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10

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# About the authors

Dr Gemma Dale is a nationally certified lead teacher, working as a senior biology teacher at a Brisbane school. With over 16 years' experience teaching senior sciences in the UK and Australia, she also has a tertiary background in Ecology and a Masters of Science in Biodiversity and Conservation. She has also completed an Education Doctorate (EdD) specialising in scientific literacy.

**Dr Gemma Dale**
**Lead author**

Dr Brodie Reid teaches secondary science and Year 11 and 12 ATAR Chemistry. He also has many years of experience teaching at the tertiary level and is an author of over ten academic publications. He has presented his research internationally, winning several awards along the way.

**Dr Brodie Reid**

The publisher thanks Victoria Shaw, Christopher Humphreys, Kyle Schellack-Potter, Naomi Sutanto and the Australian Nuclear Science and Technology Organisation for reviewing and contributing to this resource.

# About the cover

*Eucalyptus argophloia,* commonly known as Burncluith gum or Queensland western white gum, is a tall eucalyptus that grows only north-east of Chinchilla on the Darling Downs in south-east Queensland. It is listed as endangered under Queensland's *Nature Conservation Act 1992*. It has a smooth white bark and it flowers from May to June. Like other eucalyptus trees, it has tapering lance-shaped leaves, featured on the cover of this publication.

*Eucalyptus argophloia*

# Contents



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Answers are available in the Interactive Textbook and the teacher resources.

# How to use this resource

## Elements in the print book

**Glossary**
definitions of key terms are provided next to where the key term first appears in the chapter.

### Explore!

Students are encouraged to conduct research online to find and interpret information.

### Quick check

These provide quick checks for recalling facts and understanding content. These questions are also available as Word document downloads in the Interactive Textbook.

### Learning goals

These are descriptions of what the student will learn throughout the section.

### Did you know?

These are short facts that contain interesting information.

### Science as a human endeavour

These are recent developments in the particular area of science being covered. They may also show how ideas in science have changed over the years through human discovery and inventions.

### Section questions

Question sets at the ends of sections are categorised under four headings: Retrieval, Comprehension, Analysis and Knowledge utilisation. Cognitive verbs have been bolded. These questions are also available as Word document downloads in the Interactive Textbook.

## Hands-on activities

### Try this

Classroom activities help explore concepts that are currently being covered.

### Making thinking visible

Visible thinking style classroom activities to help consolidate the concepts currently being covered.

### Practical skills

These activities focus on developing one or two science inquiry skills, including using laboratory equipment. They can be conducted within one lesson. These activities are also available as Word document downloads in the Interactive Textbook.

### Investigation

These longer activities focus on developing more than one area of the experimental design. They are likely to take more than a single lesson. These activities are also available as Word document downloads in the Interactive Textbook.

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## End-of-chapter features

# Chapter review

### Chapter checklist

You can download this checklist from the Interactive Textbook to complete it.

| Success criteria | | Linked questions | Check |
|---|---|---|---|
| 2.1 | I can recall the components that make up the structure of DNA and RNA molecules. | 6, 13 | |
| 2.1 | I can describe the relationship between genes, DNA and chromosomes. | 1 | |
| 2.1 | I can describe the steps in which DNA is used to synthesise proteins. | 7, 18 | |
| 2.2 | I can recall the steps involved in DNA replication. | 3, 4, 15 | |
| 2.2 | I can describe the stages of cell division in mitosis. | 17 | |
| 2.2 | I can describe the stages of cell division in meiosis. | 17 | |
| 2.2 | I can use a karyotype to determine information about an individual. | 10 | |
| 2.3 | I can define the terms 'homozygous', 'heterozygous', 'dominant' and 'recessive' with respect to genetic inheritance. | 5 | |
| 2.3 | I can use and interpret a Punnett square to identify possible genotypes and phenotypes of offspring. | 20, 23 | |
| 2.3 | I can explain sex linkage. | 11, 19 | |
| 2.3 | I can distinguish between codominance and incomplete dominance. | 22 | |
| 2.3 | I can use a pedigree diagram to determine the type of | 19 | |

Chapter checklists help students check that they have understood the main concepts and learning goals of the chapter.

Chapter review question sets are categorised under four headings: Retrieval, Comprehension, Analysis and Knowledge utilisation. Cognitive verbs have been bolded. These questions are also available as Word document downloads in the Interactive Textbook.

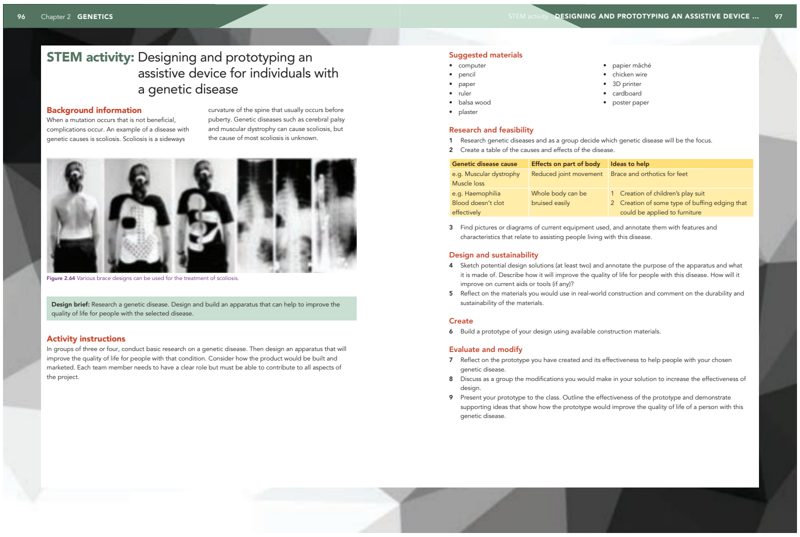
### Data questions

A student prepared an onion root tip slide and examined the cells using a light microscope. She recorded the number of cells in each stage of the cell cycle.

The table shows her results.

| Stage of cell cycle | Number of cells recorded |
|---|---|
| Interphase | 340 |
| Prophase | 13 |
| Metaphase | 4 |
| Anaphase | 3 |
| Telophase | 6 |

Data questions help students apply their understanding, as well as analyse and interpret different forms of data linked to the chapter content. These questions are also available as Word document downloads in the Interactive Textbook.



96 Chapter 2 GENETICS

STEM activity: Designing and prototyping an assistive device for individuals with a genetic disease

Background information

When a mutation occurs that is not beneficial, complications occur. An example of a disease with genetic causes is scoliosis. Scoliosis is a sideways curvature of the spine that usually occurs before puberty. Genetic diseases such as cerebral palsy and muscular dystrophy can cause scoliosis, but the cause of most scoliosis is unknown.

Figure 2.64 Various brace designs can be used for the treatment of scoliosis.

**Design brief:** Research a genetic disease. Design and build an apparatus that can help to improve the quality of life for people with the selected disease.

Activity instructions

In groups of three or four, conduct basic research on a genetic disease. Then design an apparatus that will improve the quality of life for people with that condition. Consider how the product would be built and marketed. Each team member needs to have a clear role but must be able to contribute to all aspects of the project.

STEM activity DESIGNING AND PROTOTYPING AN ASSISTIVE DEVICE … 97

Suggested materials

- computer
- pencil
- paper
- ruler
- balsa wood
- plaster
- papier mâché
- chicken wire
- 3D printer
- cardboard
- poster paper

Research and feasibility

1 Research genetic diseases and as a group decide which genetic disease will be the focus.
2 Create a table of the causes and effects of the disease.

| Genetic disease cause | Effects on part of body | Ideas to help |
|---|---|---|
| e.g. Muscular dystrophy Muscle loss | Reduced joint movement | Brace and orthotics for feet |
| e.g. Haemophilia Blood doesn't clot effectively | Whole body can be bruised easily | 1 Creation of children's play suit 2 Creation of some type of buffing edging that could be applied to furniture |

3 Find pictures or diagrams of current equipment used, and annotate them with features and characteristics that relate to assisting people living with this disease.

Design and sustainability

4 Sketch potential design solutions (at least two) and annotate the purpose of the apparatus and what it is made of. Describe how it will improve the quality of life for people with this disease. How will it improve on current aids or tools (if any)?
5 Reflect on the materials you would use in real-world construction and comment on the durability and sustainability of the materials.

Create

6 Build a prototype of your design using available construction materials.

Evaluate and modify

7 Reflect on the prototype you have created and its effectiveness to help people with your chosen genetic disease.
8 Discuss as a group the modifications you would make in your solution to increase the effectiveness of design.
9 Present your prototype to the class. Outline the effectiveness of the prototype and demonstrate supporting ideas that show how the prototype would improve the quality of life of a person with this genetic disease.

STEM activities encourage students to collaboratively come up with designs and build solutions to problems and challenges.

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## Links to the Interactive Textbook

VIDEO
These icons indicate that there is a video in the Interactive Textbook.

WIDGET
These icons indicate that there is an interactive widget in the Interactive Textbook.

WORKSHEET
Worksheets can be downloaded from the Interactive Textbook at the start of every section.

QUIZ
Automarked quizzes can be found in the Interactive Textbook for every section.

SCORCHER
Competitive questions can be found at the end of each chapter.

## Overview of the Interactive Textbook (ITB)

The **Interactive Textbook (ITB)** is an online HTML version of the print textbook, powered by the Edjin platform. It is included with the print book or available as a separate digital-only product.

**Definitions** pop up for key terms in the text.

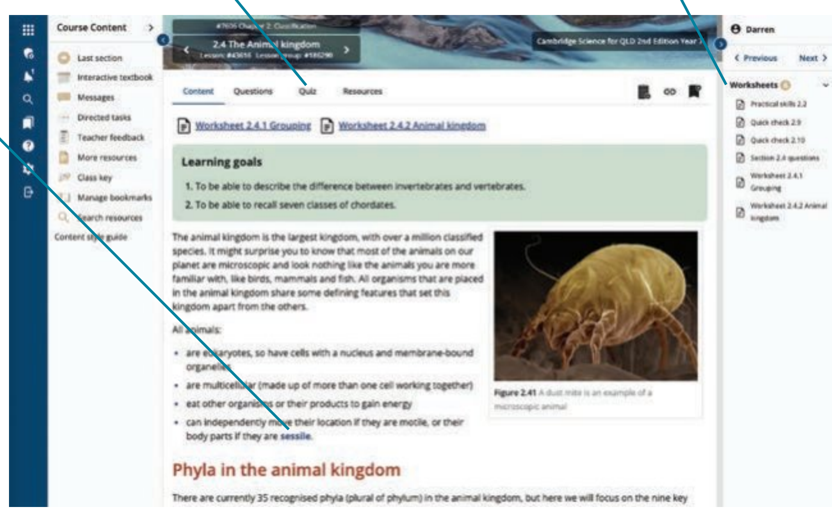
**Quizzes** contain automarked questions that enable students to quickly check their understanding.

**Worksheets** are provided as downloadable Word documents.

**Videos** summarise, clarify or extend student knowledge.

**Widgets** are accompanied by questions that encourage independent learning and observations.

**Practicals** are available as a Word document download, with sample answers and guides for teachers in the Online Teaching Suite.




**Practical skills 2.1**

**Observing *Euglena***

**Be careful**
Ensure proper microscope handling and use is observed.

**Aim**
To observe a single-celled organism under the microscope.

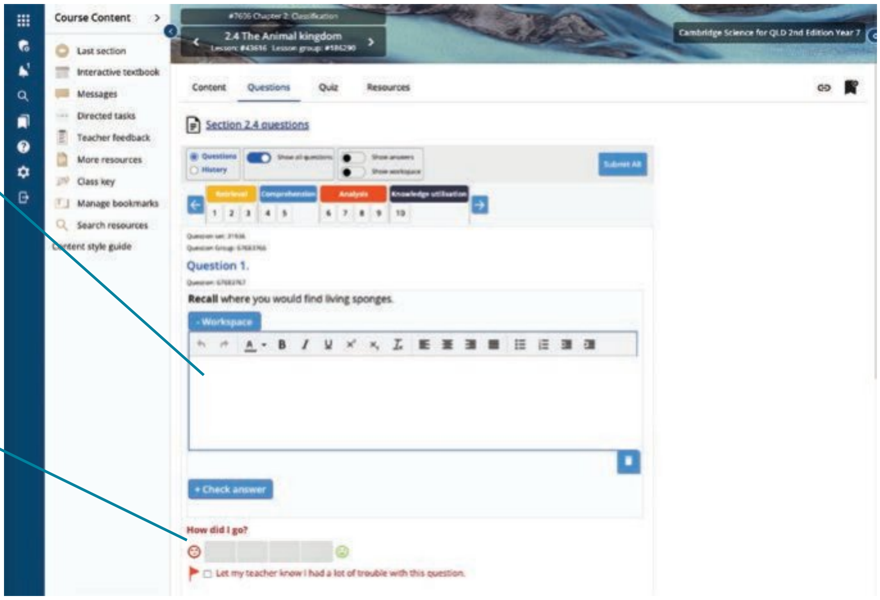
**Materials**
- *Euglena* sample
- pipette
- compound microscope
- dimple slide
- coverslip
- sharp pencil
- plain paper
- glycerol (optional)

**Method**
1. Set up the microscope on your bench.
2. Place a small drop of the *Euglena* sample into the dimple on the slide. One drop of glycerol can be added to slow the movement of the *Euglena*.
3. Lower the coverslip on an angle over the drop to protect the sample.
4. Place the slide onto the stage of the microscope and focus, using the lowest power magnification first.
5. Draw a scientific drawing of the *Euglena* you observe. Use a sharp pencil.
6. Use the internet to research the structure of *Euglena*. Label your scientific drawing.

**Analysis**
*Euglena* can make sugars like plants can, but they also have a simple 'eye' spot (sensitive to light, not a true eye). *Euglena* can also move, as you have observed. From your observations, justify whether you believe *Euglena* is more similar to animals or plants.

**Workspaces** enable students to enter working and answers online and to save them. Input is by typing, handwriting and drawing, or by uploading images of writing or drawing.

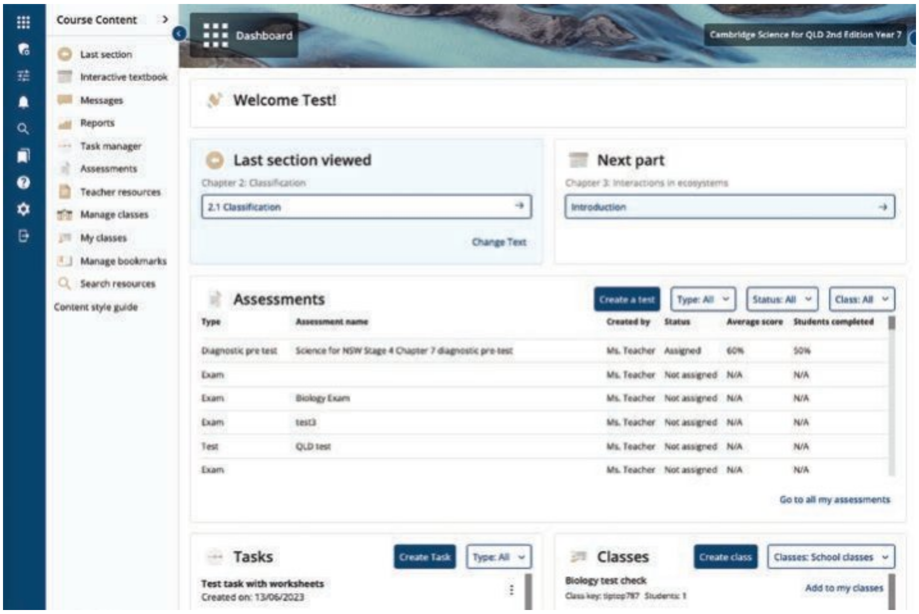
**Self-assessment tools** enable students to check answers, mark their own work, and rate their confidence level in their work. Student accounts can be linked to the learning management system used by the teacher in the Online Teaching Suite.




## Overview of the Online Teaching Suite (OTS)

The Online Teaching Suite is automatically enabled with a teacher account and is integrated with the teacher's copy of the Interactive Textbook. All the assets and resources are in one place for easy access. The features include:

- **The Edjin learning management** system with class and student analytics and reports, and communication tools
- Teacher's view of a **student's working and self-assessment**
- **Chapter tests** and **worksheets** with answers as PDFs and editable Word documents
- Editable **curriculum grids** and **teaching programs**
- **Teacher notes** for Practicals, Try this, Explore! and STEM activities.
- **Diagnostic tools**, including ready made pre- and post-tests and intuitive reporting



# Chapter 1
# Investigating in science

## Chapter introduction

Making a scientific claim requires compelling scientific evidence, which can only be produced by the rigorous planning and conducting of scientific experiments. This chapter will step you through the investigative process of career scientists, from reviewing the work of their peers to providing reliable and valid evidence to test the hypotheses of research questions. You will explore the safety and ethical implications of experimentation, as well as the use of specialised equipment and supercomputers to aid in the analysis of massive amounts of data.

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## Glossary terms

Absolute uncertainty
Accuracy
Calibrate
Confidentiality
Confounding variable
Controlled variable
Data logging
Dependent variable
Ethics
Fieldwork
Hypothesis
Independent variable
Informed consent
Mean
Median
Mode
Model
Outlier
Parallax error
Precision
Prediction
Random error
Range
Reading error
Relative uncertainty
Reliability
Repeatability
Replicability
Reproducibility
Right to withdraw
Safety data sheet
Simulation
Systematic error
Titration
Validity
Zero calibration error

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# 1.1 Planning an investigation

WORKSHEET
Energy drinks and reaction time

## Learning goals

1. To be able to distinguish independent, dependent and controlled variables in a scientific investigation.
2. To be able to write an appropriate scientific hypothesis.
3. To explore the factors that affect the reliability, validity, safety and ethics of a scientific investigation.

In previous years you have followed a scientific method for experimentation. This text will follow a more elaborate scientific method as illustrated in Figure 1.1. In this section, you will consider all of these steps in planning and carrying out an investigation.

## Literature reviews

Before planning experiments to investigate a research question, scientists will review the work of other scientists from all over the world on similar research questions. This is an important step as there is a lot

**STEP 1: OBSERVE AND ASK QUESTIONS**
A research question may be posed once a particular area of scientific knowledge has been reviewed.

↓

**STEP 2: RATIONALE**
A scientist who is interested in conducting an investigation on a certain topic will first search relevant scientific literature for past evidence and findings. This requires the ability to find and analyse research articles and results.

