

- I have identified the correct number of chromosomes.[1]
- I have explained that gametes have half the number of chromosomes compared to somatic cells.[2]

d [Josh is correct.[1]][This is because the gender of the cat is determined by its sex-chromosomes, which were obtained from the somatic cells of a male cat.[2]]

- I have identified Josh as the correct individual.[1]
- I have explained why Josh is correct.[2]

18 **a** [An egg and sperm cell can be selected from individuals with specific desired traits and combined to form a fertilised zygote via *in-vitro* fertilisation.[1]][Following the formation of a zygote, the cell will replicate multiple times, eventually becoming an embryo.[2]][In the 6–8 cell stage of this embryo, the embryo can be split apart into multiple different totipotent stem cells which can independently develop into complete organisms.[3]][These individual cell clusters are implanted into surrogate mothers, who then continue with their pregnancies as per normal.[4]]

- I have described the process of *in-vitro* fertilisation.[1]
- I have described the origin of an embryo.[2]
- I have described how the embryo can be split into multiple different sections.[3]
- I have described the implantation into surrogate mothers.[4]
- I have used key biological terminology such as: *in-vitro* fertilisation, totipotent, surrogate mothers.

b [Embryo splitting is advantageous when compared with selective breeding because multiple genetically identical offspring can be produced instead of only a single offspring.[1]]

Other acceptable responses include:

- Precise selection of desirable traits.
- The rate of reproduction is increased.

- I have suggested one possible advantage.[1]
- I have used comparative language such as: compared with, instead.

c [In meiosis, individual chromosomes are independently assorted between the four gametes.[1]][Also, genetic material is transferred between homologous chromosomes during recombination.[2]][Both of these processes help create novel genotypes which increase the genetic diversity of a population.[3]]

- I have explained the process of independent assortment.[1]
- I have explained the process of recombination.[2]
- I have explained how these processes increase the genetic diversity of a population.[3]
- I have used key biological terminology such as: independent assortment, gametes, homologous chromosomes, recombination, novel genotype.

Key science skills and ethical understanding

19 **a** [The newly invented chemical will have an effect on the fruit productivity of apple trees.[1]]

I have suggested a possible hypothesis.[1]

b [The independent variable is whether the tree is exposed to the chemical.[1]] [The dependent variable is the fruit productivity of individual apple trees.[2]]

I have correctly identified the independent variable.[1]

I have correctly identified the dependent variable.[2]

c [The environmental conditions the apple trees are grown in.[1]]

Other acceptable responses include:

- The amount of chemical applied to each tree.
- The time of day/year the chemical is applied to each tree.
- How the chemical is applied to each tree.

I have identified a possible controlled variable.[1]

d **i** [Scientists may prefer plant cuttings and grafting to plant tissue cultures because plant cuttings and grafting can produce fully grown and genetically identical apple trees faster.[1]]

Other acceptable responses include:

- Plant cuttings and grafting are more affordable than plant tissue culturing.

I have identified an advantage of plant cutting and grafting.[1]

ii [By producing genetically identical plants, the total genetic diversity of a population will be reduced which can leave populations more susceptible to disease.[1]]

I have identified a biological implication of genetically identical plants.[1]

Chapter 9 SAC practice

1 [The purpose of the ovaries is to produce egg cells.[1]] [The purpose of the testes is to produce sperm.[2]]

I have identified the purpose of the ovaries.[1]

I have identified the purpose of the testes.[2]

2 [If the Fallopian tube was damaged, the egg would not be able to migrate from the ovaries to the uterus.[1]] [Therefore, should the egg be fertilised it would not be able to implant itself in the uterus, resulting in infertility.[2]]

I have identified the inability of the egg to migrate.[1]

I have described how the inability to migrate leads to infertility.[2]

3 [The mode of embryonic development used by humans is viviparity,[1]] [where the embryo develops inside the mother's uterus, receiving nutrients from the mother's bloodstream via the placenta.[2]]

I have identified the mode of embryonic development in humans.[1]

I have described the mode of embryonic development in humans.[2]

4 [One advantage of sexual reproduction includes the increased genetic diversity of a population, and the resulting increase in the resistance of a species to a sudden environmental change.[1]] [One disadvantage includes the risk of losing offspring to outside influences such as embryo damage.[2]]

Other acceptable advantages include:

- Improves disease resistance by promoting the presence of different alleles.
- Reduces the chance of an offspring inheriting a genetic disorder.

Other acceptable disadvantages include:

- The cost of the male progeny.
- The time, energy, and resources required to find a mate.
- The risk of transferable diseases associated with sexual intercourse.

I have identified an advantage of sexual reproduction.[1]

I have identified a disadvantage of sexual reproduction.[2]

5 [As age increases, the chance of natural conception per month decreases.[1]] [This is shown by the graph as at age 22, the chance of natural conception is 25% and as age increases to 48, the chance of natural conception decreases to less than 1%.[2]]

I have described the general trend.[1]

I have used data from the graph to support the trend.[2]

6 [In IVF, the egg cell's nucleus is unaltered compared with the insertion of a somatic cell nucleus into an enucleated egg cell in somatic cell nuclear transfer.[1]]

Other acceptable responses include:

- In somatic cell nuclear transfer, the offspring is a clone of the somatic cell donor, whereas in *in-vitro* fertilisation the offspring is not a clone, as IVF is similar to sexual reproduction.

I have identified one difference between IVF and somatic cell nuclear transfer.[1]

I have used comparative language such as: compared with.

7 [A similarity between *in-vitro* fertilisation and embryo splitting involves the fertilisation of the egg *in-vitro*, which is implanted into a surrogate mother.[1]]

Other acceptable answers include:

- Both *in-vitro* fertilisation and embryo splitting involve artificial intervention by humans.

I have identified one similarity between IVF and embryo splitting.[1]

8 [Based on the bioethical concept of respect, which encourages the power for self-determination and bodily autonomy,[1]][people should not be subjected to police checks and child welfare testing as this opposes the freedom of others to make their own decisions.[2]]

Other acceptable responses include:

- Based on the bioethical concept of respect, the personal welfare of the resultant child should be considered. Therefore, prospective parents should be subjected to police checks and child welfare testing to ensure the child's future safety.

I have described the bioethical concept of respect.[1]

I have explained the relevance of respect to the scenario.[2]

9 [IVF could be beneficial for parents with genetic disorders as it would allow them to genetically screen embryos prior to implantation to ensure that they do not have the affected genes.[1]]

I have described how IVF could be beneficial for parents with genetic disorders.[1]

10 [Pollen.[1]]

I have identified the male gamete of flowering plants.[1]

11 [The reproductive process in flowering plants first involves release of pollen from the male flower, followed by the collection of pollen by the stigma of the female flower.[1]][The pollen fuses with the ovule, which is the female reproductive gamete, and produces an embryo that develops into seeds.[2]]

I have described the release and collection of pollen.[1]

I have described the formation of the embryo.[2]

I have used key biological terminology such as: pollen, stigma, ovule, gamete.

12 [Stenospermocarpy involves the abortion of the developing embryo which leads to the disruption of seed production.[1]][Triploid watermelon, which are produced by crossing a diploid and tetraploid watermelon, is a form of stenospermocarpy as the developing embryo in the newly formed triploid watermelon is disrupted by the inability of the chromosomes to pair during meiosis.[2]]

I have described stenospermocarpy.[1]

I have explained why the creation of seedless watermelon is a form of stenospermocarpy.[2]

13 [Because seedless grapevines cannot produce viable seeds, this indicates that they cannot reproduce sexually. Therefore, they must reproduce asexually through reproductive cloning techniques.[1]]

I have explained why seedless grapes must reproduce through reproductive cloning techniques.[1]

14 [First, scientists would extract plant cells from the leaves, shoots, or stem of the seedless grape vine.[1]][After, these cells would be grown on a nutrient culture medium in a controlled and sterile environment.[2]][The cells produced can then be separated into several cultures and stimulated to grow into clones of the original grapevine.[3]]

I have identified that scientists need to extract plant cells from the seedless grape vine.[1]

I have described the conditions required for plant tissue culturing.[2]

I have described how these cells could be used to produce clones of the original grapevine.[3]

15 [Sporogenesis.[1]]

I have named the correct reproductive technique.[1]

Chapter 9 Exam practice

Section A

1 B	**2** C	**3** B	**4** C
5 B	**6** A	**7** A	

Section B

8 a [Plant tissue culturing requires a controlled and sterile environment, where lighting, temperature, growth factors, and nutrient availability are closely regulated.[1]]

I have identified the conditions necessary for plant tissue culturing.[1]

b [Plant grafting involves the attachment of a scion and rootstock together.[1]][The scion is the upper portion of the plant consisting of the stem[2]][and the rootstock is the lower portion of the plant consisting of a stem and roots.[3]]

I have described the process of plant grafting.[1]

I have described the scion.[2]

I have described the rootstock.[3]

c [Sexual reproduction involves the fusion of male and female gametes.[1]][Because pollination involves the fusion of pollen, which is the male gamete, and an ovule, which is the female gamete, pollination is a form of sexual reproduction.[2]]

I have described sexual reproduction.[1]

I have identified the gametes involved in pollination.[2]

9 a [Sheep could be rapidly produced through the process of embryo splitting.[1]][In this scenario, embryo splitting would involve the selection of two sheep with the favourable trait, from which an egg and sperm cell would be collected.[2]][The egg would then be fertilised and while the embryo is still in the 6–8 cell stage, the embryo would be split into multiple embryos which can independently develop into complete organisms, as each cell is totipotent.[3]][These individual cell clusters are then implanted into surrogate mothers.[4]]

- I have identified the technique of embryo splitting.[1]
- I have described the origin of the embryo.[2]
- I have described how the embryo is split.[3]
- I have described the implantation into surrogate mothers.[4]

b [One biological implication includes decreased genetic diversity, which could leave the sheep population more susceptible to sudden environmental changes.[1]]

- I have identified a biological implication of mass-producing sheep with identical genotypes.[1]

10 **a** [Genetic diversity can be measured by analysing the gene pool, which is the sum of all alleles within a given population.[1]] [Populations with a greater genetic diversity will have a larger variety of different alleles and populations with a lower genetic diversity will have less variety.[2]]

- I have identified how genetic diversity can be measured.[1]
- I have described how the gene pool relates to genetic diversity.[2]

b [One advantage of asexual reproduction involves the ability to rapidly reproduce and form large populations relatively quickly.[1]] [Another advantage includes the lack of parental investment, removing the need to protect fragile offspring.[2]]

Other acceptable responses include:

- Organisms do not need to find a mate to reproduce.
- Organisms which have adapted specifically to a particular environment can produce genetically identical offspring with the same advantageous phenotype.

- I have identified one advantage of asexual reproduction.[1]
- I have identified a second advantage of asexual reproduction.[2]

10A Adaptations for hot environments

Theory review questions

1 B

2 A

3 Physiological: I; IV
Structural: II
Behavioural: III

4 IV

5 I–increased number of light-receiving cells in the eye; II–a light-coloured epidermis in a hot and sunny environment; III–muscle cells with high mitochondrial counts; IV–baring teeth when threatened; V–ability to run quickly on two legs over hot sand

SAC skills questions

6 A	7 B	8 C	9 C
10 C	11 C	12 A	13 A

Exam-style questions

Within lesson

14 B	15 C	16 D	17 C
18 A			

Multiple lessons

19 a [The cattle,[1]][because it will take the shortest time to become dehydrated.[2]]

Other acceptable responses include:

- The cattle, because it loses the most amount of water each day.

I have identified the correct animal.[1]

I have explained my response.[2]

b [Display nocturnal behaviour and move into the shade.[1]]

Other acceptable responses include:

- Spend the day in a burrow.
- Restrict activities during the day.