↓

**STEP 3: CONSTRUCT HYPOTHESIS, MAKE PREDICTION AND STATE VARIABLES**
A hypothesis is an educated guess about the relationship between two or more variables. It is formulated using scientific knowledge. You should make a prediction about what is expected to happen if the hypothesis is true. You should also state your independent, dependent and controlled variables.

↓

**STEP 4: METHOD**
An investigation may include controlled laboratory experiments, naturalistic observations, case studies, surveys and interviews. Conducting the experiment requires a specific methodology. The method usually contains at least three sections:

- Materials (lists the scientific apparatus required to conduct the experiment)
- Procedure (gives step-by-step instructions as to how the experiment is conducted). This may be a modified version of a previous experiment
- Risk assessment (considers how to manage any risks in the experiment).

↓

**STEP 5: PROCESSING SUFFICIENT AND RELEVANT DATA**
Collecting data in an organised manner and presenting data in an appropriate format are crucial for scientists to analyse trends and relationships between variables. It is important for scientists to clearly communicate data too, and this can be enhanced by also showing measures of centre such as the mean, median, mode and range. Error bars can also be included to represent uncertainty in any measurements.

↓

**STEP 6: ANALYSE THE DATA**
The tables and charts of data then need to be examined. Analysing data can reveal relationships, trends and patterns. The meaning of each of the results should be summarised and the uncertainty and limitations of evidence should be identified.

↓

**STEP 7: EVALUATE THE DATA**
This is a discussion of the reliability and validity of the experimental process. Suggested improvements and extensions to the experiment should be included.

↓

**STEP 8: CONCLUSION**
This is an insightful interpretation of experimental evidence through a justified conclusion that is linked to the research question.

↓

**STEP 9: REPORTING THE RESULTS**
A scientific report is completed to document the research and share the findings with other scientists. Common methods used to report the research findings include practical reports, oral presentations and poster presentations.

**Figure 1.1** The scientific method framework used in this text

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to be learned from the experience and evidence communicated by other scientific investigations. A literature review can provide knowledge and support for new research questions, but it can also show scientists that their research question might already have an answer.

Generally, scientific research is funded by the government and private industry, but to gain funding, scientists need to provide evidence that their work is worth supporting! A literature review is essential in this case, as strategies used in prior research might inform future research and improve the chance of success for future work. Research is funded because it seeks to provide knowledge or solutions to modern-day and future problems.

## Variables in an investigation

Scientists have formulated a research question after they gathered knowledge from their observations of the world and a literature review. Their question is: Does caffeine intake affect human reflex time?

To ensure that data and evidence collected from any experiment addressing this research question are fair and valid, and will provide evidence on possible causation, the scientists must only change one variable and measure one variable. All other variables that might influence the measured variable should be controlled.

The scientists will consciously manipulate or change only the **independent variable** in an experiment, and their methods will state exactly how it will be manipulated or changed. In this experiment, they would likely change the variable 'caffeine intake'. For example, the independent variable for this experiment might be the volume of coffee or energy drink consumed and the caffeine concentration, or the mass or concentration of caffeine in a tablet taken.

The **dependent variable** is the thing or factor being measured in response to a change in the independent variable. The scientists should state what the dependent variable is and how it will be measured in the experiment. For example, the dependent variable in this experiment is the 'reaction time' and might be measured as the time taken in seconds to respond to a prompt.

Other variables might also affect the measured data of the dependent variable in the experiment or the effect of the independent variable on the dependent variable. Variables that interfere with the results of an experiment are called **confounding variables**, and it is important that they are controlled. It is often challenging to identify what factors might act as confounding variables in an experiment, so the best practice is to eliminate any influence by keeping all other variables constant. Variables that are kept constant throughout an experimental procedure are called **controlled variables**. In this example, this may be the time of day the caffeine is taken and the method by which the reaction time is measured. What are some others?

**independent variable** the variable that is systematically manipulated or changed in order to investigate its effect on the dependent variable

**dependent variable** the variable that is measured in response to the independent variable

**confounding variable** a variable that influences the independent and/or dependent variable/variables

**controlled variable** a variable that is kept constant so as not to affect the dependent variable during an experiment

**hypothesis** a proposed explanation or educated guess that can be tested through further investigation and experimentation

**prediction** a statement that describes what is expected to happen if the hypothesis is true

## Writing a hypothesis

Now that the scientists have identified their variables, they can formulate a **hypothesis** for their experiment. A hypothesis is based on existing knowledge and previous observations. It is an educated guess that is formulated prior to conducting an experiment or making new observations. For a hypothesis to be considered scientific, it must be capable of being tested and should be able to be supported or refuted. It is typically formulated as an 'If ... then ...' statement that can be tested through experimentation or observation (Table 1.1).

A reasoned **prediction** is a statement that describes what is expected to happen if the hypothesis is true. It is typically based on the hypothesis and is used to guide the design of an experiment or the collection of data.

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| Construct a hypothesis | | | | |
|---|---|---|---|---|
| Formula: | If | state the change in the **independent variable**. | then | state the expected change in the **dependent variable**. |
| Example: | If | **caffeine intake** is increased | then | **reaction time** will decrease. |
| **Hypothesis**: If caffeine intake is increased then reaction time will decrease. | | | | |

**Table 1.1** How to construct a hypothesis using an 'If … then …' statement

A prediction is a statement about what will happen in a particular situation, based on the hypothesis being tested.

## Collecting data

**model**
a simplified representation of a real-world system or phenomenon used to understand, analyse or predict its behaviour

**simulation**
a computer program that uses a model to replicate the behaviour of a system over time

In a scientific investigation, data can be collected in a variety of ways. It can be collected from experiments conducted in a laboratory, from fieldwork, or by using simulations and models. The terms 'simulation' and 'model' are closely related and are often used interchangeably, but there is a difference between the two.

A **model** is a simplified representation of a real-world system or phenomenon that is used to understand, analyse or predict its behaviour.

A **simulation**, on the other hand, is a computer program that uses a model to replicate the behaviour of a system over time. A simulation allows researchers to study the behaviour of a system under different conditions or scenarios, without the need for real-world experimentation, which can be time-consuming, expensive, or even dangerous. Supercomputers can also be used to run simulations based on very large amounts of data for scientists.

### Making thinking visible 1.1

**Think, pair, share: Research question**
Consider the research question: Does light intensity affect the length of a bean sprout growth?

1 **Think** of as many variables as possible that would be required to be controlled in this experiment.
2 **Pair** up with a partner and **share** your list. Listen to your partner's thoughts.
3 Share your combined list with another group in the class. Listen to the list that the other group came up with.

The *Think, pair, share* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

### Try this 1.1

**Testing a hypothesis**
Two students had the research question 'Does light intensity affect the length of a bean sprout growth?'

They were thinking of setting this experiment up under three different conditions: darkness, ambient light and a greenhouse setting.

**Figure 1.2** Seed sprouts in a petri dish

1 State the independent variable for this experiment.
2 State the dependent variable for this experiment.
3 Write an appropriate hypothesis for this investigation using an 'If … then …' statement.
4 List four variables that must be controlled in this experiment.
5 What assumptions might have been made in this experiment regarding controlled variables?
6 How might the results of this experiment lead to further hypotheses and testing?

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## Experiments

Experiments occur in many different forms, and you might already be experimenting in your everyday life! Experiments should always be done in a controlled environment, where only the independent variable is changed, and the dependent variable measured.

Often, scientists in the field or laboratory might use a data logger for data collection. **Data logging** allows scientists to measure data more accurately, or over a prolonged period.

Experiments can take place in a laboratory, but sometimes scientists may have to do **fieldwork**. This involves collecting evidence in the real world, away from the controlled environment of a laboratory. When scientists work in the field, they often cannot manipulate the environment or control the confounding variables, which can make it more challenging to establish causal relationships.

Scientists may have to venture out into the field for several reasons. Astrophysicists may need to visit remote astronomical observatories, such as the High-Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory in Sierra Negra, Mexico. Environmental chemists may need to complete fieldwork to detect the presence and impact of chemicals in the environment. Marine biologists may need to locate, tag and track marine animals and their migratory movements. For example, researchers at Southern Cross University in Queensland track the annual movements of Migaloo, the albino humpback whale.

**data logging**
the process of using electronic equipment to collect data independently through sensors where information needs to be collected faster or for longer or more accurately than a human can do

**fieldwork**
practical work conducted by a scientist in a natural environment rather than in a laboratory

**Figure 1.3** Migaloo, the albino humpback whale

### Science as a human endeavour 1.1

**Funding for fieldwork**

Researchers from the University of Queensland discovered that the native legume *Crotalaria novae-hollandiae* is hyperaccumulating zinc (concentrating it in its tissues) at the Dugald River Mine near Cloncurry. They have speculated that this could enable phytomining, the process of harvesting substances from the living tissue of plants that act as hyperaccumulators. Such plants retain certain substances in particularly high concentrations after they are absorbed through their roots. There are around 100 known hyperaccumulators, and the ash created when these plants are burned can be a 'bio-ore', often containing more than 25% metal. These plants could potentially offer an environmentally friendly method of extracting valuable metals from mining waste materials, or of cleaning up soil contaminated with mining waste.

**Figure 1.4** *Crotalaria novae-hollandiae*

This type of research has the potential to have a great impact on the future of the metal industry, but it depends on researchers being successful in obtaining funds. To make this type of discovery, these researchers would have had to write applications for financial grants to either government or, less commonly, commercial entities. To successfully attract a grant, they have to provide compelling literature reviews and a well-designed project plan, and outline the likely future benefits of their findings for society.

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**Quick check 1.1**

Why might a literature review be important for a scientist seeking funding?

## Simulations and supercomputers

Sometimes a research question can't be tested by experimenting in the laboratory or in the field, or scientists may not have the appropriate tools to do the job. In those cases, data can be obtained from computer simulations. Simulations enable the study of system characteristics by allowing the manipulation of variables that could not be controlled in a real system. They are useful to study the properties of a model of a real-life system that would otherwise be too complex, too large, too small, too fast, too slow or simply too dangerous to change. For example, meteorologists can simulate the possible movement and effects of cyclones and tsunamis, which would be too large and dangerous or simply not feasible to trial in the real world.

Supercomputers can also be used to analyse massive amounts of data produced in experimentation, particularly using data-logging machines. Supercomputers are extremely powerful computers capable of

**Science as a human endeavour 1.2**

**Simulating tsunami effects**

Researchers at the Queensland Government's environment department have developed tsunami models and simulations that assess what would happen in the case of a one-in-750-year, one-in-3000-year or one-in-10 000-year event, including calculating the speed, height and inundation levels at different tides. The modelling was based on data from tsunamis generated in the Vanuatu, South America and Kermadec–Tonga regions. Computer simulations found that tsunamis generated in the Vanuatu region would reach Queensland's coast in the fastest time, but waves generated in the Kermadec–Tonga zone would be the most damaging. Researchers discovered that the Great Barrier Reef would provide some protection in the north as the tsunami is slowed as it travels through shallow waters, as well as being blocked by large islands. More exposed regions, such as the Gold Coast and the coastal region between Agnes Water and Bundaberg, would see greater wave heights. The simulations also revealed that the populous region of Brisbane would largely be protected, due to the location of Moreton and Stradbroke islands.

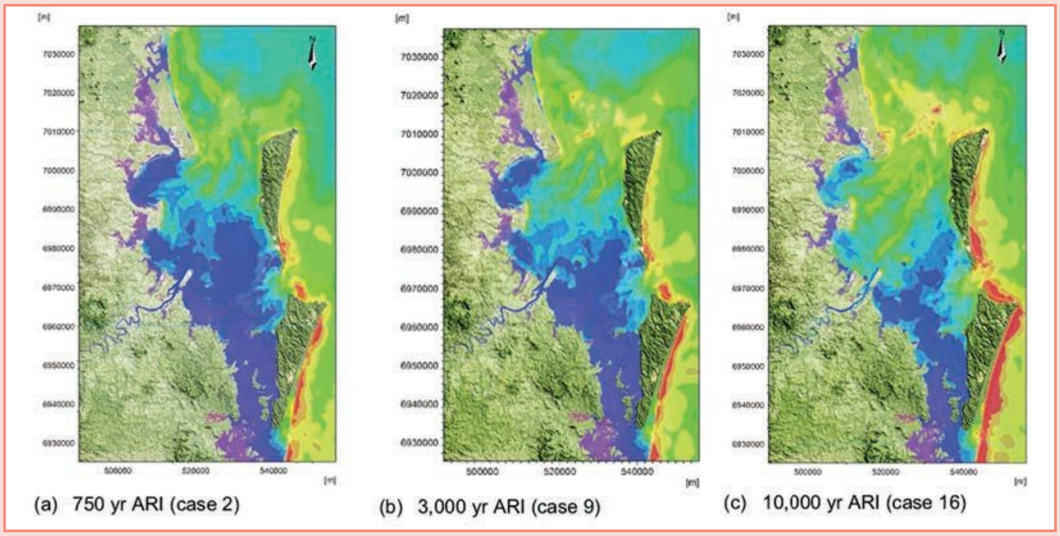


**Figure 1.5** Three of many scenarios showing tsunami models of Moreton Bay generated by a computer simulation. Red areas represent waves of eight metres.

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storing, distributing and analysing data for scientists. For example, at the Large Hadron Collider (LHC), data collected when particles collide is transmitted to the Worldwide LHC Computing Grid (WLCG). The data is sorted, filtered to remove background noise and then analysed for the scientists. This occurs millions of times per second, and the superfast grid and algorithms allow the massive amount of information to be useable by scientists in an appropriate timeframe.

**Figure 1.6** The Large Hadron Collider sends data to a superfast computer grid to sort and analyse for scientists.

## Reliability of the experimental method

Reliable experimental results are those that contain large sample sizes and are repeatable, replicable and reproducible. Experiments that rely on subjective data collection do not always produce reliable results, just as experiments with small sample sizes may also yield unreliable data. Imagine trying to decide if doctors should prescribe a new painkiller medication by asking one person if it reduced their pain. It would be unreasonable to make decisions about the healthcare of all Australians based on the opinions of one person!

Results from a single experiment may not be reliable as evidence for the research question. For example, it is difficult to perfectly control all controlled variables in an experiment, so a single experiment may be influenced by some unknown variation. Thus, scientists should ensure that they repeat their experiment under the exact same conditions multiple times, often called conducting multiple trials. If the results match well when the same scientist conducts the experiment multiple times using the same method and equipment, the experiment is said to have high **repeatability**. Results should also be replicable, which is when another scientist carries out the experiment using the same method and equipment as the original experiment and gets similar results. Finally, results should be reproducible, which is when another scientist carries out the experiment using a different method and equipment as the original experiment and still gets similar results. If experimental results are repeatable, replicable and reproducible, scientists can be confident that their results are reliable.

**Reliability** of data collected in an experiment can be improved by ensuring that there is high repeatability, **replicability** and **reproducibility** in the experimental results. That is why your teacher will always encourage you to repeat experiments multiple times to identify outlier results and average similar results. Ensuring all equipment used is correctly **calibrated** will allow for better replicability and reproducibility by other scientists, and using large sample sizes improves reliability as there is a smaller chance of error. Human error, such as in taking readings on glassware or in reflex time to stop a stopwatch, can reduce reliability, particularly the replicability and reproducibility of results. This is another reason why repeating the experiment multiple times is important, and errors can be made less impactful by averaging results.

**repeatability**
how well the results match up when the same scientist repeats the experiment under the same conditions as the original experiment, including the same equipment and laboratory or field site

**replicability**
how well the results match up when a different scientist repeats the experiment under the same conditions as the original experiment, including the same equipment and laboratory or field site

**reproducibility**
how well the results match up when a different scientist repeats the experiment under different conditions to the original experiment, including different equipment and laboratory or field site

**reliability**
how repeatable, replicable and reproducible the results are

**calibrate**
to mark or check measuring equipment against a known standard value to ensure its accuracy

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| | Repeatable | Replicable | Reproducible |
|---|---|---|---|
| Consistent results from: | Same person and lab, same method | Different person and lab, same method | Different person and lab, different method |

Table 1.2 The difference between repeatability, replicability and reproducibility

Table 1.2 summarises the difference between repeatability, replicability and reproducibility.

## Validity

WORKSHEET Testing the effectiveness of fertilisers

**validity**
the degree to which we accept the suitability of an experiment in addressing the research question, and whether it measures what it says it measures

**safety data sheet**
a document that provides information regarding hazardous chemicals and substances

Experimental **validity** assesses whether the experiment is suitable for the research question and whether it measures what it claims to be measuring. That is, does the experiment manipulate only the independent variable and measure only the dependent variable with all other variables kept constant? You may recall from previous years that validity is often associated with whether the experiment conducted was a 'fair test'. For example, an experiment that is testing the effect of temperature on enzyme action should not have one set of enzymes at 20°C and pH 4, and another at 40°C and pH 9. The validity of an experiment depends on both the experimental design and the procedure.

To state whether an experiment has provided 'valid' results, the experimenter must consider the influence of any loosely controlled variable or uncontrolled variables, rather than how much data was collected. Results might be 'reliable' but not 'valid' if a confounding variable was not controlled in the method. It is important that scientists are very strict in controlling the controlled variables to ensure validity of their results.

## Safe practices

In any experimental procedure, it is the job of the experimenter to eliminate any risks associated with the experiment. If elimination is not possible, then safe practices must be followed to protect experimenters. Equipment and materials should be assessed for risk prior to undertaking an experiment.

### Quick check 1.2

1 Identify the correct words to complete the following sentences.
   a Using the same set of scales when measuring the mass of a beaker on day 1 and day 2 of an experiment is a factor relating to the ___________ of an experiment.
   b The likelihood that another scientist performing exactly the same experiment under the same conditions will generate the same results depends on ___________.
2 Explain the importance of reproducing experiments in the field of science.

When assessing any risk, two factors are considered: the likelihood of the hazard occurring, and the level of harm that might result from the hazard. Experiments sometimes require the use of hazardous chemicals that could cause harm. A **safety data sheet** (SDS) should be provided during all experiments. An SDS is a document that provides teachers and students with relevant information about the health risks and safety of products (such as chemicals) that are classified as being hazardous substances.

Throughout this textbook are practical and investigation tasks which have been assessed for their level of risk to the experimenter. When you plan for these experiments, consider what chemical or biological hazards might have been eliminated in the design of the experiment and what low-level hazards the experimenter might still face.

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**Quick check 1.3**

1. Recall what SDS stands for.
2. Explain why SDSs are essential within the science classroom.

The safety data sheet provides precise information on how to use a substance during and after the experiment, the associated health risks and how to dispose of waste products.

## Ethical implications of scientific investigation

When conducting scientific experimentation or investigation, it is important to note possible ethical implications and guidelines, particularly when working with animals and humans. **Ethics** refers to the principles and standards upheld by scientists that guide them to display acceptable and appropriate conduct during experiments.

### Animal testing

Scientists have ethical, social and legal responsibilities when working with animals in scientific investigations. Scientists in Australia must comply with the animal welfare laws in their state or territory. These laws generally require that any experimentation on animals must be humane and should consider replacing the animal with a mathematical simulation, artificial model or a non-sentient species.

Social issues may arise when scientists commence experimentation using animals without disclosing to the public the nature of their work as, naturally, humans are concerned for the safety of animal test subjects. Hence, ethics approval is required before any animal testing.

Scientists generally follow the three Rs of animal ethics: *replace* animals with non-animal alternatives or non-sentient beings, *reduce* the number of animals used, and *refine* the techniques used such that experimentation is humane.

### Human participants

While animal test subjects can provide useful data to scientists, generally science is done by humans to influence human life. Thus, sometimes scientists need to progress their investigation to human participants, often called 'human trials'.

In fields such as psychology and medicine, using people as participants is a critical source of data in experiments. Before beginning any research involving humans, investigators must submit a research plan to an ethics committee for discussion and approval. This ensures that the participants' physical and psychological welfare is considered by a team of medical and non-medical professionals. Any participants must be voluntarily involved in the research, give **informed consent** and not be harmed by their involvement. All data must be kept **confidential**, and all participants should have the **right to withdraw** at any point for any reason and to ask to have their data removed from the experiment.

**ethics**
the standards used to appraise and guide what is considered as acceptable conduct

**informed consent**
where possible, participants are informed about the risks and procedures involved in an experiment and they sign to say they agree to participate

**confidentiality**
participants' data and results must be kept private

**right to withdraw**
the right for a participant to leave a study at any time for any reason

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## Explore! 1.1

**Ethics of working with First Nations Australians**

Collaborating with First Nations Australians on scientific investigations or to explore their cultural knowledge of Country raises ethical issues for scientists. It is important that scientists avoid possible cultural appropriation and exploitation of First Nations Australian traditional knowledge. In the context of collaboration, scientists should critically analyse scientific sources and their own reports for potential cultural bias and seek multiple sources of information. Moreover, it is important that any First Nations Australian artefacts discovered during fieldwork are left undisturbed. The scientist should contact the appropriate government agency and local Indigenous community leaders about the finding.

**Figure 1.7** It is important to report the discovery of any First Nations Australian artefacts without moving or disturbing the artefact.

Use the internet to answer the following questions:

- What is cultural appropriation and exploitation?
- How might cultural bias be present in scientific literature?
- How can cultural respect and sensitivity be demonstrated?
- What does community engagement and data ownership and control mean in First Nations contexts?
- What is the purpose of the Cultural Heritage Unit of the Queensland Government?

## Quick check 1.4

1 Define the term 'informed consent'.
2 Define the term 'right to withdraw'.
3 Define the term 'cultural appropriation'.

QUIZ

## Section 1.1 questions

### Retrieval

1 **Describe** the difference between repeatability and reproducibility in scientific experiments.

2 Biology students were learning that, on a hot day, plants lose water out of pores (called stomata) in the underside of their leaves. The students were asked to design an experiment that would test how factors of their choice influence the rate of water loss. After conducting some background research, one student identified that temperature should affect the rate at which water is lost via the stomata. They set up the experiment pictured below.

  a **Identify** the independent variable in this experiment.
  b **Identify** the dependent variable in this experiment.

Set-up A 21°C dry air   Set-up B 30°C dry air   Set-up C 21°C humid air

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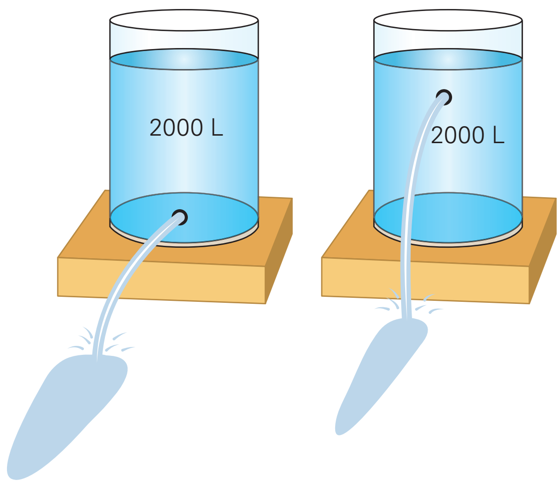
**Comprehension**

3 A farmer noticed that his leaky tanks seemed to lose water quicker if the hole was closer to the bottom of the tank. He designed the research question: Do tanks leak water faster when the hole is positioned lower on the tank?

a **Identify** the independent variable of this experiment.

b **State** three variables that must be controlled.

c The farmer repeated his experiment on five different occasions and found the same result: the water flows more strongly from the lowest hole in a water drum. **Identify** whether this is showing high or low repeatability and validity.




4 **Explain** why scientists may want to carry out fieldwork rather than completing experimental work in a lab.

**Analysis**

5 **Contrast** between a model and a simulation.

**Knowledge utilisation**

6 One example of a model is using a globe to represent Earth. **Propose** another example of a model that has been updated over time.

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# 1.2 Conducting and evaluating investigations

DOC
WORKSHEET
Using spreadsheets

**Learning goals**

1. To explore the use of specialised scientific equipment such as titration equipment and data loggers.
2. To be able to distinguish scientific terms, including accuracy, precision, error, uncertainty and outlier.
3. To be able to analyse data using measures such as mean, median, mode and range.

## Using specialised equipment

Specialised equipment can often give accurate and precise results, thereby enhancing the reliability of the experimental data.

### Titration equipment

**Titration** is a specialised procedure used in chemistry to determine the concentration of an unknown solution. It involves measuring the volume of one solution (typically an acid or a base) that is needed to neutralise a carefully measured amount of a second solution. Titrations require specialised equipment such as a pipette, burette, pH probe or data-logging device.

**titration**
a procedure used to determine the concentration of an unknown solution

Figure 1.8 A burette in a retort stand being used to perform a titration.

A pipette is an important tool to use within the laboratory, as very small amounts of solution can be measured out accurately. They are made in different sizes to deliver a specific volume.

A burette is a long, thin, glass tube used to measure the volume of solution needed for the titration reaction (Figure 1.9). A burette can release the solution into a flask by turning the tap. To release the solution the tap is placed in a vertical position, and to stop the flow the tap is placed in a horizontal position. (Figure 1.8). The volume of solution added to the flask is called the titre.

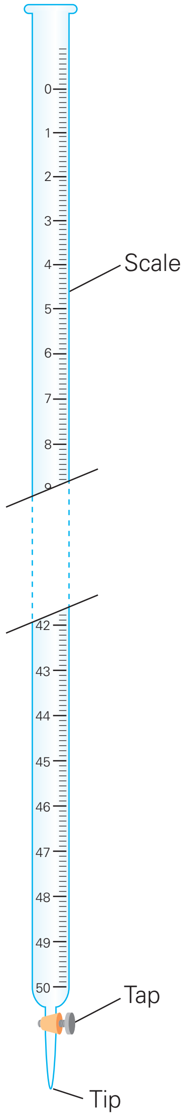


Figure 1.9 A burette

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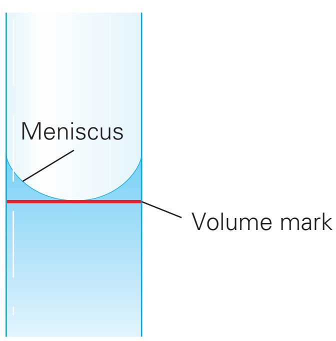
### Instructions for using a pipette

To use a pipette to deliver a fixed volume of solution, a pipette pump is attached to help fill and empty the pipette with solution (Figure 1.10).

1 Attach the pipette pump to the end of the pipette by gently twisting and securing it.
2 Turn the thumb wheel on the pipette pump to allow the solution to be drawn into the pipette.
3 Rinse the pipette using a small amount of the solution being used.
4 Draw up the solution above the volume mark of the pipette.
5 Release the solution from the pipette until the bottom of the curve of the meniscus sits just on top of the volume mark.
6 Now you are ready to deliver an accurate volume of your solution.




HINT: When drawing the solution up into the pipette, make sure the tip is always in the solution to prevent bubbles being drawn up into the pipette.

A pipette bulb (Figure 1.11) may be used in place of a pipette pump to draw up and deliver solutions.

There are a few important things to remember when using a pipette bulb:

- When inserting the pipette, hold the pipette close to the end being inserted so that the pipette does not break.
- To create a seal, do not insert the pipette too far into the bulb (1 cm should be enough).
- Never allow solution to enter the bulb. Tell your teacher immediately if this occurs.
- Make sure there is more than enough solution in the beaker to draw up into the pipette.
- Be careful when removing the pipette from the bulb at the end of an experiment. A gentle twisting motion will help you remove the pipette safely without breaking it.

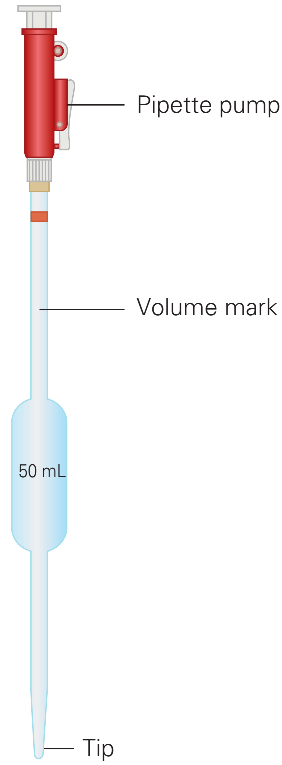



**Figure 1.10** A 50 mL volumetric pipette and pipette pump

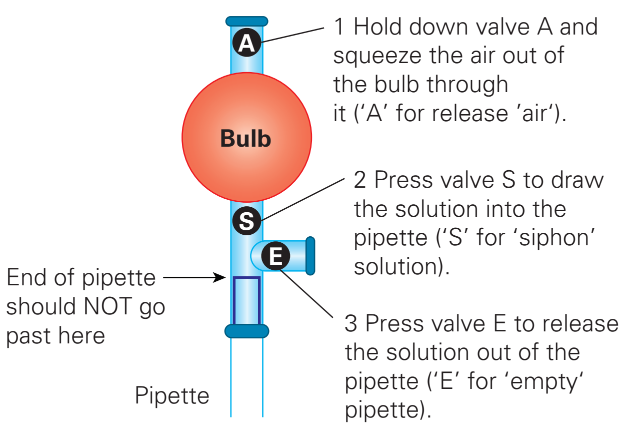



**Figure 1.11** The correct way to use the three valves in a pipette bulb

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## Practical skills 1.1

### Titration skills

**Be careful**
Wear gloves, safety glasses and a lab coat.

**Background**

Specialised equipment like burettes, pipettes and data loggers are essential in many scientific fields. Burettes (Figure 1.9) are long, graduated glass tubes used for delivering accurate volumes of liquid, typically in chemistry experiments. They are commonly used in titrations, where a small volume of one solution is slowly added to another solution until the reaction is complete. Burettes allow for precise control over the amount of liquid added, enabling accurate results. Pipettes (Figure 1.10) are like burettes, but they are smaller and used for measuring a set volume of liquid.

**Aim**

To practise using a burette and pipette.

**Materials**

- 100 mL of 0.5 mol $L^{-1}$ sodium hydroxide solution
- 20 mL of 0.5 mol $L^{-1}$ hydrochloric acid solution
- 2 or 3 drops phenolphthalein indicator
- 2 beakers
- burette
- 20 mL pipette
- funnel
- volumetric flask
- retort stand
- clamp
- white tile (to help detect colour change)

**Method**

**Part 1: Practising reading from a burette**

1 When reading from the burette, always record volumes to two decimal places. For example, if a reading is exactly on the 2.7 mL mark it should be recorded as 2.70 mL.

2 Try the example in Figure 1.12. It would be read as 1.32 mL.

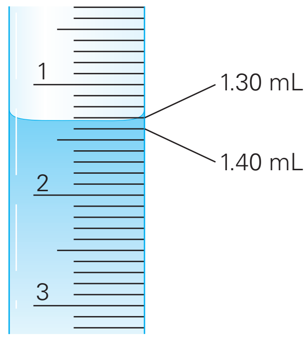


**Figure 1.12** Reading a burette to two decimal places

3 To calculate the titre volume (amount added to the flask), write down the initial and final burette readings and then subtract the final reading from the initial reading.

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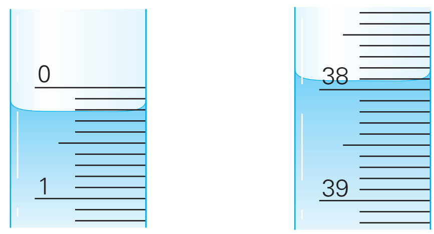
**4** Calculate the titre volumes in the following examples.

**Example 1**

Titre = final reading − initial reading
Titre = 37.91 mL − 0.21 mL
Titre = 37.70 mL

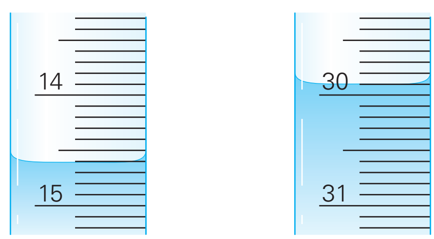



Initial reading: 0.21 mL Final reading: 37.91 mL

**Figure 1.13** Calculating a titre volume from burette readings (Example 1)

**Example 2: Try this one yourself**

Titre = final reading − initial reading
Titre =
Titre =




Initial reading:________ Final reading:________

**Figure 1.14** Calculating a titre volume from burette readings (Example 2)

**Part 2: Using a burette**

1. Measure 100 mL of 0.5 mol $L^{-1}$ sodium hydroxide solution into a clean beaker.
2. Use a clamp to secure the burette. Always keep a beaker or volumetric flask under the tip of the burette in case the tap is not fully closed when you fill the burette.
3. Making sure the tap of the burette is closed, add approximately 5 mL of the sodium hydroxide solution from the beaker to the burette using a funnel.
4. Open the burette tap to drain this solution into a waste beaker.
5. Using a funnel, add the 0.5 mol $L^{-1}$ sodium hydroxide solution to the burette, getting close to the 0.00 mL marking line. (Make sure the burette's tap is shut.)
6. To eliminate any bubbles in the burette tip, allow several drops of the solution to rinse through.
7. Slowly release the solution and try to get as close to 0.00 mL as possible.
8. Record the scale reading from the burette. Be as precise as possible by using two decimal places. This is your initial scale reading.
   NOTE: For practising purposes, 0.00 mL has been chosen, but it is not necessary to start a titration at 0.00 mL if your initial reading is accurate.

*continued…*

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*continued…*

**Part 3: Using a pipette**

1 Rinse the pipette using a small amount of the 0.5 mol $L^{-1}$ hydrochloric acid by drawing the solution up above the volume mark of the pipette.
2 Pour this into another beaker.
3 Collect some fresh hydrochloric acid, again drawing the solution up above the volume mark of the pipette.
4 Carefully release the hydrochloric acid from the pipette until the bottom of the curve of the meniscus sits just on top of the volume mark.
5 Pipette the 20 mL hydrochloric acid solution into a volumetric flask.

**Part 4: Performing a titration**

1 Add 2 or 3 drops of phenolphthalein to the hydrochloric acid solution in the flask.
2 Place the volumetric flask on the white tile under the burette.
3 Open the tap and start releasing the sodium hydroxide solution into the flask.
4 If working in pairs, one person can gently swirl the flask and the other can control the release of the solution from the burette.
5 Once the colour pink starts to appear, start adding the sodium hydroxide solution drop by drop and keep swirling the volumetric flask.
6 Once the solution maintains a constant pink colour, close off the tap. This is called the end point. It is worth noting that the lighter the shade of pink, the more accurate your titration, as shown in Figure 1.15.

**Figure 1.15** Example of titration set-up for Part 4 of this experiment with pink phenolphthalein indicating that end point is reached

7 Record the final reading from the burette to calculate the volume of hydrochloric acid solution that has been added.
8 Repeat for another two trials.
9 Record the volume of sodium hydroxide solution for these trials to then calculate the mean volume. The table below can be used.

| | Repeated trials | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Mean |
| Initial reading from burette (mL) | | | | |
| Final reading from burette (mL) | | | | |
| Titre (final reading – initial reading) (mL) | | | | |

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## Data loggers and probes

A data logger is an electronic measuring tool that accurately records data over time. It features a built-in instrument, such as a probe or sensor, that can measure a physical stimulus such as temperature, light, pressure, humidity or pH. The device is connected to a computer and converts the stimulus into a readout on the screen. This means the experimenter does not have to manually take a reading at set intervals, as the data logger takes very frequent (almost continuous) readings over time.

The benefits of using a data logger in scientific experiments include:

- highly accurate measurements
- an automated process that can be programmed and left to take readings regularly over a long period of time (for example, overnight) or many readings over a very short period of time
- removal of the risk of human error or miscalculations in interpreting a measurement scale and recording data.

The data collected from the experiment can be processed by specialised software or placed into a spreadsheet to allow for further analysis at a later point. This allows scientists to easily generate tables of values and graphs.

## Accuracy, precision and outliers

Experimental **accuracy** refers to how closely the experimental results match the 'true' values. For example, if you record the volume of water in a measuring cylinder to be 20 mL, but it actually provides 21 mL, then this measurement might be considered inaccurate. Choosing the best equipment and using a method that avoids **systematic errors** will improve the accuracy of the experiment. For example, you could use an electronic timer system to record measurements at given time intervals rather than rely on a human to use a hand-operated stopwatch.

Experimental **precision** refers to how closely repeated measurements agree with each other. For example, let's say you record the mass of a product of a chemical reaction in grams, and you repeat the experiment four times, getting results of 1.54 g, 1.55 g, 1.55 g and 1.54 g. The data shows low variation from the mean (it is clustered tightly) and can be said to be precise. Note that, even though this data is precise, it is not necessarily accurate. Precision does not give us an indication of how 'true' the data is; that is, how accurately it matches the actual values. The reading of values on glassware such as burettes, and measuring cylinders can sometimes affect precision, particularly when the experimenter needs to estimate a value between graduated markings.