I have identified two behavioural adaptations to hot, dry environments.[1]

c [The loop of Henle in the kidney is longer in animals that live in hot, dry environments.[1]][This allows these animals to re-absorb increased amounts of water from their kidney filtrate, reducing the amount of water lost through urine.[2]]

I have identified the relevant structural adaptation.[1]

I have explained how this adaptation increases water conservation.[2]

d [Abiotic factors are properties of the environments that relate to non-living things that influence an organism.[1]]

I have correctly described the term 'abiotic'.[1]

Key science skills and ethical understanding

20 A   21 C

22 a [As skin surface area increases, the rate of heat loss over the skin also increases.[1]]

I have correctly described the relationship between skin surface area and the rate of heat loss.[1]

b i [If the air temperature (T_a) is greater than the skin temperature (T_s) the animal will absorb heat from the environment[1]] [as (T_s - T_a) is negative.[2]]

I have explained the effect of a greater air temperature.[1]

I have used the heat loss equation to support my answer.[2]

ii [An animal could avoid the high temperatures by moving into environments with lower air temperatures, such as a burrow system.[1]]

Other acceptable responses include:

- Using evaporative cooling methods to release heat into the environment.
- Remain inactive during the hottest periods of the day.

I have identified how an animal might modify its behaviour to deal with excessive surface air temperatures.[1]

c i [The ethical principle of non-maleficence may be breached as[1]] [exposing birds to a high T_a may cause unnecessary harm and stress on the animal.[2]]

Other acceptable responses include:

- The ethical principle of beneficence may be breached as there may be an alternative experimental treatment which minimises potential harm to the birds while achieving the same learnings.

I have identified a relevant ethical principle.[1]

I have explained the relevance of the ethical principle to the scenario.[2]

ii [The African cuckoo had the highest internal body temperature of approximately 44.7 °C[1]][which occurred at an air temperature of 50 °C.[2]]

I have identified the species with the highest internal body temperature.[1]

I have identified the air temperature at which this occurred.[2]

iii [The lilac-breasted roller.[1]]

I have identified which species can tolerate the greatest air temperature.[1]

iv [Evaporative heat loss is effective because water has a high specific heat capacity and latent heat of vaporisation[1]] [meaning that a lot of heat can be released into the environment with small volumes of water.[2]]

I have identified properties of water that make it useful as a heat loss mechanism.[1]

I have explained how these properties ensure evaporative cooling methods are an effective heat loss mechanism.[2]

10B Adaptations for cold environments

Theory review questions

1 biotic; abiotic; low; high

2 B

3 B

4 B

5 I–entering into a state of low metabolic activity and body temperature; II–increased concentrations of dissolved cellular solutes; III–thick layer of insulating fat and fur over the entire body; IV–countercurrent blood circulation in the peripherals

SAC skills questions

6 B **7** A **8** B **9** B

10 B **11** D **12** B **13** A

14 D

Exam-style questions

Within lesson

15 D **16** C **17** B **18** B

Multiple lessons

19 D **20** A

21 **a** [Some plants can produce antifreeze proteins, preventing the freezing of water in their cells or vascular system.[1]]

Other acceptable responses include:

- Track the sun to increase light absorbance.
- Increase the concentration of solutes inside a cell.
- Alter the chemical composition of the plasma membrane.
- Produce seeds that can remain dormant in winter months.
- Losing leaves during winter to limit physical damage from strong winds and snow.

I have described an adaptation of plants in alpine environments.[1]

b [Above the tree line, temperatures are generally too cold to support large plant growth, as the water within the vascular system of plants may freeze. The tree line may also be influenced by strong winds, lack of water availability, and low nutrient soils.[1]]

I have explained why trees cannot grow above the tree line.[1]

c [Nutrients are essential compounds such as carbon, nitrogen, phosphorus, potassium, and magnesium. Low nutrient soils lack these, and plants growing in such soils may lack the building blocks required for macromolecule construction and cellular regulation, limiting overall plant growth.[1]]

I have explained why low nutrient soils limit plant growth.[1]

Key science skills and ethical understanding

22 A **23** B

24 **a** [Bioluminescence is a physiological adaptation,[1]] [as it is produced via a chemical reaction.[2]]

I have correctly described the bioluminescence adaptation.[1]

I have used evidence to justify my response.[2]

b [The independent variable is if the traps were baited with bioluminescent ghost fungi or not.[1]] [The dependent variable is how many insects were caught on the sticky trap each night.[2]]

I have identified the independent variable.[1]

I have identified the dependent variable.[2]

c [The ghost fungi-baited sticky traps would have more insects stuck to them than the control group.[1]]

I have suggested the experimenters' hypothesis.[1]

d [The experimenters did not break the ethical principle of integrity.[1]] [The trap with five bugs was an outlier, and the high number of caught insects was likely due to the nearby animal carcass, not the bioluminescent fungi. However, they should mention what data they omitted and why they omitted this data in their paper.[2]]

I have identified if the experimenters broke the ethical principle of integrity.[1]

I have explained my response.[2]

e **i** [The control group caught more bugs than the fungus-baited group.[1]] [Each control group trap caught approximately 0.55 bugs per night on average, whereas the fungus-baited group only caught 0.35 bugs per night on average.[2]]

I have identified the group that caught the most insects.[1]

I have used evidence from the graph to support my answer.[2]

ii [The first theory.[1]] [The fungus-baited traps did not attract more insects than the control group, so bioluminescence is likely not an adaptation to attract insects.[2]]

I have identified the theory refuted by the results.[1]

I have explained why this theory is refuted by the results.[2]

f **i** [Because the experiment ran only in June, any conclusions drawn can only be valid for the month of June. Insect attraction to *O. nidiformisi* may change throughout the year.[1]]

I have described how a short sampling period limits the conclusions of the study.[1]

ii [Running the experiment in all months of the year.[1]]

Other acceptable responses include:

- Increasing the number of trap replicates.
- Using a closely related non-bioluminescent fungus species as a control.

I have suggested an appropriate improvement.[1]

10C Interdependencies between species

Theory review questions

1 A

2 I-size; II-density; III-distribution

3 II; VI

4 V; VI

5 A

6 I; II; III

SAC skills questions

7 C	**8** B	**9** A	**10** C
11 A	**12** B	**13** B	

Exam-style questions

Within lesson

14 B	**15** A	**16** B	**17** D
18 C			

19 **a** **i** [The introduced dogs and cats likely acted as predators, preying on the small mammal species, causing an overall decline in their population size.[1]]

I have suggested that the introduced predators preyed upon the small mammal species.[1]

ii [The introduced dogs and cats likely outcompeted Australia's native predators.[1]][This would reduce the availability of resources for the native predators, causing a decline in population size.[2]]

I have suggested that the introduced predators outcompeted the native predators.[1]

I have explained how this could cause a decline in population size.[2]

b [Interspecific competition.[1]]

I have stated interspecific competition.[1]

Multiple lessons

20 **a** [A species whose effects on an ecosystem is far greater than expected relative to its population size.[1]]

I have correctly defined a keystone species.[1]

b **i** [An environment with a high degree of instability.[1]]

I have described an environment that promotes reproduction via the fusion of gametes.[1]

ii [Independent assortment,[1]][which results in the random assortment of sister chromatids into separate gametes.[2]] [Crossing over,[3]][which describes the exchange of genetic material between homologous chromsomes.[4]]

I have identified the process of independent assortment.[1]

I have described the process of independent assortment.[2]

I have identified the process of crossing over.[3]

I have described the process of crossing over.[4]

I have used key biological terminology such as: independent assortment, assortment, sister chromatids, gametes, crossing over, exchange, genetic material, homologous chromosomes.

Key science skills and ethical understanding

21 **a** [Distribution describes the geographical range of areas that members of a population can be found.[1]]

I have correctly explained the term distribution.[1]

b **i** [Between Jan 2013 and Jan 2014[1]][during which time the population grew from 24 individuals/km^2 to 40 individuals/km^2.[2]]

I have identified the correct one year period.[1]

I have used evidence from the graph to support my answer.[2]

ii [The carrying capacity of the island is approximately 50 individuals/km^2,[1]][as the population remains stable at this point on the graph for many years.[2]]

I have correctly identified the carrying capacity of the island.[1]

I have referred to the graph in my answer.[2]

c **i** [According to the bioethical principle of non-maleficence, the second group's methodology is preferable as the results obtained from their model are achieved without any potential harm[1]] [to the red-necked wallabies that might occur due to the trapping and tagging tactic employed by the first group of scientists.[2]]

I have identified that the second group's methodology is less likely to harm the wallabies.[1]

I have explained that harm may be caused by the first group when trapping and tagging the wallabies.[2]

ii [According to a consequences-based approach to bioethics, the benefits of directly observing the wallabies outweighs the potential harm associated with the trapping and tagging of wallabies.[1]][This is because the results that are obtained will be directly applicable to deciding which islands are suitable to support a population of wallabies.[2]]

I have explained that the benefits of observing the wallabies would outweigh the risks of harm.[1]

I have discussed that this is because the results will be directly applicable in their decision making.[2]

d [The island off the coast of Tasmania may contain more food suitable to red-necked wallabies than mainland Australia.[1]]

Other acceptable responses include:

- The Tasmanian population may be free from invasive or natural predators.
- There may be less competition for resources on the Tasmanian island.
- The climate/geography may be more suitable for red-necked wallabies on the Tasmanian island.
- The effects of disease may be less on the Tasmanian island.

I have suggested a suitable difference between mainland Australia and the Tasmanian island.[1]

10D Indigenous knowledge of the Australian ecosystem

Theory review questions

1 A

2 II; III; IV

3 cultural burning; increase; reduction; fire mosaic

4 mutualistic; digestive tract/system/gut; germinate

SAC skills questions

5 A 6 B 7 A 8 B

9 C 10 B 11 C

Within lesson

12 C

Multiple lessons

13 A 14 B

15 a [A keystone species is a species that has an effect on an ecosystem that is disproportionately large, relative to its population size.[1]]

I have explained what is meant by the term keystone species.[1]

b [An apex predator is a predator that has no natural predators.[1]][It is important to maintain apex predator levels as they are responsible for controlling the numbers of prey in the trophic levels below them, and subsequently the number of organisms in all other trophic levels in an ecosystem.[2]][An ecosystem engineer is a species that creates, alters, or maintains the structure of the physical environment/ecosystem.[3]][It is important to maintain ecosystem engineers as they are critical to the functioning of an ecosystem.[4]]

I have described the role of an apex predator.[1]

I have explained the importance of maintaining apex predators in an ecosystem.[2]

I have described what an ecosystem engineer is.[3]

I have explained the importance of maintaining ecosystem engineers in an ecosystem.[4]

Key science skills and ethical understanding

16 C

17 a [Forest, Prescribed.[1]]

I have identified the correct type of vegetation.[1]

b i [Indigenous fire practises reduce the risk of wildfires occurring by reducing the fuel load in an ecosystem.[1]][Lower levels of greenhouse gasses are emitted in these fires compared to wildfires because they burn fewer plants.[2]]

Other possible responses include:

- Lower levels of greenhouse gases are emitted because they preserve the tree canopy.

I have described one way Indigenous fire management reduces the risk of wildfire.[1]

I have explained how Indigenous fire management results in fires that emit fewer greenhouse gases relative to wildfires.[2]

ii [According to a consequences-based approach to bioethics, actions should only be taken if the outcomes that occur as a result are overall positive or beneficial to people/the environment.[1]][Indigenous fire management reduces the amount of greenhouse gases emitted into the atmosphere relative to wildfires, which is a positive outcome for the environment.[2]]

I have stated what is meant by the term 'consequences-based' approach.[1]

I have explained how a consequences-based approach to ethics could argue in favour of Indigenous fire management using the information provided.[2]

Chapter 10 SAC practice

1 I-insulation; II-evasion; III-evaporative cooling; IV-increased water input; V-evaporative cooling; VI-decreased water output

2 [The spit baths introduce moisture to red kangaroos' skin, so when the saliva evaporates, it removes heat from their bodies.[1]][As there is a large network of blood vessels near the skin, this will effectively cool large amounts of kangaroos' blood.[2]]

I have explained that as the saliva evaporates, it removes heat from kangaroos' bodies.[1]

I have referred to the cooling of the large network of blood vessels near the skin.[2]

3 [Population size.[1]]

I have stated population size.[1]

4 [Commensalism.[1]]

I have stated that the relationship is commensalism.[1]

5 [Mutualism.[1]]

I have stated that the relationship is mutualism.[1]

6 [To remove future fire hazards and control weeds.[1]]

Other acceptable responses include:

- Remove dead plants and other Country healing purposes.
- Clear impassable areas.
- Cultural practices.

I have identified two uses of fire by Indigenous Australians.[1]

7 [Respect.[1]]

Other acceptable responses include:

- Non-maleficence.

I have identified a relevant ethical concept.[1]

8 [Migrating allows animals to travel to warmer areas during the colder seasons.[1]][This can allow animals to enjoy the warmer months in an area while avoiding the harsh colder months,[2]][with the warmer areas also typically being more suitable for breeding and raising young.[3]]

I have described migration.[1]

I have explained that harsher, colder months of an area can be avoided.[2]

I have referenced that warmer areas are typically better for breeding.[3]

9 [Countercurrent circulation techniques use the heat from the blood leaving the heart to warm up the colder blood returning to the heart.[1]] [This ensures that the core body temperature of the whale remains warm and cools the blood that is destined for the peripherals, reducing heat lost to the environment.[2]]

I have described how countercurrent techniques warm the cool blood returning to the heart.[1]

I have explained that this allows for the regulation of the core body temperature and reduces heat loss for the whale.[2]

I have used key biological terminology such as: core body temperature, peripherals, heat loss.

10 [Ecosystem engineer.[1]]

I have stated ecosystem engineer.[1]

11 [Plants can minimise water loss via leaves in arid environments by reducing their stomatal density or by using sunken stomata.[1]] [Additionally, plants can also fold or roll their leaves to reduce water loss.[2]][To decrease heat uptake, plants can produce leaves with a smaller surface area,[3]][leaves that are lightly coloured or reflective,[4]] [or by orienting their leaves vertically.[5]]

I have explained that leaves stomata can be altered to reduce water loss.[1]

I have stated plants can fold or roll their leaves.[2]

I have identified that leaves with a smaller surface area reduce heat uptake.[3]

I have stated that leaves can be lightly coloured.[4]

I have stated that leaves can be oriented vertically.[5]

12 [Freezing point depression occurs when plants increase the concentration of solutes in their cells to decrease the freezing point of water, which helps them increase their resistance to freezing.[1]]

I have explained freezing point depression.[1]

Chapter 10 Exam practice

Section A

1 C **2** A **3** A **4** C

5 D **6** D

Section B

7 **a** [Population distribution.[1]]

I have stated population distribution.[1]

b [Commensalism.[1]]

I have stated that the relationship is commensalism.[1]

c [Justice,[1]][as there is an unfair and unjust distribution of benefits that arose from the discovery and commercialisation of the plant.[2]]

Other acceptable responses include:

- Respect, as the actions do not give proper regard to the cultural heritage of the Indigenous peoples and their beliefs.
- Non-maleficence, as the exploitation of the native ecosystem could introduce unjust harm to Indigenous people, in a commercial, spiritual, or social sense.

I have identified a relevant ethical concept.[1]

I have justified my response.[2]

d **i** [An endotherm is an animal that must produce the majority of its own heat via metabolic processes,[1]][whereas an ectotherm is an animal that obtains most of its heat from the external environment.[2]]

I have described an endothermic animal.[1]

I have described an ectothermic animal.[2]

I have used comparative language such as: whereas.

ii [Producing extremely concentrated urine[1]][and metabolically producing water.[2]]

Other acceptable responses include:

- Producing faeces with low water content.

I have identified an adaption for hot environments that has to do with internal water balance.[1]

I have identified a second adaptation for hot environments that has to do with internal water balance.[2]

iii [Vasodilation of blood vessels involves the blood vessels near the skin dilating, increasing the total blood flow near the surface of the skin. All this warm blood near the surface releases heat into the environment, cooling the animal.[1]]

I have explained that vasodilation of blood vessels near the skin leads to increased heat release from the body to cool the animal down.[1]

8 a [Because the concentration gradient of solutes (e.g. Na^+) between the root and the soil is less steep and the rate of water uptake by osmosis is reduced.[1]]

I have explained why water uptake is reduced in high salt soils.[1]

I have used key biological terminology such as: concentration gradient, osmosis.

b [By increasing the concentration of Na^+ in its roots, there is a greater difference in solute concentration between the root cells and the external environment, increasing the rate of water uptake via osmosis.[1]]

I have explained why *S. repens* increases the concentration of Na^+ in its roots.[1]

I have used key biological terminology such as: concentration gradient, osmosis.

c [Modification to the cell membrane[1]][and seed dormancy.[2]]

Other acceptable responses include:

- Antifreeze proteins.

I have identified one plant adaptation to the cold.[1]

I have identified a second adaptation.[2]

d i [Standard practice is to hypothesise before planning an experiment. An unwillingness to follow standard practice indicates that other aspects of the experiment may have been altered, likely compromising the integrity of the results.[1]]

Other acceptable responses:

- By changing the hypothesis the choices behind the experimental design may be unclear.
- Because the hypothesis is a prediction of how two variables will interact, not an explanation of results.

I have explained why it is bad practice to change a hypothesis after running an experiment.[1]

ii [This measurement is repeatable, as Sam knows how he rated the leaves and his judgement should remain relatively constant.[1]][The measurement is not reproducible, as Sam didn't write down how he measured greenness and other people may rate the greenness of the leaves differently.[2]]

I have explained whether the measurement is repeatable.[1]

I have explained whether the measurement is reproducible.[2]

iii [These salt crystals are salt that has been secreted by the leaves of *S. repens*.[1]][By secreting salt, the concentration of salt inside the plant leaves is reduced, providing a more osmotically balanced and healthy environment for the plant cells.[2]]

I have explained where these salt crystals came from.[1]

I have explained the purpose of these salt crystals.[2]

GLOSSARY

A

abiotic factor a property of the environment relating to non-living things. Examples include temperature, nutrient availability, and water availability p. 443, 461, 477

accurate how close a measurement is to the true value p. 11

active transport the movement of molecules across a semipermeable membrane requiring an energy input p. 103, 113

adenosine triphosphate (ATP) a high energy molecule that, when broken down, provides energy for cellular processes p. 114

adrenal gland collection of endocrine cells located above the kidneys that produce a variety of hormones involved in the stress response, including cortisol, aldosterone, and adrenaline p. 225

aerobic requiring oxygen p. 68

aestivation prolonged torpor in response to hot and dry conditions p. 446

afferent capillary incoming capillaries that deliver blood to the glomeruli of nephrons p. 214

aim the objective of an investigation or experiment p. 5

aldosterone a steroid hormone secreted by the adrenal gland following the release of renin. Aldosterone increases the reabsorption of water from kidney filtrate by increasing the reabsorption of sodium p. 273

algae a large diverse group of photosynthetic protists found in aquatic environments p. 68

allele alternate forms of a gene p. 322, 415

alpha cells cells that occupy the islets of Langerhan and secrete glucagon p. 260, 281

amensalism interactions between two organisms of different species where one organism experiences some negative effect while the other experiences neither a beneficial nor negative effect p. 482

amphipathic describes molecules with both hydrophilic and hydrophobic components. Also known as amphiphilic p. 95

anaerobic requiring no oxygen p. 68

anecdote evidence involving a personal account or report of a previous experience that may provide a certain level of support for a position p. 23

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. 326

angiosperms flowering plants with stems, roots, and leaves p. 417

antidiuretic hormone (ADH) a molecule secreted by the posterior pituitary gland in response to high solute concentrations in the blood. ADH increases the amount of water reabsorbed by the distal convoluted tubule and collecting duct and hence the amount of water conserved by the body. Also known as vasopressin p. 271

anus the opening at the end of the digestive tract that releases faeces p. 203

apex predator a predator that has no natural predators and is at the top of its food chain p. 483

apoptosis the controlled death of cells in the body. Also known as programmed cell death p. 149

apoptotic bodies vesicles containing cell contents that are released from a dying cell during apoptosis and engulfed by phagocytes p. 150

appendix a small sac of tissue that sits at the junction between the small and large intestines p. 203

applied ethics the application of ethical theories to real–life moral problems and contexts p. 34

aquaporin a family of transmembrane proteins facilitating the transport of water into and out of a cell p. 271

arrector pili muscles small muscles attached to hair follicles p. 250

asexual reproduction producing offspring without the fusion of gametes p. 131, 417

autoantibodies proteins created by the immune system that destroy an organism's own tissues p. 281

autoimmune disease a disease in which an individual's immune system initiates an immune response against their own cells p. 281

autosome any chromosome (1-22) that is not a sex chromosome p. 324

B

baroreceptor a type of receptor found throughout the body that detects changes in blood pressure p. 271

behavioural adaptation evolved modifications to an organism's actions p. 443, 461

beneficence an ethical concept that seeks to maximise benefits when taking a particular position or course of action p. 38

benign tumour a tumour that lacks the ability to spread throughout other tissues and organs p. 151

beta cells cells that occupy the islets of Langerhan and secrete insulin p. 260, 281

bias an inclination to favour a particular position or outcome p. 3

binary fission the method of cell replication used by prokaryotes p. 58, 131, 417

biodiversity the variety of life in the world or within a particular habitat p. 477

bioethical approach a decision–making framework that helps guide ethical behaviour p. 34

bioethical issue an ethical dilemma pertaining to biology that typically involves a decision–making process between two or more choices or options for an action p. 34

bioethics the study of ethical issues pertaining to biology and medicine p. 34

biotic factor a property of the environment relating to living things. Examples include predator-prey relationships, competition, and symbiotic relationships p. 443, 461, 477

bladder the hollow muscular organ that receives urine from the kidney and stores it for excretion p. 216

blebbing the bulging of the plasma membrane to form apoptotic bodies p. 150

blood circulatory system the network of blood vessels and the heart that pumps blood around the body p. 178, 224

blood glucose level a measure of the amount of glucose present in the blood. Normal homeostatic mechanisms keep blood glucose levels between 4.0 - 7.8 mmol/L p. 259

blood plasma the liquid component of blood that supports blood cells p. 259

bone marrow semi-solid tissue found within bones. Serves as the primary site of the creation of red blood cells and leukocytes p. 160

Bowman's capsule the first section of the nephron which collects filtered blood from the glomerulus p. 214

brown fat a type of body fat that is activated when the human body experiences low temperatures p. 251

brumation prolonged torpor in response to seasonal cold conditions. Occurs in ectotherms such as snakes and lizards p. 462

budding a type of asexual reproduction where a group of cells form a bud and break away from the original organism to form a clone p. 418

bulk transport a type of active transport that uses vesicles to move large molecules or groups of molecules into or out of the cell. Also known as cytosis p. 113

C

callus a mass of plant cells p. 429

cancer a disease caused by the uncontrolled replication of cells with the ability to migrate to other parts of the body p. 152

capillary action when a liquid, such as water, flows in narrow tubes due to the adhesion of the liquid to the surface of the tube p. 189

carbohydrate a class of biomacromolecules made from monosaccharide monomers consisting of carbon, hydrogen, and oxygen. Also known as saccharides or sugars p. 96, 201, 259

carnivore an animal that almost exclusively eats meat p. 206

carrier an organism that has inherited a copy of a recessive allele for a genetic trait but does not display the trait due to it being masked by the presence of a dominant allele p. 345, 399

carrier protein a membrane-based protein that undergoes conformational change to transport molecules across a membrane p. 103

carrying capacity the maximum population size that an environment can sustain indefinitely p. 477