**precision**
how closely repeated measures agree with each other

**Outliers** are anomalous data values that do not appear to fit with the other recorded values. These values are often situated a long way from the mean and may represent an experimental error, such as error in reading the scale or a fault in measuring equipment.

**accuracy**
how closely measures match the 'true' or accepted values

**systematic error**
error that occurs through a poorly calibrated device (consistently high or consistently low)

**outlier**
anomalous data value that does not seem to fit the rest of the data

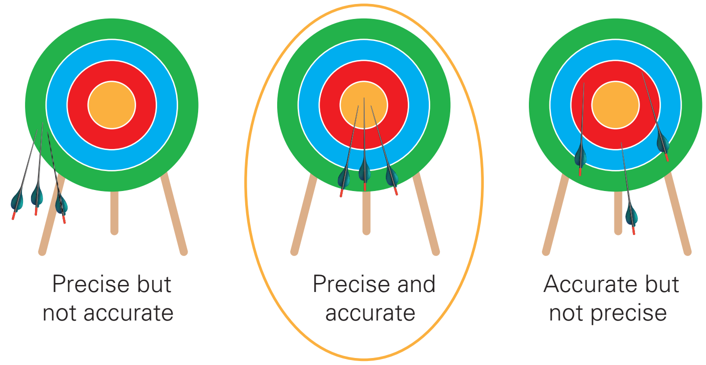


**Figure 1.16** A faulty piece of measuring equipment might consistently give wrong values, like the target on the left. This measurement would be precise, but the results are inaccurate and do not measure what they claim to measure; therefore, they have low validity.

It is important that outliers are investigated and accounted for in the discussion of your results. Sometimes, repeating the experiment eliminates the outlier, but you need to mention that this has occurred. The most common causes of outliers in a data set within the scientific laboratory are:

- data entry errors (human miscalculation)
- measurement inaccuracies (instrument error).

Outliers can easily be spotted when data is graphed. There will often be a large gap between an extremely high or low value and other observations, indicating that it differs greatly.

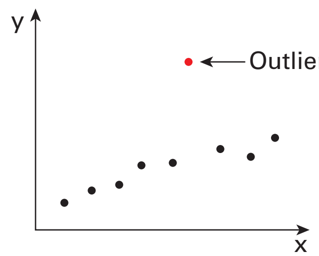


Figure 1.17 Outliers are often easily spotted in graph form.

## Quick check 1.5

1. Define the term 'outlier'.
2. Describe whether a data set with a number of outliers will give accurate results.

## Errors and uncertainties

### Systematic and random errors

Measurements are almost never perfect. The accuracy of any measurement will always be limited by the apparatus being used, the skills of the person collecting the data, the method being used and the environment where the experiment is being carried out. Whenever we do an experiment, we are attempting to determine the 'most true' data, but we will normally find variation in the results.

**zero calibration error**
a measuring instrument giving a non-zero reading when the true value should be zero

So, what are the possible reasons for the different values seen in our data? Mistakes are avoidable problems made by the person collecting the data, such as selecting the wrong piece of equipment or writing down results incorrectly. Although these are possible, a careful scientist should not make mistakes and would not include them in any report.

Errors are the difference between the results of experimental measurements and the true or reference values involved. They are not the same as mistakes.

Systematic errors arise from measured values that are either consistently larger or smaller than the true value of your data if equipment is used in the same way. Systematic errors can be minimised by careful experimental design, including calibrating measuring instruments correctly. Some examples are given below:

- **Instrument effects.** These are caused when a measuring instrument is faulty or has not been calibrated correctly. For example, if a scale used to measure a mass was not properly calibrated, so that all the readings were 3.00 grams greater than they should be, then all the measurements of mass would be consistently overestimated by 3.00 grams. This would lead to a systematic effect because the data is all wrong by the same amount each time a measurement is taken. A **zero calibration error** occurs when the initial value shown by a measuring instrument is not zero when it should be zero. For example, a scale may show 0.001 grams, even when nothing is being weighed.
- **Environmental effects.** These are caused by external factors such as temperature or humidity. For example, the measurements taken using a metal ruler will differ depending on the temperature. In low temperatures the ruler will contract, whereas in warmer temperatures it will expand. This means that all the measurements taken under those particular conditions would always be lower or higher than the correct value.

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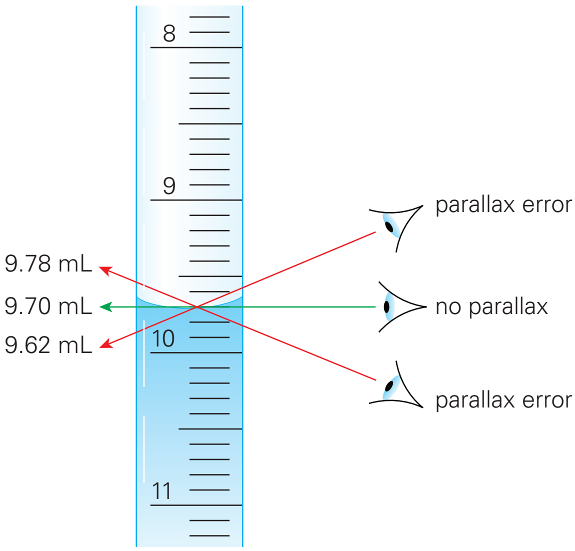


**Figure 1.18** The position where there is no parallax is the correct eye level for reading the measurement.

- **Observation errors.** These are caused by undertaking the wrong observations or reading instruments incorrectly. For example, a **parallax error** may occur when the observer's eye is positioned at an angle to the measurement markings, causing the data to be either larger or smaller than the correct value.

Even if careful experimental design removes systematic errors, **random errors** will still remain that will affect the accuracy of a measurement. These are caused by limitations of the measurement device and the observer and are equally likely to be positive or negative because they do not follow a regular pattern. They can be caused by the experimenter's inability to obtain the same measurement in the same way to get exactly the same result. You may measure the mass of a piece of magnesium ribbon three times using the same balance and produce slight variation in your results: 1.36 g 1.38 g and 1.39 g. **Reading errors** can also occur when a measurement falls between two measurement markers. An observer would have to estimate the true value, and this would differ between observers. It is likely that half of the results obtained would be estimates that are too large and half would be too small. These effects are an unavoidable part of doing experiments, and can affect result precision, but the resulting error can be reduced by repeating the experiment many times and taking average values.

## Uncertainties

Due to random and systematic effects in the experimental process, there will always be a margin of doubt about any of your results. But how big is this margin? We have looked at how these can arise, but we need to be able to quantify them. This happens through estimating the uncertainty of any measurement. This is an interval around a measured value which quantifies the likelihood that a repetition of our experiment will produce a new result that would lie within this interval.

The notation for a measurement and its uncertainty should take the following format (remember to add the appropriate units):

measured value ± uncertainty

where ± means 'give or take'. This tells us the **absolute uncertainty**.

The following rules are often used to determine the absolute uncertainty in a single measurement when using either an analogue scale or digital measuring instrument:

- The uncertainty in an analogue scale measuring instrument is equal to the smallest increment of the instrument divided by two.
- The uncertainty in a digital measuring instrument is equal to the smallest increment of the instrument.

However, if we take multiple measurements in order to calculate a mean, we can estimate the absolute uncertainty by calculating half the range.

**parallax error**
a measurement taken that is not the true value due to the position of the object along various lines of sight

**random error**
error caused by limitations of the measurement device or the observer that does not follow a regular pattern

**reading error**
a reading or measurement that is not the true value

**absolute uncertainty**
the size of the range of values within which the actual 'true value' of a measurement probably lies

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**Figure 1.19** There are different rules for single measurements using analogue (left) or digital (right) instruments. Remember to include units!

**relative uncertainty** the ratio of the absolute uncertainty to the reported value, often expressed as a percentage

For example:

- You measured the mass of different magnesium ribbon pieces as 1.36 g, 1.38 g and 1.39 g.
- The mean of these readings is $\frac{1.36 + 1.38 + 1.39}{3} = 1.38$ g.
- The range can be calculated by maximum value – minimum value = 1.39 – 1.36 = 0.03 grams.
- The uncertainty is calculated by taking half the range = 0.5 × 0.03 = 0.015 grams.
- You can then include this uncertainty when communicating your results: Mass = 1.38 ± 0.02 grams.
- The mass of the magnesium can therefore be expected to be between 1.36 and 1.40 grams.

The uncertainty of any measured value can also be expressed as a percentage or as a ratio. This is **relative uncertainty**. This is calculated by dividing the absolute uncertainty of the result by the result itself. The relative uncertainty can be more useful than the absolute uncertainty because it puts your experimental data into perspective. For example, if you made an error in measuring the length of your eraser, it would be more noticeable than if you made the same error when measuring the table. Relative uncertainties do not have units, unless the uncertainty is multiplied by 100 where it is reported as a percentage.

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Consider this example:

- You measured the length of your table (80.0 cm) using a metre rule.
- The absolute uncertainty is ±0.05 cm.
- This uncertainty can then be included when communicating your results: Length = 80.0 cm ± 0.05 cm.
- The relative uncertainty is calculated by $\frac{0.05}{80.0} = 0.000625$.
- This can then be reported as a percentage by multiplying by 100: Percentage uncertainty = 0.000625 × 100 = 0.0625%.

Now compare this result to measuring your eraser:

- You measured the length of your eraser (5.0 cm) using a metre rule.
- The absolute uncertainty is ±0.05 cm.
- This uncertainty is then included when communicating your results:
- Length = 5.0 cm ± 0.05 cm.
- The relative uncertainty is calculated by $\frac{0.05}{5.0} = 0.01$.
- This can then be reported as a percentage by multiplying by 100: Percentage uncertainty = 0.01 × 100 = 1%.

The example above illustrates the importance of considering both absolute and relative uncertainty when reporting measurement results. While the absolute uncertainty is the same for both the table and eraser measurements, the relative uncertainty is significantly higher for the eraser due to its smaller size.

### Uncertainty when measuring length

When we measure length, we normally use a ruler or a tape measure. These are scale measuring instruments, so the uncertainty should be equal to half the smallest increment of the instrument. The smallest division of a ruler you probably have is one millimetre, producing an uncertainty of 0.5 mm or 0.05 cm.

If you were measuring the length of an eraser, you would place the eraser so it was aligned at zero on your ruler, so there is an additional ±0.05 cm error at that end. Therefore, the total error for a centimetre ruler is 0.05 cm + 0.05 cm = ±0.1 cm.

### Which uncertainty should be recorded?

Often, you will be completing an experiment that uses equipment and involves recording multiple measurements. The accuracy of your investigation should consider the unit in which you are measuring the dependent and independent variables, as well as the precision of the instruments you are using (Figure 1.20).

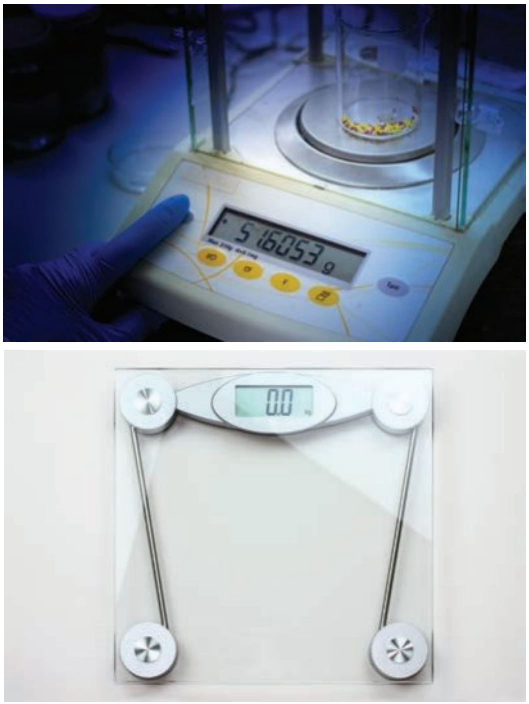


**Figure 1.20** Measurement tools vary in their precision.

You should always record the largest source of uncertainty.

### Quick check 1.6

1 State the sort of uncertainty that each of the following scenarios represents.
   a A measuring tool is incorrectly calibrated and regularly underestimates the mass.
   b A measuring tool is not very precise and the temperatures vary by approximately 0.5 of a degree in either direction.
2 Describe how the effect of random uncertainty can be reduced.

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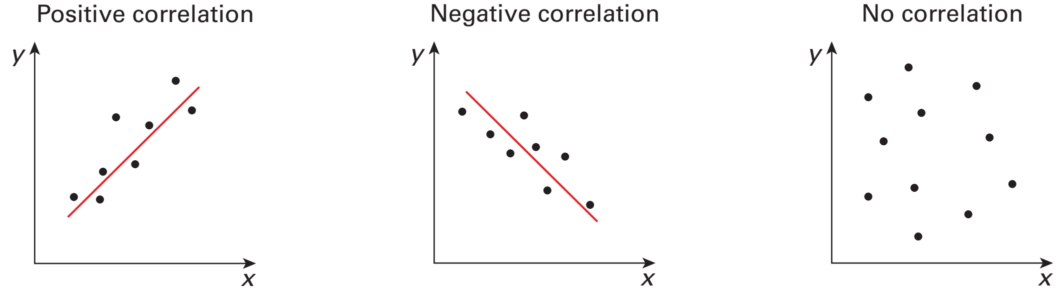


The points lie close to the line of best fit, which has a positive gradient. This shows as the independent variable increases, the dependent variable increases.

The points lie close to the line of best fit, which has a negative gradient. This shows as the independent variable increases, the dependent variable decreases.

There is no pattern in the results. There is no relationship between the independent and dependent variables.

**Figure 1.21** The relationship between two variables can be positive, negative or have no correlation.

## Processing data

Data can be presented in tables, in graphs and using descriptive statistics to better communicate trends to other scientists.

### Relationships between the variables

When you have graphed your data, you can determine if there are any patterns, trends, or relationships. One important aspect to consider when analysing data is correlation, which helps assess the strength and direction of the relationship between variables. Correlation measures the association between two variables and provides valuable insights into how changes in one variable relate to changes in another (Figure 1.21).

To investigate the correlation between variables, you can examine the scatterplot created from your data. Remember that the independent variable should be plotted on the $x$-axis, and the dependent variable should be plotted on the $y$-axis. By observing the pattern of the data points on the graph, you can make inferences about the relationship between the variables.

When stating any relationship, it's important to follow the pattern of 'As the (independent variable) (state how it changes), the (dependent variable) (state how it changes).' Additionally, it's essential to consider the direction and strength of the correlation.

**Explore! 1.2**

**Scales of measurement**

Data can be organised and represented in a variety of ways, but some types of data are more appropriate to communicate data to an audience for effective interpretation.

Use the internet to define and provide an example of the following types and scales of measurement.

**Quantitative**

- Discrete
- Continuous
  - Interval scale
  - Ratio scale

**Qualitative**

- Nominal
- Ordinal

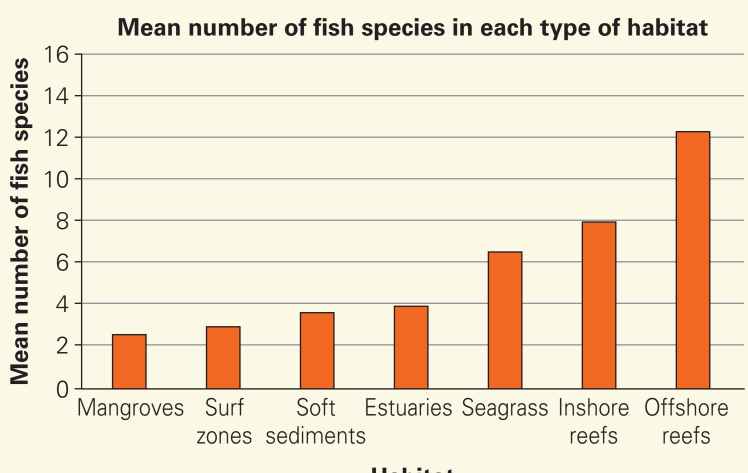


**Figure 1.22** What type of data is shown?

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## Measures of central tendency

In descriptive statistics, we can measure the centre or 'central tendency' of a data set by calculating an average.

The **mean** is used to measure the centre of a data set and is the most common statistic used to represent an average. The mean is the sum of all the values collected divided by the number of values present. However, it may not be a fair representation of the data as the mean is heavily influenced by outliers – values that are either very large or very small.

The **median** is an alternative way of measuring the centre of your data. Think about the median strip in the centre of a major highway. It is in the middle, with the same number of lanes on either side. In a set of data, the median is the value where an equal number of data points sit above it and below it. The median is the true middle of the data and is a good measure of the average when your data includes outliers. The **mode** is the most frequently occurring value or values in a data set.

**mean**
sum of all the values divided by the number of values

**median**
the middle value of the data set after all the values have been ranked (sorted in ascending order). There should be as many numbers below the median as there are above

**mode**
the most frequently occurring value or values in a data set

### Worked example 1.1

**Determining the mean, median and mode of a data set**

A group of students want to find out how long it takes to boil 500 mL of water using a particular brand of kettle. They replace the water after every boil and repeat it 10 times. Their results in minutes are: 2, 4, 4, 3, 2, 2, 3, 2, 13, 4.

Determine the mean, median and mode of the data set.

| Working | Explanation |
|---|---|
| **Calculating the mean** | |
| $\frac{(2+4+4+3+2+2+3+2+13+4)}{10} = 3.9\text{ minutes}$ | To calculate the mean, we add the values collected. Then we divide it by the number of values collected, in this case, there are 10 values. |
| **Determining the median** | |
| 2, 2, 2, 2, 3, 3, 4, 4, 4, 13 | First, we need to order the values from smallest to largest. |
| 2, 2, 2, 2, **3**, **3**, 4, 4, 4, 13 | If there is an odd number of values, then we pick the middle number.<br>In this case, there is an even number of values, so we must find the mean of the two middle numbers.<br>Note that there is an even number of values on either side of the values in red: four on the left, and four on the right. |
| $\frac{(3+3)}{2} = 3\text{ minutes}$ | In this case, because the middle numbers are the same, the median is simply 3. If the middle numbers were 3 and 5, then the median would be $\frac{(3+5)}{2} = 4$ minutes. |
| **Determining the mode** | |
| 2, 2, 2, 2, 3, 3, 4, 4, 4, 13 | First we need to order the values from smallest to largest. |
| **2, 2, 2, 2,** 3, 3, 4, 4, 4, 13 | The most frequently occurring number, the mode, is 2 minutes. |

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## Range

We can also measure the distribution of the data. This provides information about the spread of a particular variable's values. One way of doing this is to calculate the **range**, which is the difference between the smallest and largest values. Range bars can be plotted on graphs to visually represent this information. The larger the range bars, the more variation in the variable's values, suggesting that the data is less reliable. Usually, outliers are excluded from range calculations.