Casparian strip the impermeable barrier between the root cells and vascular tissue that forces water and solutes travelling by the extracellular pathway into the cytoplasm of cells p. 187

caspase enzymes catalysts that cleave specific intracellular proteins during apoptosis p. 150

categorical variable a factor that is qualitative, typically describing a characteristic such as gender, birth order (1st, 2nd, 3rd), or nationality p. 18

causation when change in one variable leads to reliable change in another p. 23

cell the smallest functional unit of a living organism p. 174, 477

cell plate a component involved in the formation of a cell wall p. 141

cell theory the idea that all living things are made of cells, cells are the smallest functional unit of living things, and all cells come from pre-existing cells p. 57

cell wall a sturdy border outside the plasma membrane that provides strength and structure to plant, bacterial, and fungal cells p. 65

cellular respiration the biochemical process in all living things that converts glucose into ATP. Can be aerobic or anaerobic respiration p. 67

centrioles cylindrical structures composed of protein which form the spindle fibres during mitosis and meiosis p. 141

centromere the structure which holds sister chromatids together p. 139

cerebral cortex the outer layer of the brain that plays a key role in a number of processes including memory, attention, and perception p. 249

chemical digestion the breakdown of food into smaller molecules by digestive enzymes p. 202

chiasma the point/location of overlap between two non-sister chromatids p. 336

chlorophyll a green pigment found in the thylakoids of chloroplasts. It is responsible for absorbing light energy in photosynthesis p. 68

chloroplast the site of photosynthesis p. 68

cholesterol a steroid-alcohol that regulates fluidity in plasma membranes p. 96

chromatid one half of a replicated chromosome. Prior to cell division, chromosomes are duplicated and two copies join together at their centromeres (joined chromatids are known as sister chromatids) p. 139, 323

chromatin chromosomes (DNA and proteins) that have been unwound and loosely packed during interphase p. 139

chromosome a structure composed of DNA tightly wrapped around histone proteins. Carries the genetic information (genes) of a cell p. 138, 323

chromosome condensation the shortening and thickening of chromosomes, as DNA is tightly wrapped around histone proteins p. 141

chyme mixture of partially digested food and digestive juices that passes from the stomach to the small intestine p. 203

cleavage furrow an indentation of the plasma membrane during cytokinesis p. 141

clone a genetically identical organism or section of DNA p. 417, 426

codominance a pattern of dominance where both alleles from the genotype of a heterozygous individual are dominant and expressed in the phenotype of that organism p. 348, 374

collecting duct the final section of the nephron tubule that collects urine and delivers it to the kidney for secretion p. 214

commensalism interactions between two organisms of different species where one gains some benefit while the other experiences no significant benefit or harm p. 481

community a group of interacting populations of different species in the same geographical region p. 477

companion cell the cells of the phloem that ensure sieve cells remain alive and regulate entry into the phloem p. 188

competition interactions between two or more organisms competing for the same pool of resources p. 482

complete dominance a pattern of dominance where only the dominant allele from the genotype of a heterozygous individual is expressed in the phenotype of that organism p. 345

concentration gradient the difference in solute concentration between two adjacent areas p. 103

conduction the transfer of heat through physical contact with another object p. 248

conformational change a change in the three-dimensional shape of macromolecules such as proteins p. 105, 114

connective tissue collection of many different animal cells that connects and supports the other major tissue types p. 177

consanguineous breeding breeding of two individuals that are closely related. Also known as inbreeding p. 396

consequences-based approach an approach to bioethics that aims to maximise positive outcomes while minimising negative outcomes p. 36

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. 8

controlled experiment an investigation into the effect of an independent variable on a dependent variable, while keeping all other factors constant p. 3

controlled variable a factor that is kept constant throughout the experiment. Also known as a constant variable p. 5

convection the transfer of heat via the movement of a liquid or gas between areas of different temperature p. 248

correlation when there is a relationship between two variables p. 23

countercurrent circulation an efficient heat transfer method where separate components of the circulatory system flow next to each other in opposite directions. Used to cool blood heading to the peripherals and heat blood heading back to the body's core p. 464

Country an area that is traditionally owned and looked after by an Aboriginal language group or community, or by certain people within that group. The term may indicate more than simply a geographical area – it is also a concept that can encompass the spiritual meaning and feelings of deep connection and attachment associated with that area p. 4, 494

crenate the distorted shape taken by cells when exposed to a hypertonic environment p. 269

crista (pl. cristae) the folds of the inner membrane of the mitochondria p. 67

crossing over the exchange of genetic material between non-sister chromatids during prophase I of meiosis, resulting in new combinations of alleles in daughter cells p. 336, 386

cytochrome c a protein embedded in the inner mitochondrial membrane p. 150

cytokinesis the division of the cytoplasm and formation of two daughter cells p. 132, 138, 336

cytoplasm the cytosol and organelles inside the plasma membrane, excluding the nucleus p. 64

cytoplasmic pathway the pathway by which roots absorb the majority of nutrients and essential minerals from the soil. Also known as the symplastic route p. 187

cytoskeleton the microscopic web of protein filaments in the cytoplasm. It provides structure and support, and transports products around the cell p. 65, 96

cytosol the aqueous fluid that surrounds the organelles inside a cell p. 58, 64, 103

D

daughter cell the formation of a new cell following cell replication p. 140

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. 150

density-dependent factors environmental factors that affect population growth and become stronger as population density increases p. 479

density-independent factors environmental factors that affect population growth but are not affected by population density p. 479

deoxyribonucleic acid (DNA) 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. 58, 321

dependent variable (DV) the factor/s measured in the experiment that are changed when the IV is manipulated p. 5

dermal tissue collection of cells that form the outer linings of a plant p. 176

desert a geographic area receiving on average less than 250 mm of rain per year p. 443

differentiation the development of a stem cell into a specialised cell with a particular function p. 158

diffusion the passive movement of molecules from areas of high concentration to areas of low concentration (down the concentration gradient) p. 103

digestion the process of breaking down a substance into its basic components p. 202

digestive system the collection of specialised tissues and organs responsible for the digestion of food and absorption of nutrients p. 178, 202

digestive tract the pathway of organs that food and liquids travel through after being swallowed, leading to digestion and elimination. Also known as the gastrointestinal tract or alimentary canal p. 202

dihybrid cross a genetic cross used to observe the inheritance of alleles and phenotypes for two genes p. 383

diploid cells or organisms that have two sets of chromosomes ($2n$) p. 140, 345

distal convoluted tubule the portion of the nephron tubule that lies between the loop of Henle and the collecting duct p. 214

DNA methylation the process by which methyl ($-CH_3$) groups are added to particular nucleotides in a DNA segment so as to modify the expression of a gene p. 358

dominant allele the variant of a gene that masks the effect of a recessive allele of the same gene on a homologous chromosome p. 345

Dreamtime the set of stories and beliefs of some Indigenous Australians, particularly pertaining to the world and its creation p. 496

E

duty- and/or rule-based approach an approach to bioethics that promotes the responsibility of the agent above all else, and places importance on the duty of each individual p. 36

ecology the study of how organisms interact with one another and their environment p. 477

ecosystem multiple communities interacting with one another and their physical environment p. 477

ecosystem engineer an organism that creates, significantly alters, or maintains the structure of an environment p. 483

ectotherm an animal that obtains heat primarily from the environment, rather than its own metabolic heat p. 248, 446

effector a molecule, cell, or organ that responds to a signal and produces a response p. 239

efferent capillary outgoing capillaries that carry blood away from the glomeruli of nephrons p. 214

embryo splitting the division of an early embryo into several individual embryos p. 428

embryonic stem cell a pluripotent stem cell present during the early stages of human development p. 160

emmigration the migration of individuals out of a population p. 478

endocrine system the collection of glands in animals responsible for producing hormones that can be transported in the bloodstream to regulate distant organs/cells p. 224, 283

endocytosis a type of bulk transport that moves large substances into the cell p. 115

endometrium the lining of the uterus p. 284

endosymbiosis when one organism lives inside another in a mutually beneficial relationship p. 69

endosymbiosis theory a theory suggesting that chloroplasts and mitochondria were once free-living organisms before being engulfed by a larger cell p. 69

endotherm an animal that produces the majority of its own heat via metabolic processes p. 248, 446

endurers generally larger animals that do not avoid extreme temperatures p. 448

enucleated a cell that has had its nucleus removed or destroyed p. 427

environment the conditions and resources external to an organism with which that organism typically interacts p. 357

epicormic shoots a fresh growth from a plant that is stimulated to develop after the plant has been damaged p. 494

epidermal cell the plant's outermost cells which separate the plant from the external environment. These cells coat the leaves, fruits, stems, flowers, and roots of a plant. Also known as epidermis p. 194

epigenetics changes to an organism's phenotype resulting from modifications to gene expression p. 358

epithelial tissue one of the basic tissue types in animals that lines the outer surface of organs and blood vessels p. 177, 204

equator the centre line between opposite ends of the cell that the chromosomes line up on during metaphase p. 141

error differences between observed values and the true value p. 3

ethical concept a specific perspective or lens used to consider multiple angles of an ethical dilemma p. 34

ethics a field of knowledge that helps individuals exercise moral judgment and determine what is right and wrong p. 15, 34

eukaryotes a group of single and multi-celled organisms with a nucleus and linear strands of DNA. Animals, plants, fungi, and protists are eukaryotic p. 58

evaders generally smaller animals that modify their behaviours to avoid extreme temperatures and high internal body temperatures p. 448

evaporation the loss of heat via the conversion of water from liquid to gas p. 248, 447

excrete to separate and eliminate waste from the body p. 213

excretory system the collection of organs and tissues that removes excess and waste materials from the body p. 178, 213

exocytosis a type of bulk transport that moves large substances out of the cell p. 115

exophthalmos a symptom of Graves' disease in which the eyes of patients bulge out of their sockets p. 285

experimental group a group of individuals/samples in which the independent variable is manipulated. Also known as the treatment group p. 8

extracellular outside a cell p. 94

extracellular fluid the fluid outside of cells p. 268

extracellular pathway the pathway by which roots absorb the majority of water from the soil. Also known as the apoplastic route p. 187

F

facilitated diffusion a type of passive transport where molecules move through a phospholipid bilayer with the aid of a membrane protein p. 105

fatty acid tail the hydrophobic lipid subunit of a phospholipid p. 95

fertilisation the process by which two gametes (such as sperm and egg cells) fuse and form a zygote p. 416

filter to pass a substance through a porous material p. 213

filtrate the fluid filtered from blood that passes through the nephron p. 213

fire mosaic the pattern created by Indigenous Australian cultural fire management in which some areas of land are burned while others are left to regenerate p. 495

flowers the reproductive organ of angiosperms. Grows into fruit following fertilisation p. 176

fluid mosaic model the theory of how the plasma membrane is structured p. 97

foetus a human embryo after 8 weeks of development p. 160

fragmentation a type of asexual reproduction where a parent organism breaks into fragments, each of which may develop into individual clones p. 418

fruit the seed-bearing structures that are responsible for the protection of developing seeds and seed dispersal p. 176

G

gallbladder bile-storing organ that releases bile into the small intestine p. 203

gametes reproductive cells that arise from germline cells that contain half the genetic material (n) of a somatic cell. In humans, gametes are sperm and eggs p. 58, 334

gene a section of DNA that carries the code to make a protein p. 321, 415

gene expression the process of reading the information stored within a gene to create a functional product, typically a protein p. 358

gene pool the total number of individual alleles within a particular population p. 415

genome the complete set of DNA contained within an organism's chromosomes p. 321

genotype the genetic composition of an organism at one particular gene locus, as represented using letter symbols p. 346

germline cells cells that are involved in the generation of gametes in eukaryotes p. 58, 334

gland a group of cells that secretes chemical substances to regions of the body or discharges them into the surroundings p. 224

glomerulus a network of capillaries that deliver blood to the Bowman's capsule p. 214

glucagon a hormone secreted by alpha cells of the pancreas when blood glucose levels are low p. 260

glucose a six-carbon carbohydrate that comes from the food we eat p. 258

glucose transporter a group of membrane proteins that transport glucose across the plasma membrane p. 259

glycogen a polysaccharide of glucose that stores energy. Serves as the main storage of glucose in the body p. 259

glycogenesis the process of creating glycogen from glucose p. 259

glycogenolysis the process of breaking down glycogen into glucose p. 259

glycolipid a phospholipid bound to a carbohydrate p. 96

glycoprotein a protein bound to a carbohydrate p. 96

goitre a swelling in the neck caused by an enlarged thyroid gland p. 285

Golgi body stacked flattened sacs that are the site of protein sorting, packaging, and modifying. Also known as the Golgi apparatus or Golgi complex p. 65, 115

gonads the organs that produce gametes from germline cells. In humans these are the testes (male) and ovaries (female) p. 334

granum (pl. grana) a stack of thylakoids p. 68

Graves' disease an autoimmune disease that causes hyperthyroidism p. 285

ground tissues an encompassing term for many different plant tissue types, many of which are involved in metabolism and support p. 176

guard cell a pair of curved cells that surround a stoma. When hot they lose turgor pressure and become flaccid, closing the stomata to limit water loss p. 193, 451

H

haploid describes a single set of chromosomes (*n*) p. 322

herbivore an animal that almost exclusively feeds on plant material p. 206

heterotroph an organism that cannot produce its own food and instead gains nutrition by eating plant or animal matter p. 201

heterozygous having different alleles for the same gene on homologous chromosomes p. 345

hibernation prolonged torpor in response to seasonal cold conditions. Occurs in endotherms such as mammals and birds p. 462

histone protein highly basic proteins that associate with DNA inside the nucleus and help it condense into a chromosome allowing it to fit inside the nucleus p. 323

holistic an approach to knowledge that views all things as intimately connected p. 493

homeostasis the maintenance of a relatively stable internal environment in the body despite changes in the external environment p. 57, 239, 260

homologous chromosomes a pair of chromosomes of similar length, gene position, and centromere location. One of the pair is inherited from the mother (maternal chromosome) and the other from the father (paternal chromosome) p. 324

homologue a homologous chromosome p. 324

homozygous having identical alleles for the same gene on homologous chromosomes p. 345

hormone a signalling molecule released from endocrine glands that regulates the growth or activity of target cells p. 178, 223

hydrophilic having a tendency to be attracted to and dissolve in water p. 95, 103

hydrophobic having a tendency to repel from and be insoluble in water p. 95, 103

hyperglycaemia the state of having blood glucose levels above the normal range (>7.8 mmol/L) p. 259, 282

hyperthyroidism overactivity of the thyroid gland, resulting in increased production and secretion of thyroid hormones p. 284

hypertonic describes a solution with a higher solute concentration when compared to another solution p. 106, 269

hypoglycaemia the state of having blood glucose levels below the normal range (<4.0 mmol/L) p. 259, 282

hypothalamus a section of the brain in mammals that controls the maintenance of the body's internal environment p. 225, 250, 271

hypothesis a testable statement that describes how experimenters expect the dependent variable to change as the independent variable changes p. 4

hypothyroidism a condition in which the thyroid gland is underactive, resulting in decreased production and secretion of thyroid hormones p. 286

hypotonic describes a solution with a lower solute concentration when compared to another solution p. 106, 269

I

immigration the migration of individuals into a population p. 478

immune system collection of organs and tissues that provide resistance to and protection from infection and diseases p. 178

in-vitro fertilisation the fertilisation of an egg outside of the body p. 428

incomplete dominance a pattern of dominance where neither allele from the genotype of a heterozygous individual is dominant and both are expressed in an intermediate phenotype p. 348

independent assortment the random orientation of homologous chromosomes along the metaphase plate during metaphase I p. 336, 386

independent variable (IV) the factor/s that is/are manipulated in an experiment p. 5

Indigenous Australian Ways of Knowing a system of knowledge and beliefs cultivated and preserved by Indigenous Australians p. 493

inheritance the genetic transmission of traits from parent to offspring p. 322

insulin a hormone secreted by beta cells of the pancreas when blood glucose levels are elevated p. 260

insulin replacement therapy the injection of insulin to maintain blood glucose levels within normal limits p. 283

integral protein a protein that is permanently secured to the plasma membrane p. 96

integrity an ethical concept that encourages a full commitment to knowledge and understanding as well as the honest reporting of all sources of information and results p. 38

integumentary system the organs and tissues responsible for protecting the body from the external environment p. 178

interphase the first stage of the eukaryotic cell cycle which involves cellular growth and duplication of chromosomes. Composed of three phases: G1, S, and G2 p. 138

interspecific competition the competition for resources between members of different species p. 482

intracellular inside a cell p. 94

intracellular fluid the fluid inside cells p. 269

intraspecific competition the competition for resources between members of the same species p. 482

islets of Langerhans regions of the pancreas that contain cells that secrete hormones p. 260

isotonic describes a solution with the same solute concentration as another solution p. 106, 269

J

justice an ethical concept that encourages fair consideration of competing claims, and ensures that there is no unfair burden on a particular group from an action p. 38

K

karyotype a visual representation of an individual's entire genome organised into homologous pairs p. 324

key science skills (KSSs) the set of capabilities that VCE Biology students must learn to design, conduct, analyse, and report valid experiments p. 3

keystone species a species whose effects on an ecosystem are greater than expected relative to its population size p. 483

kidneys a pair of bean-shaped organs that are responsible for removing waste substances from the blood and the production of urine p. 213

kinetic energy the energy a particle or body possesses due to motion p. 103

L

large intestine the final area of absorption along the digestive tract and the site of faeces production p. 203

leaves the plant organs that are responsible for photosynthesis p. 176

lignified when a cell is strengthened by woody lignin deposits p. 188

linked genes genes that are found closer together on the same chromosome and are likely to be inherited together p. 386

lipid the class of biomacromolecules typically made from fatty acids and glycerol monomers consisting of C, H, and O. Characterised by their nonpolar nature p. 201

liver a large organ found in the abdomen that is involved in many metabolic processes including the breakdown of toxins p. 203, 213

living thing anything that can move, respire, sense, grow, reproduce, maintain equilibrium, excrete waste, and take up nutrients p. 56

locus (pl. loci) the fixed position on a chromosome where a particular gene is located p. 322

loop of Henle a u-shaped loop of the nephron that recovers water and salts from filtrate p. 214

lumen the space within a cavity which can act as a passageway p. 67, 204

lungs a pair of organs situated within the rib cage responsible for the process of oxygenation and excretion of carbon dioxide in humans p. 216

lyse to cause a cell plasma membrane to burst or break p. 107

lysosome a membrane-bound vesicle that contains digestive enzymes. They are responsible for breaking down cell waste p. 65, 116

M

malignant tumour abnormal cells with the ability to invade nearby tissue and migrate to other parts of the body. Also known as cancerous cells p. 151

map units a measure of the distance between two genes on the same chromatid. Genes that are closer together are more likely to be linked genes p. 387

matrix the space inside the inner membrane of the mitochondria p. 67

meiosis a specialised form of cell division used to produce gametes in sexually-reproducing organisms p. 58, 334

membrane-bound organelle structure within a cell that is enclosed by a phospholipid bilayer p. 58, 67

metabolism the set of chemical reactions within cells that help maintain the body's normal functioning including converting food and drink to energy p. 248

metaphase plate the equator of a dividing cell where chromosomes will line up during metaphase p. 336

metastasis the migration of tumour cells from the primary tumour site to distant parts of the body p. 152

metathinking the practice of reflecting upon and evaluating the way we think, including the different strategies and tools for problem-solving and learning p. 34

method the steps followed in a scientific investigation p. 7

methodology the strategy or overarching framework followed in a scientific investigation p. 7

microtubules long tube-like fibre proteins that form part of the cytoskeleton of a eukaryotic cell and help give the cell its structure. Microtubules are used for a variety of cell movements, including transport of cell organelles and the movement of chromosomes during cell division p. 336

microvillus (pl. microvilli) microscopic projections on the surface of cells that increase cellular surface area p. 205

migration the seasonal movement of animals from one area to another p. 465

minerals inorganic compounds that are essential for regular growth and nutrition p. 202

mitochondrial pathway the pathway of apoptosis which is initiated by the detection of internal cellular damage. Also known as the intrinsic pathway p. 150

mitochondrion (pl. mitochondria) the primary site of energy production from aerobic cellular respiration p. 67

mitosis the second stage of the eukaryotic cell cycle, which involves the complete separation of sister chromatids and nuclei p. 58, 138

modulator location where information from receptors is sent to and compared to a set point, and where molecules altering the functioning of an effector are released. Also known as the processing centre p. 239

monohybrid cross a genetic cross performed to observe the inheritance of alleles and phenotypes for a single gene p. 372

monosomy a genetic abnormality where an organism has one missing chromosome p. 326

multipotent stem cells which can differentiate into a limited number of specialised cell types belonging to a specific tissue or organ p. 160

muscle tissue collection of animal cells that are capable of contraction. Includes skeletal, cardiac, and smooth muscle p. 177

muscular system collection of muscle tissues that circulate blood and enable movement p. 178

mutualism interactions between two organisms of different species where both parties experience some overall benefit p. 480, 497

N

negative feedback system a stimulus-response process in which the response counters the stimulus p. 239

nephron a functional unit of the kidney consisting of a glomerulus and tubule system through which filtrate passes and urine is produced p. 214

nervous system the network of nerve tissue that receives, transmits, and responds to stimuli p. 178

nervous tissue collection of animal cells that sense stimuli and initiate responses. Also known as nerve tissue p. 177

non-maleficence an ethical concept that discourages causing harm – or when harm is unavoidable, ensuring that the harm is not disproportionate to the benefits from any position or course of action p. 38

nonpolar describes a molecule without a clearly positive or negative end. These tend to be hydrophobic p. 95, 103

nucleic acid the class of macromolecules that includes DNA and RNA. All nucleic acids are polymers made out of nucleotide monomers p. 321

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. 321

nucleus a double membrane-bound organelle that protects and confines the genetic information (DNA) of a cell. Inside the nucleus is a smaller structure known as the nucleolus which is the site of ribosome production p. 58

numerical variable a factor that is measured as a number such as height, count of population, and age p. 18

O

oesophagus muscular tube lined with mucus that connects the mouth and stomach p. 203

omnivore an animal that eats a variety of food from plants to other animals p. 206

opinion the personal belief or viewpoint of an individual which typically has not been verified as fact p. 3

oral cavity beginning of the digestive tract where food is prepared for the stomach. Also known as the mouth p. 203

organ the combination of tissues and cells into a distinct structure that performs a specific function p. 175

organelle a cellular structure that performs specific functions p. 64

organism a living thing made up of one or more cells p. 57, 174, 477

osmolality the total concentration of solute in a given weight of water p. 269

osmoreceptor a type of receptor found primarily in the hypothalamus that detects changes in osmolality p. 269

osmoregulation the homeostatic regulation of osmolality in the body via the alteration of water and solute balance p. 269

osmosis the passive transport of a solvent (typically water) through a semipermeable membrane from a region of low solute (high solvent) to a region of high solute (low solvent) p. 106, 115, 269

outlier a reading that varies drastically from other results p. 11

ovaries female reproductive organ in which both egg cells and hormones such as oestrogen are produced p. 225

ovum a fully mature female egg cell which, when fertilised, can divide and give rise to an embryo p. 76