**range**
the difference between the highest and lowest values in the data set

In order to analyse the trends in data to make meaning of the results, it is important that results are organised and presented in appropriate and meaningful ways. Descriptive statistics and their associated errors and uncertainties provide strong evidence of the reliability and accuracy of the data and can give scientists confidence in the outcome of their experimentation.

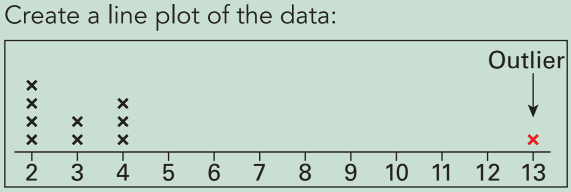
## Evaluation

The evaluation should be a critical and justified discussion of the reliability and validity of the experimental process. This involves considering the quality of your data, including identifying any outliers and giving potential reasons for their appearance. Any problems you have identified with your results need to be explained by considering the limitations imposed by the equipment and experimental techniques used. Remember to consider both random and systematic errors. Use your results to assess the accuracy of the data you collected. Accuracy can be assessed by looking at things like whether the line of best fit closely aligns with your data, or if the error bars are large or small. Consider if there are any outliers. You should also suggest and explain improvements and extensions that are logically derived from the analysis of your data.

### Worked example 1.2

**Identifying outliers in a dataset**

Using the data in Worked example 1.1, determine which data point is a likely outlier, as well as the range of the data. The results in minutes are: 2, 4, 4, 3, 2, 2, 3, 2, 13, 4.

| Working | Explanation |
| --- | --- |
| **Outliers** | |
| Create a line plot of the data:<br><br><br>Time taken to boil | Creating a line plot allows us to easily see that 13 minutes to boil is likely to be an outlier. |
| **Range** | |
| 4 − 2 = 2 minutes | Excluding the outlier, 13 minutes, we subtract the smallest value, 2, from the largest value, 4. If we include the outlier, the range would be 13 − 2 = 11 minutes. |

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**Try this 1.2**

**Descriptive statistics**

Consider the following data set: 17, 14, 18, 21, 21, 19, 12, 20, 16.

1 Calculate the mean, median, mode and range of the data.

2 Put the data into a spreadsheet software and explore how you can determine the mean, median, mode and range of the data using analysis from the software.

## Conclusion

In the conclusion you should answer your original research question, stating whether your hypothesis is supported or not. You should start with a general statement that refers to your findings in a general way, but then justify this by using actual data from your results to support this statement. You can also use your own scientific knowledge to explain your results.

The strength of a conclusion depends on the quality of the data collection and evaluation of trends through the scientific method. This is especially crucial when the investigation aims to support or refute a claim. To ensure an insightful conclusion, the experiment must be thoroughly planned and executed with a focus on gathering reliable and valid evidence.

## Making claims

Making a claim prior to or after conducting a scientific investigation must be considered very carefully. The work of scientists is reviewed by other scientists in their field of expertise, so it is imperative that any claim made is supported by reasonable evidence. Scientists first conduct literature reviews from a wide range of secondary sources and select reliable data and results which have already been supported by evidence and peer-reviewed in the past. These details improve the credibility of the source, and therefore improve the credibility of their own experimental work. In their literature review, scientists may refute claims from other secondary sources, including media reports, if there is not sufficient evidence to fully support the claims.

When making claims, scientists select data appropriate to the audience with which they are communicating. Often the audience targeted may be those who could be providing funding for the research, and due to competition between scientists, the claims made must be supported by evidence.

**Figure 1.23** A science research team meets to discuss their conclusions and claims

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## Practical skills 1.2

### Comparing the effect of indigestion remedies

**Background**

The stomach is an essential organ involved in the digestion of food. It achieves this by creating a highly acidic environment (pH of approximately 2 to 3) through the production of hydrochloric acid. However, an excess of acid in the stomach can cause painful indigestion.

Antacids are a common treatment option as they are alkaline and neutralise excess stomach acid. Now that you have the skills to measure volume accurately, design an experiment that will compare three different antacids (A, B and C) to determine which is most effective in relieving indigestion.

**Materials**

- hydrochloric acid (1 mol $L^{-1}$)
- 3 different antacids
- titration equipment
- electronic balance
- spatula
- Congo red indicator
- watchglass

**Method**

Design the method. Plan your experiment with a lab partner, taking into consideration:

- your research question
- the independent variable and dependent variables
- the variables that will be controlled in this experiment
- how you will document the results, including the results table, graph and analysis of the trends.

Carry out the experiment and derive your conclusion. Consider how you could improve the accuracy of your results in future.

QUIZ

## Section 1.2 questions

**Retrieval**

1 **State** the meaning of the term 'outlier'.

2 **Name** one specialised piece of equipment used in a titration.

**Comprehension**

3 **Explain** how the use of a data logger can be beneficial to an experiment.

**Analysis**

4 **Classify** the following errors as either random errors or systematic errors.

- a Instrument error: A burette is leaking so every reading taken is 0.1 mL lower than the actual value.
- b Human error: When recording the data, the researcher has a poor understanding of rounding decimals and consistently rounds them up to the nearest whole number.
- c Instrument error: A set of scales is not very precise and the displayed mass is often out by around 1–3 grams in either direction.

5 **Compare** the mean to the median of a data set.

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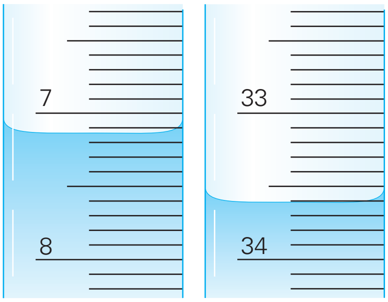
**Knowledge utilisation**

6 Take the readings from the burette below to **determine** the overall titre volume.
Initial reading: _________ Final reading: _________ Titre: _________




7 Jake took 12 identical pots and 12 identical plants. In four pots he placed soil, 10 grams of fertiliser A and one plant. In another set of four pots he placed in each a plant, 15 grams of fertiliser B and an identical amount of soil as in the previous four pots. In another four pots he placed the same amount of soil with a plant but provided no fertiliser. All 12 pots were placed in the same location and received the same amount of water and sunlight every day. Plants with fertiliser B grew much larger than all the others. Jake concluded that fertiliser B was better than fertiliser A. **Discuss** whether his conclusion is valid.

## Extension practical

### Titration using a pH probe

**Aim**

To complete a titration using a pH probe linked up to a data-logging program to produce a graph showing pH changes as a base is added to an acid.

**Be careful**

Wear appropriate personal protective equipment.

**Materials**

Four different combinations of acid and base solutions are supplied for the class to test. Such combinations include strong acid–strong base, strong base–weak acid, strong acid–weak base and weak base–weak acid.

- pipette
- burette
- burette funnel
- conical flask
- retort stand
- burette clamp
- pipette bulb
- bosshead
- clamp
- wash bottle
- pH probe and data logger
- computer or laptop
- data-logging software

*continued…*

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*continued…*

**Method**

You will be provided with four different combinations of acid and base solutions to titrate. Decide who will be in charge of the continuous stirring of the solution in the beaker and who will be in charge of releasing the base into the beaker using the burette.

1 Set up the burette and apparatus as shown in Figure 1.24 by using a clamp and a retort stand to secure the pH sensor.

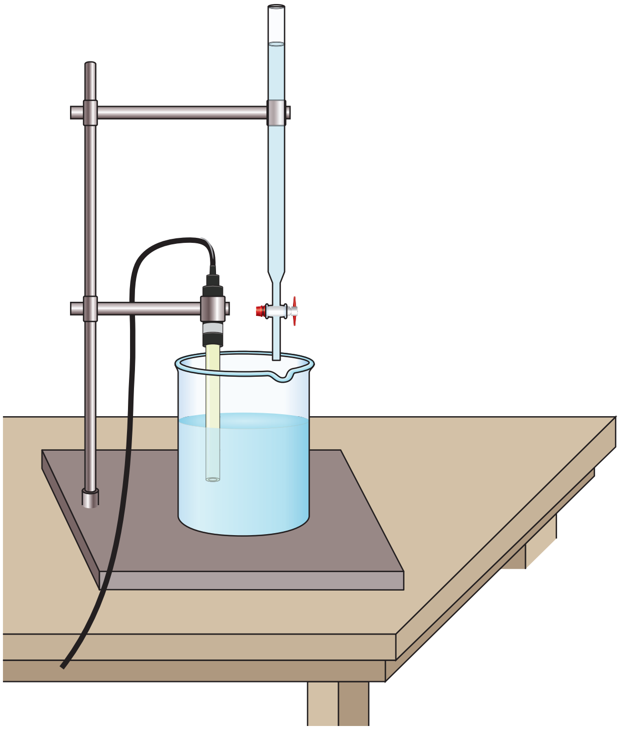

**Figure 1.24** Experimental set-up

2 Rinse the burette thoroughly with a few millilitres of the basic solution.

3 Fill the burette using approximately 50 mL of basic solution and record the precise volume.

4 Add 50 mL of distilled water to a 250 mL beaker.

5 Pipette 10 mL of the acid into the beaker of distilled water.

6 Connect the data logger and pH sensor to the computer or laptop and open up the relevant 'Acid–Base' titration program.

7 Monitor the pH for approximately 20 seconds and wait for the reading to stabilise.

8 Enter 0 mL as the first data point of base added in the computer program.

9 Slowly start to add some of the basic solution until the pH has risen approximately 0.2 units.

10 Wait for a stable pH reading and record the burette reading (volume of base left in the burette) to the nearest 0.01 mL.

11 Repeat steps **9** and **10** until the pH starts to get close to 3.5.

12 Start adding smaller equal volumes of approximately 0.1 mL of basic solution to the beaker, making sure to record the burette reading into the software after each increment.

*continued…*

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*continued…*

13 When the pH reaches close to 10, add larger amounts of basic solution that raise the pH approximately 0.2 units.

14 Continue adding the basic solution until the pH remains constant and stable.

15 Click stop on the software and save copies of the table and graph.

16 Dispose of the beaker contents as directed by your teacher and the safety data sheet.

**Results**

Print out your table and graph.

**Analysis**

1 Compare the four different graphs you have produced.

2 Discuss the different shapes of curves that were produced in relation to the strength of the acid and base combinations used. Compare them to Figure 1.25, which represents a standard titration graph of the kind that would be found in a literature review.

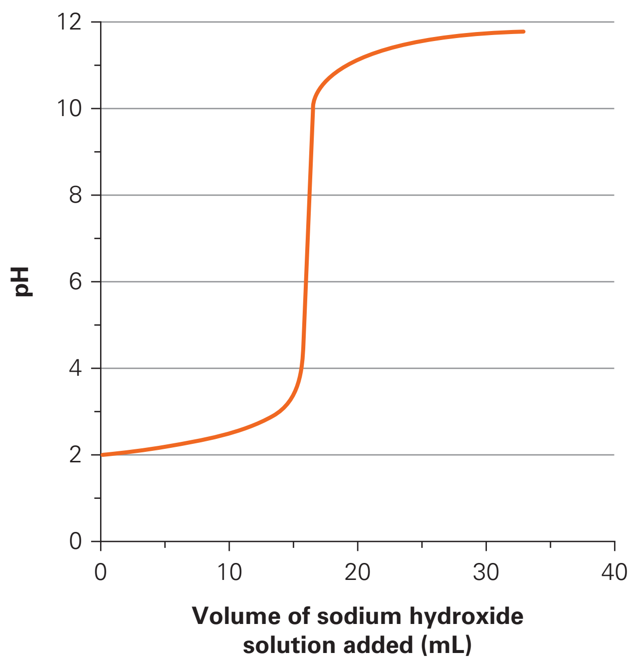


**Figure 1.25** A graph showing how the pH (concentration) changes as a volume of sodium hydroxide (a strong base) is titrated into a strong acid

**Evaluation**

1 Discuss whether this experiment would have been possible without the use of a data logger.

2 Propose any extensions or improvements that could be made to this experiment if you were to do it again.

**Conclusion**

1 State a conclusion that can be made regarding the pH when a base is titrated into an acid.

2 Justify your conclusion by using the data you gathered.

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# Chapter review

## Chapter checklist

You can download this checklist from the Interactive Textbook to complete it.

| Success criteria | | Linked questions | Check |
|---|---|---|---|
| 1.1 | I can describe each stage of the experimental design process. | 4 | |
| 1.1 | I can identify independent, dependent and controlled variables. | 2 | |
| 1.1 | I can recognise the difference between reliability and validity. | 11 | |
| 1.1 | I can recognise the need to write a risk assessment before completing any experiment. | 4 | |
| 1.1 | I can describe the information found on a safety data sheet (SDS). | 3 | |
| 1.1 | I can describe the ethical requirements of working with humans and animals. | 1 | |
| 1.2 | I can describe the use and importance of specialised equipment such as burettes, pipettes and data loggers. | 6 | |
| 1.2 | I can recognise the difference between accuracy and precision. | 9 | |
| 1.2 | I can recognise outliers in scientific data. | 6 | |
| 1.2 | I can provide examples of common systematic and random errors in scientific experiments. | 5 | |
| 1.2 | I can calculate the mean, median, mode and range in scientific data. | 7 | |
| 1.2 | I can define the absolute and relative uncertainty in a measurement. | 10 | |

## Review questions

SCORCHER

### Retrieval

1 **Recall** what a scientist should do if they discover a First Nations Australian artefact during fieldwork.

2 **Define** the following terms.

a independent variable
b dependent variable
c controlled variables

3 **Recall** the reason a safety data sheet (SDS) should be understood before conducting an experiment.

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### Comprehension

4 **Describe** why it is necessary to complete a risk assessment before conducting the experiment.

5 **Explain** why repeating an experiment multiple times is considered a method to minimise random errors.

6 **Describe** why a burette is used in an experiment.

### Analysis

7 The table below shows the effect of changing the pH of a pond on the number of tadpoles in the pond.

| pH of water | Number of tadpoles | | |
|---|---|---|---|
| | Trial pond 1 | Trial pond 2 | Trial pond 3 |
| 8 | 45 | 44 | 43 |
| 7.5 | 69 | 71 | 70 |
| 7 | 78 | 80 | 81 |
| 6.5 | 88 | 85 | 89 |
| 6 | 43 | 43 | 43 |
| 5.5 | 23 | 24 | 5 |

a **Identify** the independent variable and dependent variable of this study.

b **Identify** the optimum pH for tadpole growth.

c **Identify** an outlier in the data.

d **Calculate** the mean and median number of tadpoles in a pond with a pH of 7.5.

e **Calculate** the range of the number of tadpoles in a pond with a pH of 6.5.

f **Construct** a graph of the number of tadpoles in trial pond 1 against the pH of water. Label the axes correctly and write an appropriate title.

8 Read the following text.
Research has been conducted on the effect of short, daily exercise on mice and rats. The mice and rats were all exercised mildly for 10 minutes once a day. When the mice and rats exercise, it was shown that they develop more new brain cells, compared to if they do not exercise. These new cells were mostly located in or around the hippocampus, which is involved in the creation and storage of memory, improving their memory and learning abilities when tested.

**Source:** Even a 10-Minute Walk May Be Good for the Brain', Gretchen Reynolds, *The New York Times*, 24 October 2018

Using the information, **categorise** the following variables as independent, dependent or controlled.

a Memory ability

b Exercise intensity

c Age of rodent

d Undertaking exercise

e Time taken to exercise

9 **Distinguish** between accuracy and precision.

10 **Contrast** relative and absolute uncertainty.

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### Knowledge utilisation

11 A Year 10 student was interested in testing the effects of sleep deprivation on memory recall in secondary school students. He chose four of his Year 10 male friends to be the participants. Two of them said they went without sleep for 24 hours and were then given 20 three-letter nonsense words (for example, tuf, pud, wes) to memorise for two minutes and then recall. The other two of his friends said they slept for their usual time and were given the same memory test: 20 three-letter nonsense words to memorise for two minutes and then recall. Results are shown below.

| | Mean recall score of three-letter nonsense words (out of 20) |
|---|---|
| Sleep-deprived group | 5 |
| Non-sleep-deprived group | 11 |

a **Write** a hypothesis for this experiment.

b **List** the independent variable, dependent variable and two possible controlled variables in the experiment.

c **Propose** a conclusion that can be drawn from the results obtained.

d **Evaluate** the possible limitations to the reliability and validity of this experiment.

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## Data questions

High school students were analysing the content of ethanoic acid in a commercial vinegar sample and had made up a dilute solution of 0.1 mol $L^{-1}$ ethanoic acid based on the concentration of ethanoic acid given on the bottle of vinegar. The students set up a titration with 20.00 mL of their ethanoic acid in a conical flask (via pipette) and filled a burette with 0.1 mol $L^{-1}$ NaOH.

If the ethanoic acid content quoted on the vinegar bottle was correct, the students hypothesised that 'if 20 mL of 0.1 mol $L^{-1}$ ethanoic acid is present, then 20 mL of 0.1 mol $L^{-1}$ NaOH will be required to reach an end point'. The titration data from two students carrying out six replicated trials are tabulated below.

| Titration | Volume (mL) 0.1 mol $L^{-1}$ NaOH to end point | |
|---|---|---|
| | Student 1 | Student 2 |
| 1 | 19.95 | 20.50 |
| 2 | 20.00 | 20.50 |
| 3 | 20.50 | 20.50 |
| 4 | 22.70 | 29.30 |
| 5 | 19.95 | 20.40 |
| 6 | 20.00 | 20.40 |
| **Mean** | | |

### Apply

1 **Identify** and circle any outliers in each student's trials.

2 **Calculate** the mean volume of NaOH required to reach the titration end point, after removing outliers for each student.

3 The 'true' value for the titration given the actual concentration of ethanoic acid should have been 20.00 mL of 0.1 mol $L^{-1}$ NaOH. **Recognise** the validity of this experiment in identifying the concentration of ethanoic acid.