P

pancreas an organ of the digestive and endocrine system that releases both digestive juices and hormones, namely insulin and glucagon which regulate blood glucose levels p. 203, 225, 260

parasitism interactions between two organisms of different species where one organism obtains nutrients at the expense of a host organism p. 482

parathyroid gland four small glands in the neck that control the levels of calcium in the body p. 225

parental chromosome a chromosome which contains the same combination of alleles as one of the parents' chromosomes p. 387

parthenogenesis a type of asexual reproduction where an embryo can develop from a single unfertilised gamete p. 418

passive transport the movement of molecules through a semipermeable membrane and down the concentration gradient, without an input of energy p. 103

pedigree chart a diagram showing the expression of a trait over multiple generations p. 395

peripheral protein a protein that is temporarily secured to the plasma membrane p. 96

periphery the outside surface or boundary of a structure. In an animal, the peripherals refer to structures such as the arms, legs, or skin p. 464

peristalsis coordinated muscular contractions and relaxations of the digestive tract wall that move food along the system p. 203

personal error mistakes or miscalculations due to human fault. Can be eliminated by performing the experiment again correctly p. 15

phagocyte a cell of the immune system responsible for engulfing and destroying harmful microorganisms and foreign material p. 151

phagocytosis endocytosis of solid material or food particles p. 117, 151

phenotype the physical or biochemical characteristics of an organism that are the result of gene expression (or set of genes) and the environment p. 322, 345

phloem tissue transports sugars and other nutrients in two directions, to all the cells of the plant p. 186

phosphate head the hydrophilic subunit of a phospholipid p. 94

phospholipid the main molecule of which membranes are composed. They have a phosphate head and two fatty acid tails p. 94

phospholipid bilayer a double layer of amphiphilic molecules that forms the primary component of cell membranes p. 94

photosynthesis the process of converting light energy, carbon dioxide, and water into glucose and oxygen p. 68

photosynthetic organs the macro structures that are the site of photosynthesis in plants, including leaves and photosynthetic branches p. 450

physical digestion the breakdown of food into smaller pieces by processes such as chewing and peristalsis. Also known as mechanical digestion p. 202

physiological adaptation evolved modifications to an organism's internal functioning or metabolic processes p. 443, 461

pineal gland a small gland in the brain which helps regulate sleep patterns p. 225

pinocytosis endocytosis of liquid or dissolved substances p. 117

pituitary gland a gland in the brain that plays a large role in maintaining bodily functions by controlling the activity of several other endocrine glands p. 225, 271

placebo a substance that has no active ingredients or side effects p. 9

placenta an organ that develops during pregnancy and provides oxygen and nutrients to a foetus p. 225

plant cutting the growth of plants using a fragment of the original p. 430

plant grafting the attachment of two individual plant stems together p. 430

plant tissue culturing the cloning of plant cells on a nutrient culture medium in a controlled environment p. 429

plasma membrane the phospholipid bilayer and embedded proteins which separate the intracellular environment from the extracellular environment p. 58, 94, 103

plasmid a small, circular loop of DNA that is separate from a chromosome, typically found in bacteria p. 58, 131

plasmolysed describes plant cells with weak and sagging plasma membranes from water loss p. 107

pluripotent stem cells that can differentiate into multiple cell types p. 160

polar describes a molecule with both a positive end and a negative end. These tend to be hydrophilic p. 95, 103

pollination a form of sexual reproduction in plants that involves the fusing of pollen (male gamete) and ovule (female gamete) and leads to the production of seeds p. 417

polyploidy when an organism contains additional sets of chromosomes in its genome p. 326

population a group of individuals of the same species living in the same location p. 12, 415, 477

population density the number of individuals in a population per unit area p. 479

population distributions the range of geographical areas that members of a population can be found in p. 479

population size the number of individuals in a population p. 477

positive feedback system a stimulus-response process in which the response increases the stimulus p. 239

precise two or more measurements that closely align with each other p. 11

predation interactions between different species where one organism hunts and kills another organism for food p. 481

primary data results collected from experiments, interviews, or surveys undertaken by the researcher p. 17

prokaryotes a group of single-celled organisms with no nucleus and a circular loop of DNA. Bacteria and archaea are both prokaryotic p. 58

proportionate heritability the amount of phenotypic variance that can be explained by genes in a given population p. 357

protein a class of biomacromolecules made of amino acid monomers folded into a 3D shape, consisting of C, H, O, N, and sometimes S p. 96, 202

protein carrier a polypeptide that undergoes a conformational change to transport molecules across a membrane p. 114

protein channel a membrane-based protein pore in a phospholipid bilayer that selectively enables transport of large or polar molecules p. 105

protein pump a polypeptide that transports molecules across a membrane against its concentration gradient with the aid of ATP p. 114

protein-mediated active transport a type of active transport which involves using membrane proteins to move molecules across a membrane against their concentration gradient. Also known as active transport p. 113

proximal convoluted tubule the portion of the nephron tubule that lies between the Bowman's capsule and the loop of Henle p. 214

Punnett square a square diagram used to predict the genotypes of offspring p. 373

pyrophilic a plant for which fire is a necessary part of its life cycle p. 494

Q

quiescent dormant cells which can re-enter the cell cycle p. 139

R

radiation the transfer of heat via waves of light p. 249

random error variation in results caused by uncontrollable conditions between replicates, resulting in a less precise spread of readings. Can be reduced using more replicates or refining the measurement process p. 11

ratio a comparison between two things to show proportions p. 79

raw data results that have not been processed, manipulated, or formatted for use p. 17

reabsorb to absorb a substance that has undergone filtration p. 213

receptor a structure that detects a signal or external change, usually a protein p. 224, 239

recessive allele the variant of a gene that is masked by a dominant allele on a homologous chromosome p. 345

recombinant chromosome a chromosome which is not identical to one of the homologous chromosomes in a diploid cell p. 387

rectum the final section of the large intestine that delivers faeces to the anus p. 203

red blood cells cells that transport oxygen through the bloodstream and do not contain a nucleus p. 76

reliable describes an experiment, tool, or measurement that produces similar results when repeated and reproduced p. 3

renal arteries arteries that deliver blood from the heart to the kidneys p. 213

renin an enzyme secreted by the kidneys in response to low blood pressure and volume. Renin initiates a process which increases the reabsorption of water and sodium, and increases the excretion of potassium in the distal convoluted tubule and collecting duct p. 271

repeatable an experiment/measurement in which scientists, using the methods they designed, can obtain the same result multiple times p. 8

replicates multiple measurements that are exposed to the same level of the IV, are very close in value, and are close to the 'true' value of the quantity being measured p. 11

replication the process of running your test/experiment multiple times p. 10

representitive a sample that accurately reflects the characteristics of the larger population p. 12

reproducible an experiment/measurement in which a group of scientists, using methods designed by others, can obtain the same results as another group's experiment p. 8

reproductive cloning technologies artificially induced human interventions to produce genetically identical clones p. 426

reproductive strategies adaptations to reproduction that improve the success of survival of a species p. 416

reproductive system the sex organs responsible for sexual reproduction p. 178

research question a testable, achievable, and specific question that an investigation sets out to answer p. 4

respect an ethical concept that encourages the acknowledgment of the intrinsic value of living things, and considers the welfare, beliefs, customs, and cultural heritage of both the individual and the collective p. 38

respiratory system the organ system that allows an organism to breathe and exchange gases with the external environment p. 178

response the action of a cell, organ, or organism caused by a stimulus p. 239

ribosomal RNA (rRNA) a type of nucleic acid that is a key structural component of ribosomes p. 67

ribosomes small RNA-protein structures that are the site of protein synthesis. They either float freely in the cytoplasm or are attached to the RER p. 58, 115

root hair cell a cell with lateral hair-like extensions that absorbs water and nutrients from the soil into the root p. 187

root system organ system in plants that is responsible for providing support to the plant and water and nutrient absorption from soil p. 176, 186

roots the plant organ embedded in the ground. Absorbs water and nutrients from soil, and provides support for the plant p. 176

rootstock the lower stem of a plant with a well-developed root system p. 430

rough endoplasmic reticulum (RER) a membranous chain of connected and flattened sacs which are coated with ribosomes on their outer surface that synthesise and modify proteins p. 65, 115

S

salivary glands collection of cells that produce saliva and secrete it into the oral cavity p. 203

sample a subset of the larger population being studied p. 12

saturated a fatty acid chain with only single bonds between carbon atoms p. 97

scion the upper stem of a plant used in grafting p. 430

secondary data results from sources other than the researcher's own investigations p. 17

secrete to discharge a useful (non-waste) substance from a cell or tissue p. 213

secretory products the substances inside a vesicle that are being transported out of the cell p. 115

selective permeability a property of plasma membranes that ensures only specific substances pass across them. Also known as semipermeable p. 94, 103

septum a dividing wall formed during binary fission p. 132

sex chromosome a chromosome responsible for determining the gender of an organism. In humans, sex chromosomes can be either an X or Y chromosome p. 324

sex-linked genes genes that are located on a sex chromosome p. 349

sexual reproduction the fusion of two distinct haploid gametes to produce a single diploid zygote composed of two sets of chromosomes p. 416

shoot system organ system in plants made up of reproductive organs, stems, and leaves p. 176, 186

sieve cell the living hollow tubes of the phloem which stack end-to-end p. 188

sieve plates the porous plates separating adjacent sieve cells p. 188

signalling molecule a molecule which can interact with and initiate a response in a target cell p. 223

sink a tissue of a plant where substances are stored p. 192

sister chromatids the two identical halves of a chromosome p. 138

skeletal muscle a type of muscle that is voluntarily controlled and that is usually attached to bones p. 240

skeletal system the organ system comprised of bone and cartilage that supports the body and muscular system to enable movement p. 178

skin the thin layer of tissue covering the outer region of the body of vertebrates p. 216

small intestine connects the stomach to the large intestine and is a major site of nutrient absorption during digestion p. 203

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. 65

solute a substance dissolved in the solvent p. 103, 269

solvent a liquid in which a solute is dissolved, forming a solution p. 103

somatic cell any cell that is not a reproductive cell (such as sperm and egg cells). Somatic cells are diploid ($2n$), meaning they contain two sets of chromosomes - one inherited from each parent p. 58, 140, 323

somatic cell nuclear transfer (SCNT) the transference of a somatic cell nucleus into an enucleated egg cell p. 426

somatically heritable genetic traits or alterations to a cell which are inherited by daughter cells during the course of regular mitotic cell division p. 359

source a tissue of a plant where substances are produced or enter the plant p. 192

specialised cells which serve a unique, particular function p. 158, 174

spindle fibres structures which aid in the movement of chromosomes to either pole of the cell during mitosis and meiosis p. 141

spores small haploid units used as a means of asexual reproduction in sporogenesis p. 418

sporogenesis a type of asexual reproduction where spores form on the surface of the organism and are dispersed into the surroundings where they may develop into individual clones of the original p. 418

stem the main body of the plant that provides support and connects the whole plant p. 176

stem cell undifferentiated cells with the capability of differentiating into specialised cells p. 158

sterile surgically clean and free from contamination by microorganisms. Also known as aseptic p. 16

stimulus (pl. stimuli) an event or molecule that can initiate a response p. 239

stimulus-response model a model that describes how a system responds to a stimulus p. 239

stoma (pl. stomata) small pores on the leaf's surface that open and close to regulate gas exchange p. 189, 451

stomach a muscular organ that receives food from the oesophagus and temporarily stores it, where it is broken down by stomach acids and peristaltic movements p. 203

stomatal pore the opening in the centre of a turgid stoma, where gases freely enter or exit a leaf p. 193

stroma the fluid substance that makes up the interior of chloroplasts p. 68

structural adaptation evolved modifications to an organism's physical structure p. 443, 461

surface area the sum of the area of all exposed sides of a three-dimensional shape. Measured in (units of length)^2 (i.e. mm^2, cm^2, m^2) p. 77

surface area : volume ratio (SA:V) a comparison of the amount of surface area per unit of volume. In Biology, SA:V influences temperature regulation, and a high SA:V leads to more effective transport into and out of cells p. 79, 445

symbiosis an interaction between two organisms of different species living in close proximity to each other p. 480

system a collection of organs and tissues that perform specific functions necessary for survival p. 175

systematic error errors which cause results to differ by a consistent amount each time, typically due to faulty equipment or calibration, resulting in a less accurate result. Can be reduced by calibrating and maintaining instruments p. 15

T

target cell a cell that will receive and respond to a specific signalling molecule p. 224

terminally differentiated cells that have fully specialised and no longer replicate p. 139

test cross when an individual expressing the dominant phenotype but with an unknown genotype is crossed with a homozygous recessive individual. The results indicate whether the individual with the dominant phenotype is homozygous dominant or heterozygous p. 376

testes male reproductive organ in which both sperm cells and hormones such as testosterone are produced p. 225

tetrasomy a genetic abnormality where an organism has two extra chromosomes p. 326

thermoregulation the homeostatic process of maintaining a constant internal body temperature p. 248, 443

thylakoid a flattened sac-like structure inside the chloroplast p. 68

thymus a gland found between the lungs that plays a role in the body's endocrine and immune systems p. 225

thyroid gland a butterfly-shaped gland in the neck that produces hormones that influence metabolic rate p. 225, 283

thyroid-stimulating hormone a hormone released by the anterior pituitary gland that stimulates the thyroid gland. Also known as TSH p. 284

thyroid-stimulating immunoglobulin the antibody present in Graves' disease that is responsible for overstimulation of the thyroid gland. Also known as TSI p. 285

thyrotropin-releasing hormone a hormone released by the hypothalamus that stimulates the anterior pituitary gland. Also known as TRH p. 284

thyroxine a hormone produced and secreted by the thyroid gland. Also known as T4 p. 283

tissue a cluster of cells which perform a shared function p. 175

tolerance range the range of environmental conditions in which an organism can survive p. 443

tonicity a measure of the relative concentration of solutes on either side of a semipermeable membrane, described as hypertonic, hypotonic, or isotonic p. 106

torpor a physiological state in which the metabolism of an animal is reduced to conserve energy p. 446, 462

totipotent stem cells which can differentiate into any cell type p. 160

tracheid the smaller elements of the xylem whose endings overlap with one another p. 188

transcription the process whereby a sequence of DNA is used to produce a complementary sequence of mRNA p. 358

transduction the series of events that occur after the reception of a signal which results in the generation of a response p. 242

transformed data results that have been converted from their raw format into a more visually comprehensible format that is easier to analyse p. 17

translation the process whereby an mRNA sequence is used to produce a protein p. 358

translocation the movement of substances from a source to other tissues in the plant via the phloem. Also known as source and sink p. 192

transmembrane protein an integral protein that spans from the intracellular to the extracellular side of the plasma membrane p. 96

transpiration the evaporation of water from leaves and movement of liquids up the xylem p. 189

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. 20

triiodothyronine a hormone produced and secreted by the thyroid gland. Also known as T3 p. 283

trisomy a genetic abnormality where an organism has one extra chromosome p. 326

true value the value that would be obtained by a perfect measurement without the influence of errors p. 11

tumour a mass of abnormal cells p. 151

turgid describes plant cells that are swollen and firm from water uptake p. 106

type 1 diabetes an autoimmune disease in which beta cells of the pancreas are destroyed, resulting in an inability to regulate blood glucose levels p. 280

type 2 diabetes a disease in which the body becomes resistant to the effects of insulin and/or doesn't produce enough insulin to maintain normal blood glucose levels p. 281

U

unbiased a sample or measurement that is unaffected by a scientist's expectations p. 12

uncertainty a quantification of the error associated with a measurement, often represented by the symbol '$\pm$' after a reading p. 15

uncontrolled variable a factor that is not kept constant or accounted for throughout the experiment. Also known as an extraneous variable p. 5

unlinked genes genes located on different chromosomes, or far apart on the same chromosome. Unlinked genes have less chance of being inherited together p. 383

unsaturated a fatty acid chain with at least one double or triple bond between carbon atoms p. 97

urea the main nitrogenous product of protein breakdown in mammals. Excreted in urine p. 213

ureter the tube through which urine passes from the kidney to the bladder p. 216

urethra the duct through which urine is excreted from the bladder and out of the body p. 216

urinary tract the series of channels in which urine is produced and excreted from the body p. 213

urine a fluid formed by the kidneys and stored in the bladder. One of the body's major ways to remove excess water, solutes, and waste substances from the blood p. 213

V

vacuole a membrane-bound sac that is used for water and solute storage. It can also play a role in maintaining plant cell structure p. 65

valid a measurement or experiment that actually tests what it claims to be testing p. 8

vascular bundles the close arrangement of xylem and phloem tissues p. 186

vascular plants a group of plants that contain vascular tissues p. 186

vascular tissues conducting tissues that transport water and nutrients within the plant. An encompassing term for the xylem tissue and phloem tissue p. 175, 186

vasoconstriction the narrowing of blood vessels p. 250, 463

vasodilation the widening of blood vessels p. 250, 446

vegetative propagation a type of asexual reproduction where a plant grows from fragments, such as stem or root cuttings, of its parents p. 418

vesicle a small membrane-bound sac that transports substances into, out of, and around a cell, or stores substances within a cell p. 65, 115

vessel element the larger components of the xylem which stack end-to-end p. 188

villus (pl. villi) finger-like projections from the surface of membranous structures to increase the surface area p. 205

virtues-based approach an approach to bioethics that emphasises the individual goodness of the agent, and promotes acting in accordance with the values of a 'moral' person, such as honesty and compassion p. 36

vitamins organic compounds that the body requires in small amounts and which perform a variety of functions p. 202

volume the amount of space inside an object. Measured in (units of length)^3 (i.e. mm^3, cm^3, m^3) p. 77

X

X-linked traits a trait controlled by a gene that is located on the X chromosome p. 349

xylem tissue transports water and minerals in one direction, from the roots to the leaves p. 186

Y

Y-linked traits a trait controlled by a gene that is located on the Y chromosome p. 349

Z

zygote the diploid cell formed by the combination of two haploid gamete cells p. 160, 334, 416

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RNDr. Josef Reischig, CSc. **p. 141**, 144, Table 1 / Question 7/https://commons.wikimedia.org/wiki/File:Mitosis_(261_09)_Pressed;_root_meristem_of_Vicia_faba_(cells_in_telophase).jpg/Doc. RNDr. Josef Reischig, CSc. **p. 141**, 144, Table 1 / Question 7/https://upload.wikimedia.org/wikipedia/commons/b/b4/Mitosis_%28261_03%29_Pressed%3B_root_meristem_of_Vicia_faba_%28cells_in_prophase%2C_metaphase%29.jpg/Doc. RNDr. Josef Reischig, CSc. **p. 141**, 144, Questions 11–17/https://commons.wikimedia.org/w/index.php?search=telomere&title=Special%3ASearch&go=Go&ns0=1&ns6=1&ns12=1&ns14=1&ns100=1&ns106=1#/media/File:Telomere_caps.PNG/U.S. Department of Energy Human Genome Program **p. 145**, Question 20/https://commons.wikimedia.org/wiki/File:Glucose-day-english.svg/Jakob Suckale, Michele Solimena **p. 266**, Figure 6/https://commons.wikimedia.org/wiki/File:Drosophila_Gene_Linkage_Map.svg/Twaanders17 **p. 387**, Figure 4/https://commons.wikimedia.org/wiki/File:X-ray(Chest)Cancer.jpg/Unknown author **p. 152**, Question 8/https://www.vcaa.vic.edu.au/Documents/exams/biology/2008biol2-w.pdf/VCAA **p. 170**, Figure 14/https://commons.wikimedia.org/wiki/File:Neck_of_girl_with_Turner_Syndrome_%28before_and_after%29.jpg/Johannes Nielsen **p. 326**, Question 16/https://commons.wikimedia.org/wiki/File:45,X.jpg/The cat **p. 332**, Figure 7//Tnarg 12345 **p. 446**, Figure 9//Kristian Bell **p. 447**, Figure 10//horsemen **p. 448**, Figure 11/https://unsplash.com/photos/eeFz8HHvZQI/YIFEI CHEN **p. 448**, Figure 14/https://commons.wikimedia.org/wiki/File:Saltbush_at_Bundey.JPG/Scott Davis **p. 450**, Figure 15/https://commons.wikimedia.org/wiki/File:Allocasuarina_decaisneana_juvenile.jpg/Mark Marathon **p. 450**, Figure 18/https://commons.wikimedia.org/wiki/File:Gymnosperm_Leaves_Stomatal_Pits_in_Single_Needled_Pinus_(36445776096).jpg/Berkshire Community College Bioscience Image Library **p. 451**, Figure 19/https://commons.wikimedia.org/wiki/File:European_Marram_Grass_(Ammophila_arenaria)_rolled_leaf_close-up.jpg/domdomegg **p. 451**, Figure 11/https://commons.wikimedia.org/wiki/File:Treeline_In_The_Tararuas.JPG/William Demchick **p. 466**, Figure 12/https://commons.wikimedia.org/wiki/File:Field_beside_the_Caddon_Water_-_geograph.org.uk_-_913930.jpg/Richard Webb **p. 466**, Figure 15/https://commons.wikimedia.org/wiki/File:Alpine_Cushion_Plant.jpg, https://commons.wikimedia.org/wiki/File:Cushion_Plants_-_Flickr_-_brewbooks.jpg/Javier A-Mon, brewbooks **p. 468**, Figure 16/https://commons.wikimedia.org/wiki/File:Nototheniidae_-_Trematomus_bernacchii.JPG/Hectonichus **p. 468**, Question 6–14/https://commons.wikimedia.org/wiki/File:View_from_Mount_Kosciuszko_Summit_to_the_north.jpg/Pimlico27 **p. 471**, Question 6–14/https://commons.wikimedia.org/wiki/File:Thredbo_as_seen_from_Kosciuszko_Lookout.jpg/Cimexus **p. 471**, Hook/https://commons.wikimedia.org/wiki/File:Rheobatrachus_silus.jpg/Benjamin Healley **p. 426**, Figure 6/https://commons.wikimedia.org/wiki/File:Panama_disease_Banana_2.jpg/Scot Nelso **p. 431**, Question 7/https://commons.wikimedia.org/wiki/File:Zweij%C3%A4hrige-Gei%C3%9Ffu%C3%9Fveredelu.jpg/Kobako **p. 433**, SAC Practice/https://commons.wikimedia.org/wiki/File:Starr-090810-4149-Citrullus_lanatus-Sugarland_seedless_Oahu_variety-Olinda-Maui_(24341411814).jpg/Forest and Kim Starr **p. 438**, Question 5/https://www.vcaa.vic.edu.au/Documents/exams/biology/2010biology2-w.pdf/VCAA **p. 439**, Figure 12/https://commons.wikimedia.org/wiki/File:Tomato_Hornworm_5.JPG/Max Wahrhaftig **p. 482**, Figure 16/https://commons.wikimedia.org/w/index.php?search=greater+bilby&title=Special:Search&go=Go&ns0=1&ns6=1&ns12=1&ns14=1&ns100=1&ns106=1#/media/File:Greater_Bilby_(Macrotis_lagotis)_(9996143106).jpg/Bernard DUPONT **p. 483**, Table 2/https://commons.wikimedia.org/wiki/File:Sea-otter-morro-bay_13.jpg/Mike Baird from Morro Bay, USA (bairdphotos.com) **p. 484**, Table 2/https://commons.wikimedia.org/w/index.php?search=termite+mound&title=Special%3ASearch&go=Go&ns0=1&ns6=1&ns12=1&ns14=1&ns100=1&ns106=1#/media/File:Litchfield_National_Park_(AU),_Magnetic_Termite_Mounds_--_2019_--_3732.jpg/Dietmar Rabich **p. 484**, 7.3 Figure 1/http://pipeline.lbl.gov/cgi-bin/gateway2 /Frazer et al., 2004 **p. 552**, 7.3 Figure 2/http://pipeline.lbl.gov/cgi-bin/gateway2 /Frazer et al., 2004 **p. 553**, 7.3 Figure 3/http://pipeline.lbl.gov/cgi-bin/gateway2 /Frazer et al., 2004 **p. 553**, 7.3 Figure 4/http://pipeline.lbl.gov/cgi-bin/gateway2 /Frazer et al., 2004 **p. 553**, 7.3 Figure 5/http://pipeline.lbl.gov/cgi-bin/gateway2 /Frazer et al., 2004 **p. 553**, Figure 2/No longer exists/Designua **p. 269**, Question 16/https://www.vcaa.vic.edu.au/Documents/exams/biology/2004biol1.pdf/VCAA **p. 278**, Question 17/https://www.vcaa.vic.edu.au/Documents/exams/biology/2004biol1.pdf/VCAA **p. 278**, Question 18/https://www.vcaa.vic.edu.au/Documents/exams/biology/2016/2016biology-w.pdf/VCAA **p. 279**, Question 18/https://www.vcaa.vic.edu.au/Documents/exams/biology/2016/2016biology-w.pdf/VCAA **p. 279**

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Australian Curriculum, Assessment and Reporting Authority (n.d.), Teacher background information- Classification helps organise the diverse group of organisms. https://australiancurriculum.edu.au/TeacherBackgroundInfo?id=56826

Australian Institute of Health and Wellbeing. (2019). Cancer data in Australia. Retrieved from https://www.aihw.gov.au/reports/cancer/cancer-data-in-australia/contents/summary

Baird, A. H., Pratchett, M. S., Hoey, A. S., Herdiana, Y., & Campbell, S. J. (2013). *Acanthaster planci* is a major cause of coral mortality in Indonesia. Coral reefs, 32(3), 803-812.