### Analyse

4 **Identify** if any patterns occur in the results obtained by the students.

5 **Contrast** the data tabulated. Was each student accurate?

6 **Analyse** the data tabulated. Were the students precise?

### Interpret

7 **Justify** whether the data presented by students 1 and 2 provide evidence to support the hypothesis.

8 **Compare** the data fluctuations for each student. Do the data points fluctuate randomly above and below the true value or are they biased in one direction?

9 Based on the data presented, **infer** whether the experiment was repeatable and reproducible.

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# Chapter 2
# Genetics

## Chapter introduction

Everyone is unique, but you may look similar to your parents. This is thanks to the genes that they passed on to you. Genes carry the information that determines your traits and are made of DNA. This chapter explores the structure and function of DNA and genes in heredity. You will consider how variation is increased in offspring and predict patterns of inheritance. You will also examine what happens when there are problems with DNA and how these may be caused by the environment.

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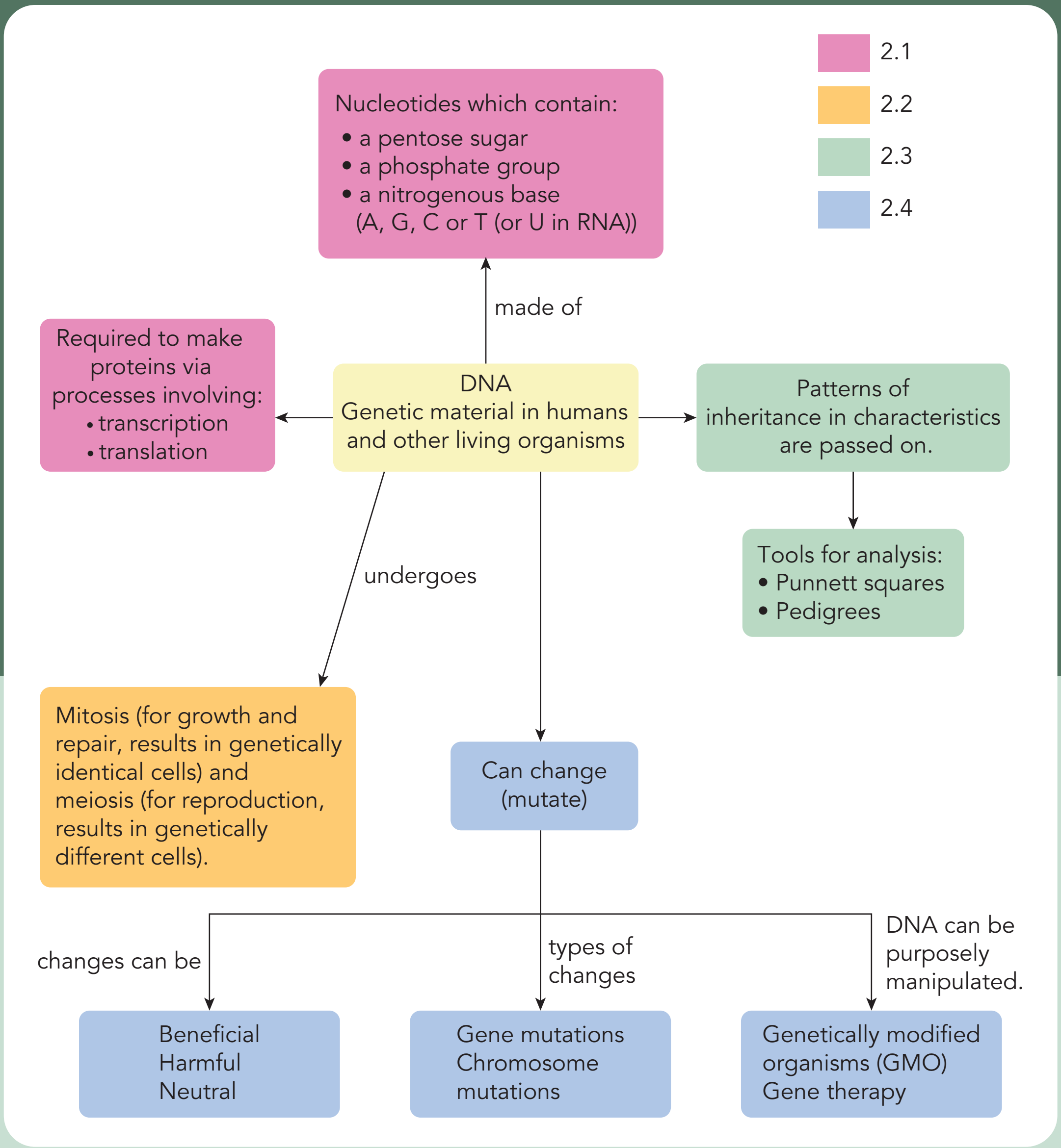
# Concept map

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## Curriculum

| Explain the role of meiosis and mitosis and the function of chromosomes, DNA and genes in heredity and predict patterns of Mendelian inheritance (AC9S10U01) | |
|---|---|
| using models and diagrams to represent the relationship between genes, chromosomes, and DNA of an organism's genome | 2.1 |
| explaining how genetic information passed on to offspring from both parents by meiosis and fertilisation increases the variation of a species | 2.2 |
| using Mendelian inheritance to predict the ratio of offspring genotypes and phenotypes in monohybrid crosses involving dominant and recessive alleles or in genes that are sex-linked | 2.3 |
| using pedigree diagrams to show patterns of inheritance of simple dominant and recessive characteristics through multigenerational families | 2.3 |
| investigating First Nations Australians' knowledges of heredity as evidenced by the strict adherence to kinship and family structures, especially marriage laws | 2.3 |
| exploring environmental and other factors that cause mutations and identifying changes in DNA or chromosomes | 2.4 |
| exploring the role of DNA in cancer or genetic disorders such as haemochromatosis, sickle cell anaemia, cystic fibrosis or Klinefelter syndrome | 2.4 |



## Glossary terms

Allele
Aneuploidy
Autosome
Base triplet
Carrier
Centromere
Chromatin
Chromosome
Chromosome mutation
Codominance
Codon
Complementary base pairing
Deletion
Diploid (2*n*)
DNA
Dominant
Embryo
Fertilisation
Gametes
Gene
Gene mutation
Gene therapy
Genetic engineering
Genetic screening
Genetically modified organism
Genetics
Genome
Genotype
Germline mutation
Gonads
Haploid (*n*)
Heredity
Heterozygous
Homologous chromosomes
Homozygous
Hydrogen bonds
Incomplete dominance
Induced mutation
Insertion
Inversion
Karyotype
Locus
Meiosis
Mitosis
Monohybrid cross
Monomer
Mutagenic
Mutation
Non-disjunction
Non-homologous chromosomes
Nucleotide
Ova
Pedigree
Phenotype
Point mutation
Polymer
Polypeptide
Punnett square
Recessive
Recombination
Reduction division
Sex chromosomes
Sexual reproduction
Sister chromatids
Somatic cells
Somatic mutation
Spontaneous mutation
Substitution
Telomeres
Test cross
Transcription
Transgenic organism
Translation
Trisomy
Zygote

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# 2.1 Introduction to genetics and DNA

WORKSHEET DNA structure

VIDEO Structure of DNA

**Learning goals**

1. To recall the components that make up the structure of DNA and RNA molecules.
2. To be able to describe the relationship between DNA, genes and chromosomes.
3. To describe the steps in which DNA is used to synthesise proteins.

## Genetics

**Genetics** is the study of how certain traits (characteristics) can be inherited from a previous generation. It involves the study of **genes**, genetic variation and **heredity**. Genes are considered the basic unit of inheritance. They are made of **d**eoxyribo**n**ucleic **a**cid, or **DNA** for short. This hereditary material is passed from parents to offspring and contains the information needed to specify traits.

## Structure of DNA

DNA is a double-stranded molecule that forms a 'double helix' shape, like a twisted ladder. DNA is a **polymer** as it is made up of many **monomer** subunits called **nucleotides**.

The nucleotides that make up DNA have three major components:

- a five-carbon (pentose) deoxyribose sugar
- a nitrogenous base – one of adenine (A), guanine (G), cytosine (C) or thymine (T)
- a negatively charged phosphate group.

The nucleotides bind together to form two long strands that wind around each other. Each strand has a backbone made of alternating deoxyribose sugar and phosphate groups.

**genetics**
the study of genes, genetic variation and heredity

**gene**
a length of chromosome made of DNA, the basic unit of inheritance

**heredity**
the genetic passing on of traits from one generation to the next

**DNA**
the molecular unit of heredity, containing the genetic information responsible for the development and function of an organism (deoxyribonucleic acid)

**polymer**
a molecule made from many repeating subunits called monomers

**monomer**
a single subunit that when joined together repeatedly makes a polymer

**nucleotide**
a monomer subunit of a nucleic acid, consisting of a phosphate group bound to a five-carbon sugar, which in turn is bound to a nitrogenous base

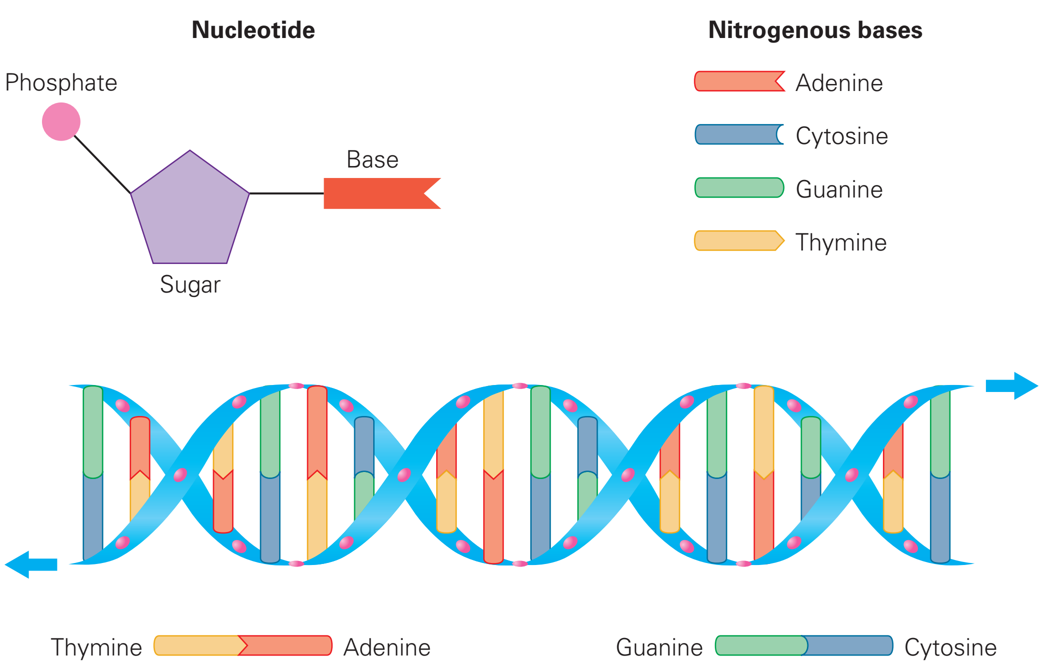


**Figure 2.1** The double helix structure of DNA: the subunits called nucleotides all join up to form the double-stranded DNA. Note the sugar–phosphate backbone on the edge of the DNA molecule and the nitrogenous bases joining in the centre.

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**hydrogen bonds** chemical bonds that hold the two DNA strands together

**complementary base pairing** adenine only binds with thymine and cytosine only binds with guanine

The nitrogenous bases from one strand bind to complementary bases on the other strand using **hydrogen bonds**.

Adenine (A) always pairs with thymine (T), and guanine (G) always pairs with cytosine (C). One way to remember the A–T and G–C pairings is 'AT the Gold Coast'. This **complementary base pairing** occurs because of the shape of the nitrogenous bases and the number of hydrogen bonds they can form (Figure 2.3).

Guanine and adenine have a double-ring structure, which means they belong to a group of chemical molecules called purines. A helpful way to remember that adenine and guanine are purines is 'Pure As Gold'. Cytosine and thymine have a single-ring structure and belong to the group called pyrimidines. Purines always pair with pyrimidines, but the number of hydrogen bonds between them depends on the structure. Guanine binds with cytosine with three hydrogen bonds, while adenine and thymine form two hydrogen bonds.

Figure 2.2 Traits are passed on from generation to generation.

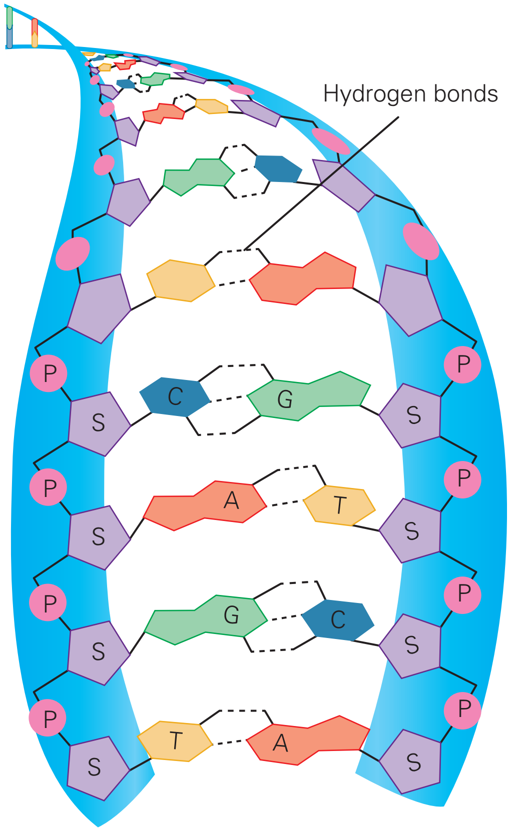


Figure 2.3 A closer look at the structure of DNA. The sugar–phosphate backbone forms the outer edge of the helix and the nitrogenous bases form complementary pairs in the centre. Hydrogen bonds hold the two strands together.

## Try this 2.1

### Modelling DNA using lollies

**Materials**

- liquorice ribbons or sour strips
- a handful of jelly babies
- cocktail sticks

**Be careful**

Do not to consume lollies in the laboratory. Beware of allergies.

**Method**

1. Sort the jelly babies into four groups of colours.
2. Pair up the jelly babies so that one particular colour always goes with another particular colour, for example, red with yellow and orange with green.
3. Place a pair of jelly babies onto each cocktail stick as if you were making lolly kebabs. Ensure that the pairs are always of matched colours.
4. Attach your lolly kebabs to the long strips of liquorice.
5. Keep doing this until you have about 5–7 horizontal cocktail sticks attached and it starts to look a bit like a ladder.
6. The paired coloured sweets represent the base pairs, while the liquorice is the sugar–phosphate backbone.
7. Pick up your lolly ladder and twist it to represent the double helix shape of DNA.

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## Practical skills 2.1

### Extracting DNA from cells

**Be careful**
Wear safety glasses and a lab coat. Do not consume food items.

**Time period**
Approximately 1 hour

**Aim**
To investigate and extract DNA from strawberries.

**Materials**
- plastic sandwich bag (or other material to contain strawberry and liquid)
- strawberry
- DNA extraction solution provided (10 mL)
- filter funnel and gauze (or other gauze-style filter)
- cold ethanol solution
- test tube (or small beaker)
- stirring rod
- plastic pipette

DNA extraction mixture:
- dishwashing liquid or shampoo (5 mL)
- table salt (0.75 g)
- water (45 mL)

**Method**
1. Wash the strawberry with tap water and remove the green leaves. Add the strawberry to the plastic sandwich bag.
2. Add the DNA extraction solution (10 mL) and close the sandwich bag, removing the excess air.
3. Squash the strawberry into the liquid using your hands until the strawberry is roughly crushed.
4. Pour the strawberry mixture through a filter funnel lined with gauze into a test tube.
5. Discard the gauze and strawberry remains into a bin.
6. Add an equal volume of cold ethanol to the test tube using a plastic pipette.
7. Slowly mix the two layers of liquid with a stirring rod.
8. Collect the white solid that forms on the stirring rod. This is DNA.

**Results**
Write observations for what occurs during each step of the method.

**Discussion**
1. Describe whether the white solid could contain all of the DNA of the strawberry.
2. Visually compare the amount of solid you collected to that of other groups in the classroom. Were results consistent? Explain your answer.
3. Describe the variables that were not kept consistent between groups in the classroom.
4. Suggest any changes that could be made to the method to improve the quality of the recorded data in future experiments. Justify your suggestions by explaining how each change would improve the data quality.

**Conclusion**
Draw a conclusion regarding the efficiency of this method at extracting all the DNA from a strawberry, based on your and other groups' observations.

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**Did you know? 2.1**

**How long is DNA?**

The DNA found in only one cell, if fully unravelled, would be around two or more metres long! The length of a piece of double-stranded DNA is commonly expressed as the number of complementary nitrogenous base pairs it contains. The DNA in an average human cell has an estimated 63 000 000 base pairs.

**Quick check 2.1**

1 Recall the three key components that make up a nucleotide.
2 Describe the overall shape of DNA.
3 If a strand of DNA contained the nitrogenous bases seen below, state the bases in its complementary strand. DNA strand: ATATAGATAGATCAGACA.

**Explore! 2.1**

**The discovery of DNA**

Friedrich Miescher was a Swiss biochemist who first observed DNA in 1869. However, it took almost a century for scientists to understand the structure of DNA and the mechanisms by which it carries genetic information.

Research the following scientists who, among many others, contributed to our understanding of DNA:

- Friedrich Miescher
- Erwin Chargaff
- Francis Crick and James Watson
- Rosalind Franklin and Ray Gosling
- Maurice Wilkins.

Summarise their contributions and place them on a timeline.