Baker, D. J., Childs, B. G., Durik, M., Wijers, M. E., Sieben, C. J., Zhong, J., Saltness, R., Jeganathan, K. B., Versoza, G. C., Pezeshki, A., Khazaie, K., Miller, J. D., & van Deursen, J. (2016). Naturally occurring p16Ink4a-positive cells shorten healthy lifespan. Nature, 530 (7589), 184-189.

Bero, L., Oostvogel, F., Bacchetti, P., & Lee, K. (2007). Factors Associated with Findings of Published Trials of Drug–Drug Comparisons: Why Some Statins Appear More Efficacious than Others. Plos Medicine, 4(6), e184. doi: 10.1371/journal.pmed.0040184

Birkeland, C. (1982). Terrestrial runoff as a cause of outbreaks of *Acanthaster planci* (Echinodermata: Asteroidea). Marine Biology, 69(2), 175-185.

Bonhommeau, S., Dubroca, L., Le Pape, O., Barde, J., Kaplan, D. M., Chassot, E., & Nieblas, A. E. (2013). Eating up the world's food web and the human trophic level. Proceedings of the National Academy of Sciences, 110(51), 20617-20620.

Boulay, R., Aron, S., Cerdá, X., Doums, C., Graham, P., Hefetz, A., & Monnin, T. (2017). Social life in arid environments: the case study of Cataglyphis ants. Annual Review of Entomology, 62, 305-321.

Bray, F., Ferlay, J., Soerjomataram, I., Siegel, R. L., Torre, L. A., & Jemal, A. (2018). Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA: a cancer journal for clinicians, 68(6), 394-424.

Brick, K., Thibault-Sennett, S., Smagulova, F., Lam, K., Pu, Y., & Pratto, F. et al. (2018). Extensive sex differences at the initiation of genetic recombination. Nature, 561(7723), 338-342. doi: 10.1038/s41586-018-0492-5

Bringslimark, T., Hartig, T., & Patil, G. G. (2007). Psychological benefits of indoor plants in workplaces: putting experimental results into context. American Society for Horticultural Science, 42(3), 581-587.

Brodie, J., Fabricius, K., De'ath, G., & Okaji, K. (2005). Are increased nutrient inputs responsible for more outbreaks of crown-of-thorns starfish? An appraisal of the evidence. Marine pollution bulletin, 51(1-4), 266-278.

Bruno, J. F., & Selig, E. R. (2007). Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons. PLoS One, 2(8), e711.

Cancer Research UK. (2020). Acute myeloid leukaemia (AML) incidence statistics. Retrieved from https://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/leukaemia-aml/incidence

Cipriani, A., Furukawa, T. A., Salanti, G., Chaimani, A., Atkinson, L. Z., Ogawa, Y., Leucht, S., Ruhe, H. G., Turner, E. H., Higgins, J. P. T., Egger, M., Takeshima, N., Hayasaka, Y., Imai, H., Shinohara, K., Tajika, A., Ioannidis, J. P. A., & Geddes, J. R. (2018). Comparative efficacy and acceptability of 21 antidepressant drugs for the acute treatment of adults with major depressive disorder: a systematic review and network meta-analysis. The Lancet, 391(10128), 1357–1366. https://doi.org/10.1016/s0140-6736(17)32802-7

Comanns, P., Withers, P. C., Esser, F. J., & Baumgartner, W. (2016). Cutaneous water collection by a moisture-harvesting lizard, the thorny devil (Moloch horridus). Journal of Experimental Biology, 219(21), 3473-3479

Dadonaite, B., Roser, M. (2019). Pneumonia. Retrieved from https://ourworldindata.org/pneumonia

Department of Agriculture, Water and the Environment. (2020). Feral cats. Retrieved from https://www.environment.gov.au/biodiversity/invasive-species/feral-animals-australia/feral-cats

Duss, S., André, S., Nicoulaz, A. L., Fiche, M., Bonnefoi, H., Brisken, C., & Iggo, R. D. (2007). An oestrogen-dependent model of breast cancer created by transformation of normal human mammary epithelial cells. Breast Cancer Research, 9(3), R38.

Fischer, J., & Lindenmayer, D. B. (2000). An assessment of the published results of animal relocations. Biological Conservation, 96(1), 1-11.

Gowaty, P. (1997). Feminism and evolutionary biology. New York: Chapman & Hall.

Haworth, C. M., Carnell, S., Meaburn, E. L., Davis, O. S., Plomin, R., & Wardle, J. (2008). Increasing heritability of BMI and stronger associations with the FTO gene over childhood. Obesity (Silver Spring, Md.), 16(12), 2663–2668.

Healthdirect. (2018). Infertility. Retrieved from https://www.healthdirect.gov.au/infertility

Jack, S., Madhivanan, K., Ramadesikan, S., Subramanian, S., Edwards, D. F., II, Elzey, B. D., … Aguilar, R. C. (2019). A novel, safe, fast and efficient treatment for Her2-positive and negative bladder cancer utilizing an EGF-anthrax toxin chimera. International Journal of Cancer, 146(2), 449–460. doi:10.1002/ijc.32719

Kirsch, I. (2019). Placebo Effect in the Treatment of Depression and Anxiety. Frontiers in Psychiatry, 10, 407.

Koch, G. W., Sillett, S. C., Jennings, G. M., & Davis, S. D. (2004). The limits to tree height. Nature, 428, 851-854.

Krapohl, E., Rimfeld, K., Shakeshaft, N., Trzaskowski, M., McMillan, A., & Pingault, J., Asbury, K., Harlaar, N., Kovas, Y., Dales, P. S., & Plomin, R. (2014). The high heritability of educational achievement reflects many genetically influenced traits, not just intelligence. Proceedings Of The National Academy Of Sciences, 111(42), 15273-15278.

Krebs, C. J., Boonstra, R., Boutin, S., & Sinclair, A. R. (2001). What Drives the 10-year Cycle of Snowshoe Hares? The ten-year cycle of snowshoe hares—one of the most striking features of the boreal forest—is a product of the interaction between predation and food supplies, as large-scale experiments in the yukon have demonstrated. BioScience, 51, 25-35.

Kwisda, K., White, L., & Hübner, D. (2020). Ethical arguments concerning human-animal chimera research: a systematic review. BMC Medical Ethics, 21(1).

Larsen, L., Adams, J., Deal, B., Kweon, B. S., & Tyler, E. (1998). Plants in the workplace: the effects of plant density on productivity, attitudes, and perceptions. Environment and Behaviour, 30(3), 261-281.

Liu, R., How-Kit, A., Stammitti, L., Teyssier, E., Rolin, D., Mortain-Bertrand, A., Halle, S., Liu, M., Kong, J., Wu, C., Degraeve-Guibault, C., Chapman, N. H., Maucourt, M., Hodgman, T. C., Tost, J., Bouzayen, M., Hong, Y., Seymour, G. B., Giovannoni, J. J., & Gallusci, P. (2015). A DEMETER-like DNA demethylase governs tomato fruit ripening. Proceedings of the National Academy of Sciences of the United States of America, 112(34)

Liu, Z., Cai, Y., Liao, Z., Xu, Y., Wang, Y., Wang, Z., Jiang, X., Li, Y., Lu, Y., Nie, Y., Zhang, X., Li, C., Bian, X., Poo, M., Chang, H.-C., & Sun, Q. (2019). Cloning of a gene-edited macaque monkey by somatic cell nuclear transfer. National Science Review, 6(1), 101–108. https://doi.org/10.1093/nsr/nwz003

Lyninger, H. S. (2019). Genetic Counseling for Transgender Patients: Perspectives on Terminology, Disclosure of Transgender Status, and Proposed Pedigree Nomenclature. UC Irvine. ProQuest ID: Lyninger_uci_0030M_15765. Merritt ID: ark:/13030/m5dc33jf. Retrieved from https://escholarship.org/uc/item/8mm7f57j

Ma, C. X., Sanchez, C. G., & Ellis, M. J. (2009). Predicting endocrine therapy responsiveness in breast cancer. Oncology, 23(2).

Meyer, C., Beer, T., Müller, J., Gillett, R., Weeks, I., Powell, J., Tolhurst, K., McCaw, L., Cook, G., Marney, D., & R. Symons. (224). Dioxin emissions from bushfires in Australia. National Dioxide Program Technical Report No. 1, Australian Government Department of the Environment and Heritage, Canberra.

Moore, D., Stow, A., & Kearney, M. R. (2018). Under the weather?—The direct effects of climate warming on a threatened desert lizard are mediated by their activity phase and burrow system. Journal of animal ecology, 87(3), 660-671.

Moran, P. J. & De'Ath, G. (1992). Estimates of the abundance of the crown-of-throns starfish *Acanthaster planci* in outbreaking and non-outbreaking populations on reefs within the Great Barrier Reef. Marine Biology, 113(3), 509-515.

NIDA. (2020, June 9). How Does Drug Abuse Affect the HIV Epidemic?. National Institutes of Health. https://www.drugabuse.gov/publications/research-reports/hivaids/how-does-drug-abuse-affect-hiv-epidemic

Piel, F. B., Hay, S. I., Gupta, S., Weatherall, D. J., & Williams, T. N. (2013). Global burden of sickle cell anaemia in children under five, 2010–2050: modelling based on demographics, excess mortality, and interventions. PLoS medicine, 10(7). doi:10.1371/journal.pmed.1001484

Qiu, P., Jiang, J., Liu, Z., Cai, Y., Huang, T., Wang, Y., … Chang, H.-C. (2019). *BMAL1* knockout macaque monkeys display reduced sleep and psychiatric disorders. National Science Review, 6(1), 87–100. https://doi.org/10.1093/nsr/nwz002

Ruseckaite, R., Ahern, A., Ranger, T., Dean, J., Gardam, M., Bell, S., Burke, N. (2017). The Australian Cystic Fibrosis Data Registry Annual Report, 2017. Monash University, Department of Epidemiology and Preventive Medicine, March 2019, Report No 20.

Sapirstein, G., & Kirsch, I. (1998). Listening to Prozac but hearing placebo: A meta-analysis of antidepressant medication. Prevention & Treatment, 1, np. https://doi.org/10.1037//1522-3736.1.0002a

Smit, B., Whitfield, M. C., Talbot, W. A., Gerson, A. R., McKechnie, A. E., & Wolf, B. O. (2018). Avian thermoregulation in the heat: phylogenetic variation among avian orders in evaporative cooling capacity and heat tolerance. Journal of Experimental Biology, 221(6).

Smith-Woolley, E., Ayorech, Z., Dale, P., von Stumm, S., & Plomin, R. (2018). The genetics of university success. Scientific Reports, 8.

Sofou, K., De Coo, I. F. M., Isohanni, P., Ostergaard, E., Naess, K., De Meirleir, L., … Darin, N. (2014). A multicenter study on Leigh syndrome: disease course and predictors of survival. Orphanet Journal of Rare Diseases 9, 52.

Terio, K.A., Marker, L., & Munson, L. (2004). Evidence for chronic stress in captive but not free-ranging cheetahs (*Acinonyx jubatus*) based on adrenal morphology and function. Journal of Wildlife Diseases, 40(2), 259-266.

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Weinstein, P., Delean, S., Wood, T., & Austin, A. D. (2016). Bioluminescence in the ghost fungus *Omphalotus nidiformis* does not attract potential spore-dispersing insects. IMA fungus, 7(2), 229-234.

Young, L., Zaun, B., & VanderWerf, E. (2008). Successful same-sex pairing in Laysan albatross. Biology Letters, 4(4), 323-325. doi: 10.1098/rsbl.2008.0191