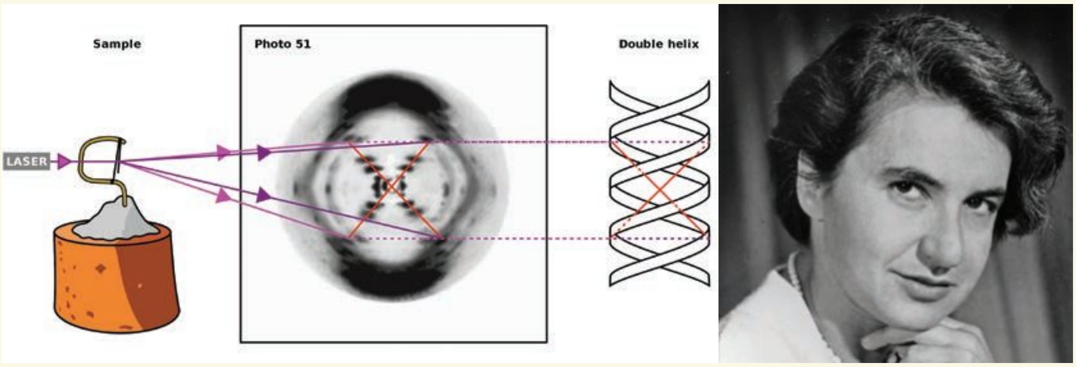


Figure 2.4 Dr Rosalind Franklin (right) and Ray Gosling fired X-rays at a DNA strand stretched across a paperclip in 1952. The resulting picture was critical to the discovery of the double helix structure of DNA, providing key information that enabled James Watson and Francis Crick to build the first correct model of the structure of DNA.

## What is a chromosome?

**chromatin**
a mixture of DNA and proteins that form chromosomes

**chromosome**
a thread-like structure of tightly wound DNA and proteins

The DNA found in the nucleus of a cell is usually in a form called **chromatin**. This is a highly organised complex of DNA and associated proteins such as histones. By wrapping around histones, the long strands of DNA can fit inside the nucleus.

When it is time for the cell to replicate, chromatin condenses into structures called **chromosomes**. Each molecule of DNA forms one chromosome. Along the chromosome are genes, which are the units of inheritance. Genes are sections of DNA that hold the specific instructions required for making every protein in our bodies.

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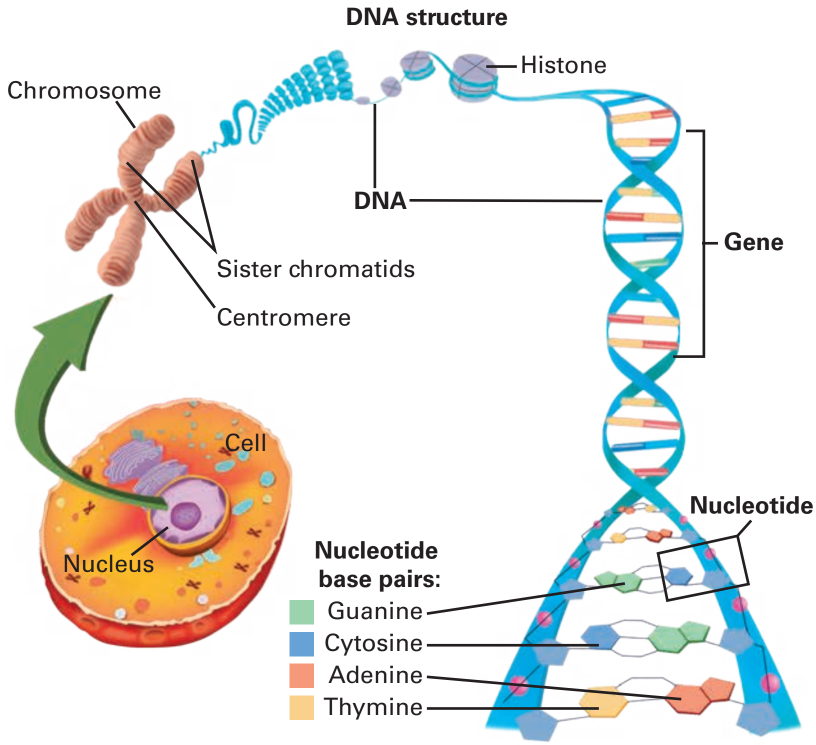


Figure 2.5 The relationship between DNA and chromosomes

**sister chromatids**
two copies of the same chromosome, connected at a centromere

**centromere**
a structure that holds two sister chromatids together

**telomeres**
structures made from DNA and proteins that protect the ends of chromosomes

VIDEO
DNA and RNA

The familiar X-shape of a chromosome is only seen after DNA replication has occurred. Shortly before replication, the chromosome appears as a single condensed DNA molecule. DNA replication produces two identical **sister chromatids** that are joined together by **centromeres** to form the distinct X-shape (Figure 2.6). At the ends of each chromosome are protective structures made of DNA and protein called **telomeres**. These protect the chromosomes, but every time DNA replicates, the telomeres shorten. Eventually, the telomeres shorten to the extent that replication can no longer occur.

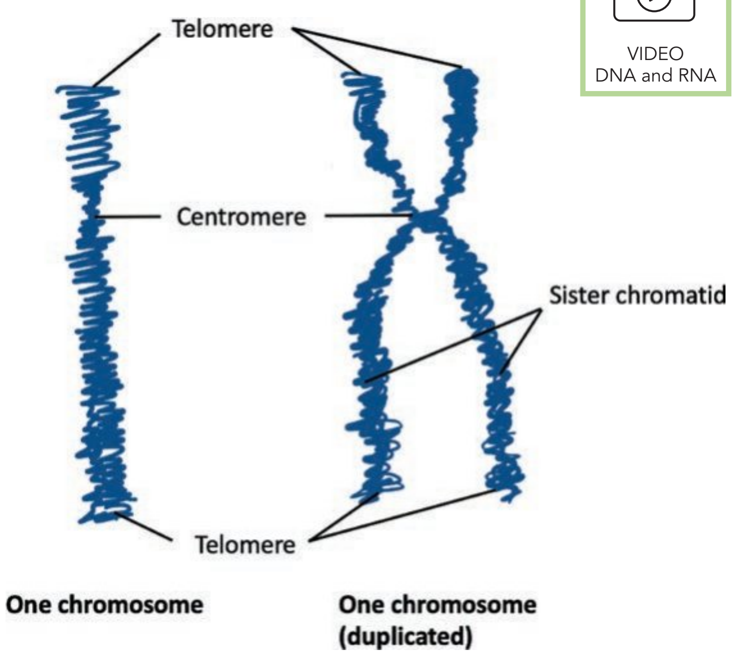


Figure 2.6 Before replication, a chromosome is a single molecule (left). After DNA replication, each chromosome consists of two molecules called sister chromatids (right).

## Different forms of nucleic acids

There are four types of biological macromolecules: proteins, carbohydrates, lipids (fats and oils) and nucleic acids. Nucleic acids are found in two forms: DNA and **r**ibo**n**ucleic **a**cid (RNA). The two types of nucleic acids differ in several key ways, which are outlined in Table 2.1 and shown in Figure 2.10.

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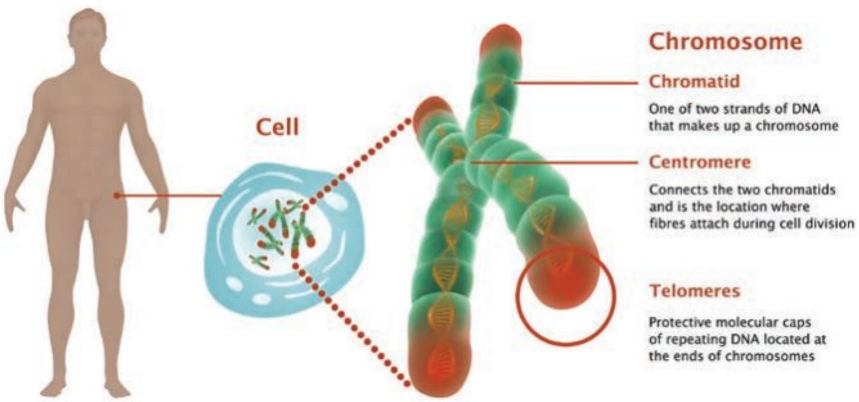


**Figure 2.7** The distinct X-shaped chromosome, showing the two sister chromatids and the centromere

**Figure 2.8** A scanning electron micrograph of a duplicated human chromosome

## Making thinking visible 2.1

### Compass Points: Telomeres and immortality

Telomeres contain thousands of repeated copies of the base sequence TTAGGG. When we are infants, our telomeres are approximately 10 000 bases long, but each time the cell divides, they slowly get shorter. A cell will die when its telomeres become too short. By the time we are in our 80s, our telomeres may only be 5000 bases long, but this varies from tissue to tissue and from person to person. A person in their 30s may well have telomere lengths of a person in their 90s and vice versa.

This means that telomeres are a key component of ageing, and there are efforts to use them to slow down or reverse the ageing process. Some companies say they can measure your telomere length, suggesting that it will indicate your true, biological age. Despite limited evidence, there are also companies that sell products that they claim can maintain or lengthen telomeres – in effect, making you younger or possibly allowing immortality.

Complete the Compass Points activity about manipulating telomeres to prevent ageing:

E = Enthusiastic
What generates enthusiasm within you regarding this concept? What are the potential benefits?

W = Worries
What causes concern about this idea? What are the potential drawbacks?

N = Need for Information
What other details or facts are necessary to evaluate this idea? What additional knowledge would aid in assessment?

S = Suggestion for Progress

What is your current viewpoint or proposal regarding this idea? How can you continue to assess this concept?

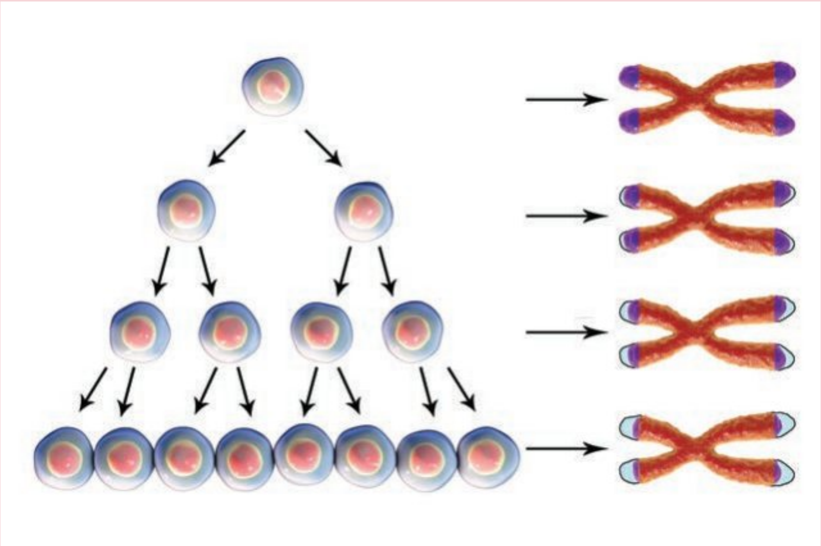

**Figure 2.9** Telomeres shorten every time a cell divides.

The *Compass points* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

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| | DNA | RNA |
|---|---|---|
| Number of strands | Two | One |
| Type of sugar | Deoxyribose | Ribose |
| Nitrogenous bases | Guanine<br>Cytosine<br>Adenine<br>Thymine | Guanine<br>Cytosine<br>Adenine<br>Uracil |
| Where is the molecule found? | Nucleus, mitochondria and chloroplasts (in eukaryotes)<br>Cytoplasm (in prokaryotes) | Cytoplasm<br>Nucleus<br>Ribosomes |
| Different forms | DNA<br>Mitochondrial DNA (mtDNA)<br>Chloroplast DNA (cpDNA) | Messenger RNA (mRNA)<br>Transfer RNA (tRNA)<br>Ribosomal RNA (rRNA) |

**Table 2.1** The main differences between the two nucleic acids, DNA and RNA

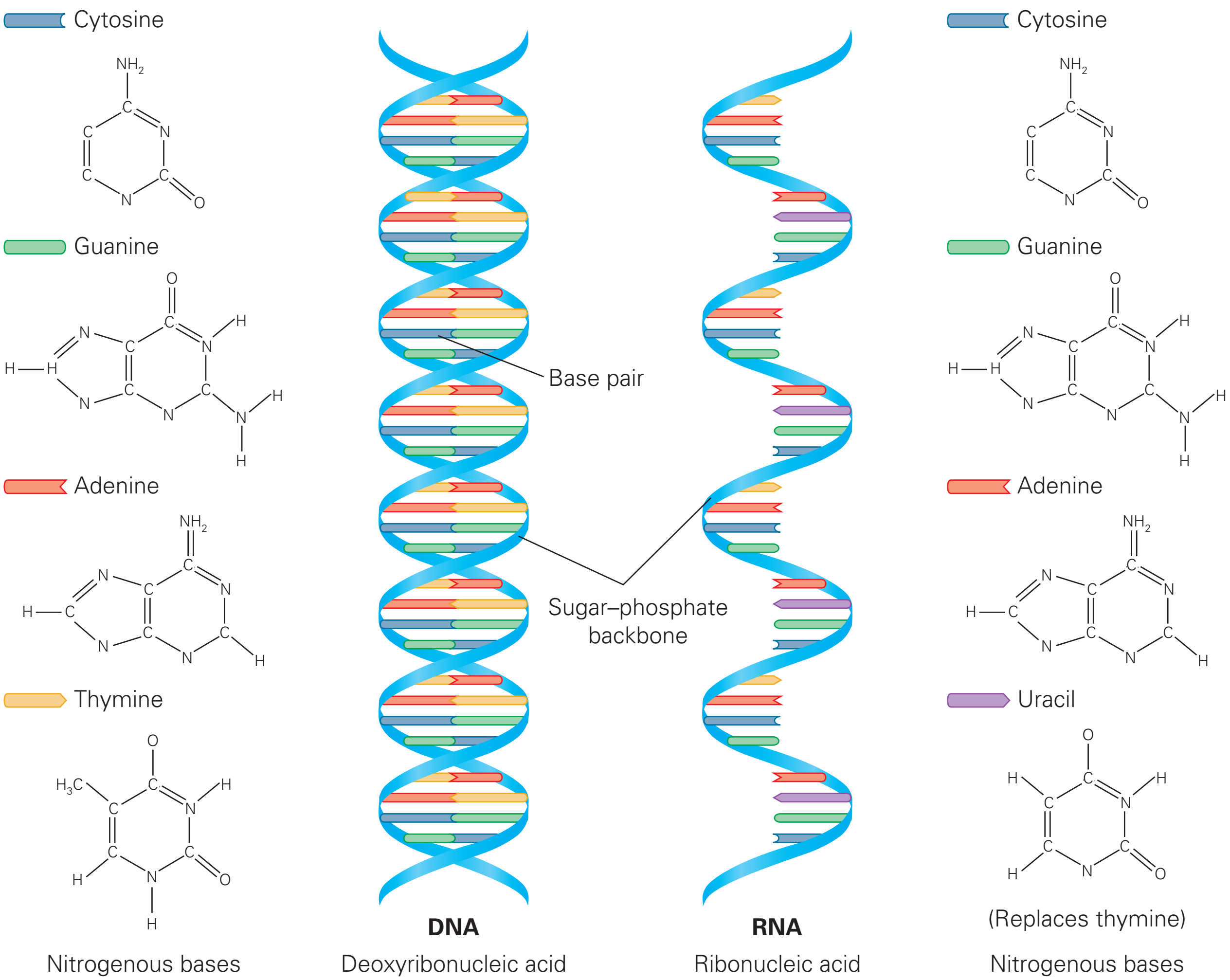


**Figure 2.10** DNA and RNA

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**Quick check 2.2**

1 Describe the relationship between chromosomes, genes, DNA and base pairs.
2 Contrast the structures of DNA and RNA.

## The purpose of DNA: Making proteins

### Why do we need proteins?

Proteins are complex molecules that play a critical role in many body functions. We use approximately one billion proteins every day, just to function normally. Proteins help provide structure to cells and build and repair tissue. Protein molecules play many other varied roles in the body; they include haemoglobin molecules that carry oxygen around our body and the hormones that regulate our glucose levels and development. Collagen and keratin are structural proteins, making up the structural components of organs. Enzymes such as amylase and lipase are catalytic proteins that help control the rates of reactions. Other proteins help us fight pathogens, transport molecules and move our muscles.

DOC
WORKSHEET
Protein synthesis

**base triplet**
a set of three nitrogenous bases that code for an amino acid

**transcription**
the first stage of protein synthesis in which the base sequence of DNA is copied into mRNA

**translation**
the second stage of protein synthesis in which a sequence of mRNA is translated into a sequence of amino acids

**Explore! 2.2**

**Protein functions**

The many roles of protein include structural, contractile, transport, catalytic, regulatory and immunological functions. Research the following proteins and determine their function.

| Protein | Function |
|---|---|
| Oxytocin | |
| Actin | |
| Ferritin | |
| Insulin | |

## The link between DNA and proteins

Genes are sections of DNA that hold the specific instructions required for making each of the proteins in our bodies. The sequence of the nitrogenous bases in a gene provides the instructions (or code) to produce a protein. A group of three nitrogenous bases is called a **base triplet**, and these code for a particular amino acid. Amino acids are the monomers of proteins, so the order of nitrogenous bases specifies the sequence of amino acids that forms a particular protein.

**Quick check 2.3**

1 Recall why proteins are important.
2 Describe the relationship between DNA, amino acids and proteins.

## Protein synthesis

To synthesise (or build) proteins using the DNA code in genes, the gene must be expressed; that is, the instruction in the DNA is converted into a protein. This means two processes need to occur: **transcription** and **translation**.

To transcribe means to put into written form, so in this process the DNA code for a specific protein is 'written down' in the form of mRNA (messenger RNA).

To translate means to convert into another form, so in this process the code (written down as mRNA) is converted into a chain of amino acids. Recall that a chain of amino acids is a protein.

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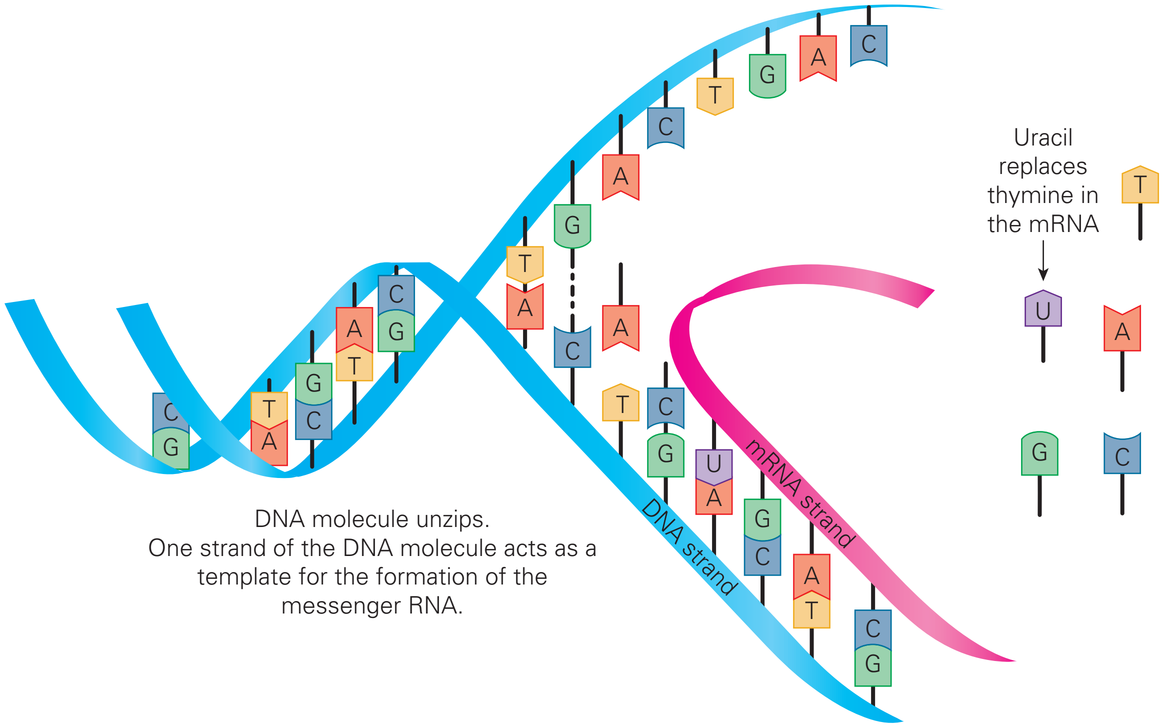


**Figure 2.11** When the DNA double helix unwinds and unzips, one strand of the DNA acts as the template on which messenger RNA strand is formed.

## Transcription

Transcription happens in the nucleus of the cell. The transcription process requires getting access to the DNA code in the genes, otherwise the code cannot be copied. Transcription begins when an enzyme (RNA polymerase) binds to the gene being copied. This causes the DNA double helix to unwind, allowing the enzyme to read the code on one of the DNA strands (called the DNA template strand). As the enzyme reads the code, it builds a complementary copy of the gene using RNA nucleotides: C, G, A and U. RNA follows the same complementary pairing rules as DNA, with one exception. Where DNA has the nitrogenous base thymine (T), RNA has uracil (U). The newly formed single-stranded RNA is called messenger RNA (mRNA). When the mRNA peels away from the DNA template strand, the DNA double strands rejoin and wind back up into a helix. The mRNA then leaves the nucleus and goes to the site of protein production, the ribosomes.

### Try this 2.2

**Base pairings**

Complete the base sequence of the DNA complementary strand and then the mRNA strand formed from the DNA template strand given below.

| | |
|---|---|
| **Complementary DNA** | |
| **DNA template** | T A C C C G A A A G T G |
| **mRNA** | |

## Translation

Once mRNA reaches the ribosomes in the cytoplasm, it must be 'decoded' or translated to make the necessary protein. The nitrogenous bases in the mRNA are decoded in groups of three called **codons** (base triplets in the original DNA template strand). Each codon in the mRNA specifies which amino acid is added to the **polypeptide** chain.

WIDGET Building a protein

**codon**
three nucleotides (base triplet) on mRNA that code for an amino acid

**polypeptide**
a chain of amino acids, forming part or the whole of a protein molecule

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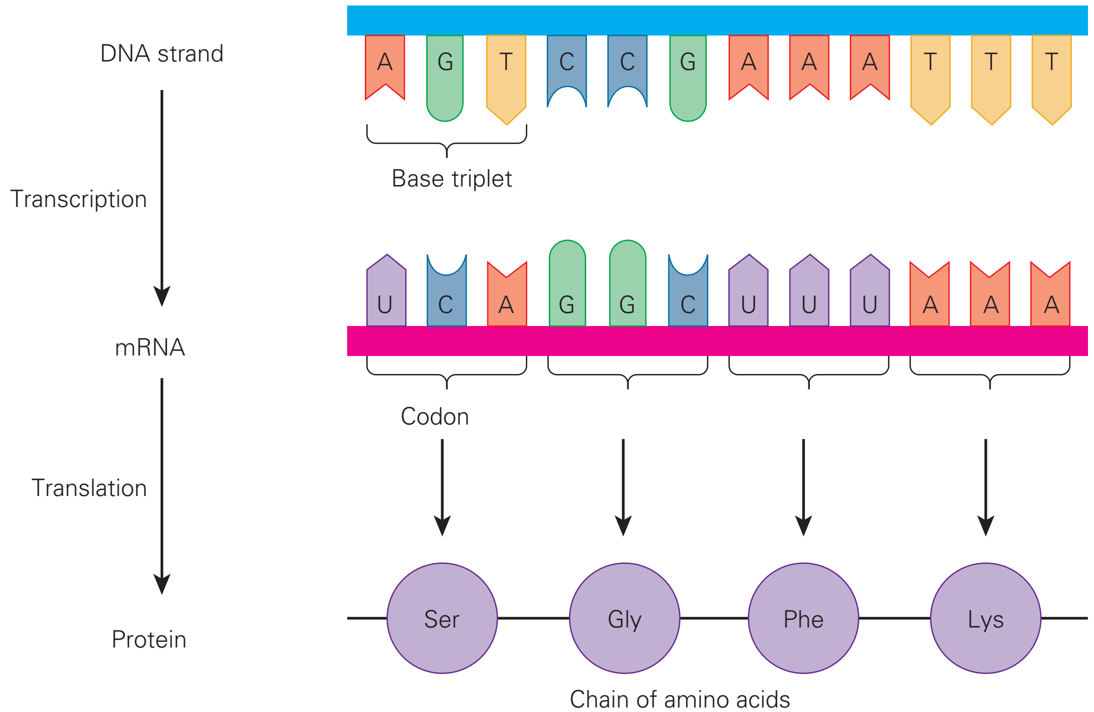


**Figure 2.12** The process of transcription and translation from a DNA molecule to an amino acid chain

Second letter in the codon

| First letter in the codon | U | | C | | A | | G | | Third letter in the codon |
|---|---|---|---|---|---|---|---|---|---|
| **U** | UUU | Phe (F) | UCU | Ser (S) | UAU | Tyr (Y) | UGU | Cys (C) | **U** |
| | UUC | | UCC | | UAC | | UGC | | **C** |
| | UUA | Leu (L) | UCA | | UAA | STOP | UGA | STOP | **A** |
| | UUG | | UCG | | UAG | STOP | UGG | Trp (W) | **G** |
| **C** | CUU | Leu (L) | CCU | Pro (P) | CAU | His (H) | CGU | Arg (R) | **U** |
| | CUC | | CCC | | CAC | | CGC | | **C** |
| | CUA | | CCA | | CAA | Gln (Q) | CGA | | **A** |
| | CUG | | CCG | | CAG | | CGG | | **G** |
| **A** | AUU | Ile (I) | ACU | Thr (T) | AAU | Asn (N) | AGU | Ser (S) | **U** |
| | AUC | | ACC | | AAC | | AGC | | **C** |
| | AUA | | ACA | | AAA | Lys (K) | AGA | Arg (R) | **A** |
| | AUG | Met (M) START | ACG | | AAG | | AGG | | **G** |
| **G** | GUU | Val (V) | GCU | Ala (A) | GAU | Asp (D) | GGU | Gly (G) | **U** |
| | GUC | | GCC | | GAC | | GGC | | **C** |
| | GUA | | GCA | | GAA | Glu (E) | GGA | | **A** |
| | GUG | | GCG | | GAG | | GGG | | **G** |

**Table 2.2** Table of amino acids showing that the genetic code is degenerate, which means that more than one codon can code for a single amino acid. This redundancy means that 61 of the 64 codons code for the 20 amino acids (the other three are stop codons).

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Figure 2.12 simplifies the process of translation. In reality, translation requires several enzymes and another type of RNA called transfer RNA (tRNA). It occurs at the ribosomes, which may be freely floating in the cytoplasm or attached to the endoplasmic reticulum (ER). Each tRNA molecule transports one specific amino acid towards the ribosome for delivery.

Table 2.2 shows the 20 different amino acids that form the building blocks for every protein. Using this table, you can identify the amino acid that each codon codes for. For example, if the first codon of your mRNA strand is AUG, you locate the A in the left column and the U in the top row and find where they intersect. At that spot is a box containing four different codons. You then find where the G in the right column of the table intersects and you will see your codon AUG. Next to the codon it says Met, which means AUG codes for the amino acid methionine in eukaryotes. The codon AUG is unique as it is also a START codon. This means that it always is the first codon in the transcribed mRNA that undergoes translation. There are also three STOP codons which signal for the process of translation to stop rather than coding for another amino acid.

## Explore! 2.3

**Using biotechnology to produce therapeutic proteins**

Traditionally, vaccines contain a weakened virus, or a protein of the virus, to trigger the body's immune response and provide immunity.

Two of the common COVID-19 vaccines work in that way. AstraZeneca (a viral vector vaccine) contains material from the SARS-CoV-2 virus within the shell of another virus. Novavax (a protein subunit vaccine) contains part of the coronavirus spike protein which is injected directly.

mRNA vaccines have been in development for decades but had been progressing slowly. Financial backing from governments and commercial organisations is critical for research, and the significant funding provided worldwide to address the COVID-19 pandemic accelerated mRNA vaccine biotechnology.

mRNA vaccines work differently to traditional vaccines. Instead of delivering a viral protein, the vaccines deliver mRNA. COVID-19 mRNA vaccines contain instructions for making the spike protein from the SARS-CoV-2 virus. The Pfizer and Moderna vaccines package the mRNA into a lipid nanoparticle that can pass through the cell membrane.

Vaccine mRNA is modified to be more efficient at protein synthesis and resistant to degradation. This means it can be used as a template many times. Manufacturers use computer-controlled techniques for generating the required strands of RNA. This method is cheaper and safer than manufacturing proteins or growing viruses. mRNA vaccines have huge potential for preventing and controlling future epidemics and pandemics.

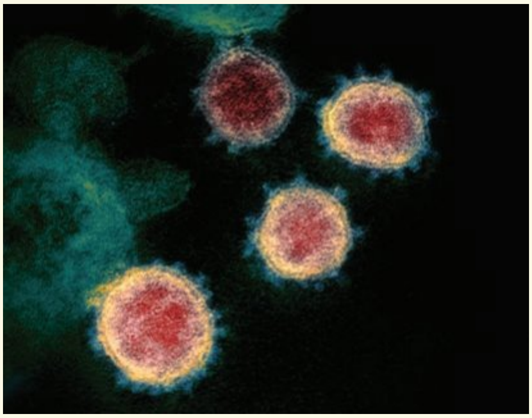

**Figure 2.13** A colourised electron microscope image of SARS-CoV-2 virus particles. The spike proteins around the edge give coronaviruses their name, as *corona* is Latin for crown.

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### Quick check 2.4

1 The following codons are found in a strand of DNA: TAA TTA TCG ACT ACT AGC. State the complementary mRNA strand.
2 Contrast transcription and translation.
3 Explain why you do not need to read the code on both strands of DNA when transcribing DNA into mRNA.

QUIZ

## Section 2.1 questions

**Retrieval**

1 **Name** the basic building blocks or subunits of DNA.
2 **Recall** where proteins are created (synthesised) in the cell.
3 **Recall** the name for the shape of DNA.
4 **Illustrate** and label a nucleotide.
5 **Recall** the four bases found in DNA and the complementary base pair rule.
6 **Recall** why all mRNA strands start with the codon AUG.
7 A template strand of DNA is found to contain the following bases: TAC GGA TCA TCG TGG GAA GCA GGC ATT.
   a **State** the complementary DNA strand.
   b Using the above template strand of DNA, **state** the bases on the mRNA strand.
   c Using Table 2.2, **identify** the amino acids that this strand of DNA would code for.

**Comprehension**

8 **Describe** the purpose of DNA.
9 **Describe** the relationship between DNA, genes and chromosomes.
10 **Explain** how the body produces so many different proteins with only four different nitrogenous bases.
11 **Explain** how the genetic information found in the chromosomes within the nucleus of a cell reaches the ribosomes for protein synthesis.
12 Make a flow chart to **summarise** the key steps in transcription and translation.

**Analysis**

13 **Contrast** the structures of mRNA and DNA.
14 **Differentiate** between a structural protein and a catalytic protein, providing examples of each.

**Knowledge utilisation**

15 A template strand of DNA is found to contain the following bases: TCC TGA TGA TGG GGG GCA AAA CGC GTA.
   Something went wrong during the transcription of this template strand, and the mRNA strand contains the following bases:
   AGG ACU ACU ACC CUC CGU UUU GCG CAU.
   a **Determine** the mistake in the mRNA strand above.
   b **Propose** the outcome of this mistake on the protein produced.
16 **Propose** what may occur if there was a problem with a certain protein in your body.

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# 2.2 Passing on genetic information

WORKSHEET
DNA replication and reproduction

VIDEO
Sexual reproduction

## Learning goals

1. To be able to recall the steps involved in DNA replication.
2. To be able to describe the stages of cell division in mitosis and meiosis.
3. To be able to use a karyotype to determine information about an individual.

Two different forms of reproduction occur among organisms: asexual and **sexual reproduction.** Sexual reproduction requires two organisms to each contribute a **gamete**; these are the sex cells that combine to produce a unique offspring. Gametes are formed in the **gonads** of the male (testes) and the female (ovaries). Each gamete contains half the genetic information needed to form a new organism of the same species. When the gametes – sperm and **ova** (eggs) – meet and fertilise, they form a **zygote** with a full set of genetic information. The zygote divides and as the number of cells increases, cells begin to take on special functions. Eventually, the zygote becomes an **embryo**.

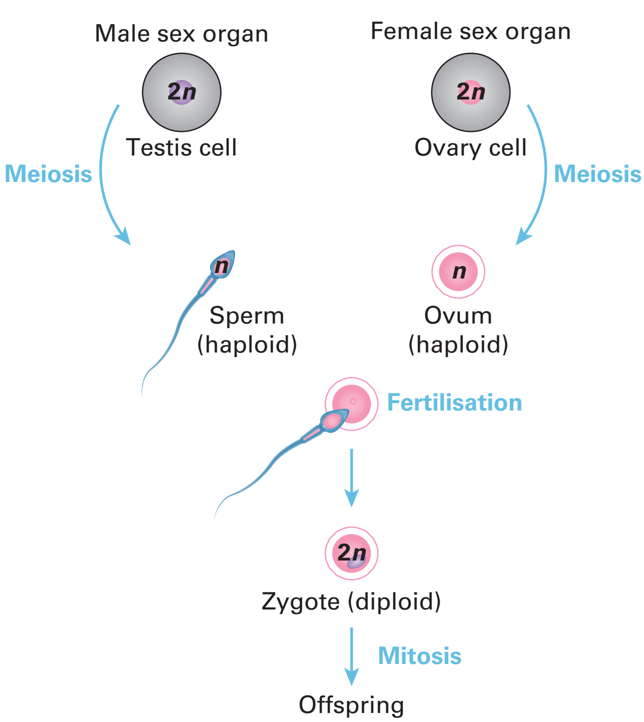


Figure 2.14 Sexual reproduction involves a gamete from a male and a female combining to form a zygote.

You will notice that Figure 2.14 has some new terms:

- Cells that contain only one set of chromosomes are known as **haploid (*n*)**. Gametes are haploid.
- Cells that contain two sets of chromosomes are known as **diploid (2*n*)**. **Somatic cells** (body cells) and the zygote are all diploid.
- **Meiosis** is the name of the process by which the gonads make the haploid gametes.
- **Mitosis** is the name of the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair.

In humans, the haploid number (*n*) is 23. This means that gametes contain 23 single unpaired chromosomes. When the egg and sperm meet and fertilise, the two sets of chromosomes come together and form the diploid zygote (2*n*). The zygote contains 23 pairs of chromosomes, meaning the diploid number (2*n*) in humans is 46. The haploid and diploid numbers vary between species, but always remain the same for all the organisms within that species. For example, the platypus has a diploid number (2*n*) of 52, which means it has 26 pairs of chromosomes in its somatic cells. This also means the egg and sperm of the platypus contain half this amount of genetic information, so its haploid number (*n*) is 26 chromosomes.

**sexual reproduction**
form of reproduction that involves two parents and introduces variation to the offspring

**gametes**
sex cells (sperm and ova) with half the usual number of chromosomes

**gonads**
the sexual organs: testes in males and ovaries in females

**ova**
(singular: **ovum**) mature female reproductive cells

**zygote**
a fertilised egg produced by the fusion of male (sperm) and female (ovum) gametes

**embryo**
the initial stage of early development in multicellular organisms

**haploid (*n*)**
a cell containing only one set of unpaired chromosomes

**diploid (2*n*)**
a cell containing two sets of chromosomes

**somatic cells**
the body cells of an organism

**meiosis**
the process by which the gonads make the haploid gametes

**mitosis**
the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair

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## Did you know? 2.2

**Different diploid numbers**

The diploid number of chromosomes in a species is not related to whether an organism is bigger or more complicated. For example, a koala, a tammar wallaby and garlic all have a diploid number of 16 but are very different!

Figure 2.15 Some very different organisms contain the same number of diploid chromosomes.

## Quick check 2.5

1 Differentiate between the terms 'haploid cell' and 'diploid cell', providing an example of each.
2 If a sheep's body (somatic) cell contained 54 chromosomes, calculate how many chromosomes would be found in their gametes.

## How does DNA copy itself?

Before a cell divides, the DNA must be replicated to provide two copies of each chromosome, one for each new cell. This occurs before the processes of mitosis and meiosis. DNA replication must be precise, otherwise errors can affect the code in the DNA and lead to **mutations** (permanent changes in the DNA). The steps involved in DNA replication are outlined below and summarised in Figure 2.16.

**mutation**
a change in the genetic code of a cell

1 The DNA molecule unwinds and 'unzips' (breaks the hydrogen bonds) between the nitrogenous bases. This happens with the help of an enzyme called DNA helicase.
2 Another enzyme called DNA polymerase attaches new nucleotides to the exposed nitrogenous bases. The enzyme follows the complementary pairing rule, where adenine can only join with thymine, and cytosine can only join with guanine. The two new strands of DNA will be identical to the original parent strand.
3 The newly added nucleotides are connected with new hydrogen bonds, which results in two identical strands of double-stranded DNA being formed. Each new strand is one-half of the original strand and one-half that was newly built. For this reason, replication is sometimes described as being semi-conservative.

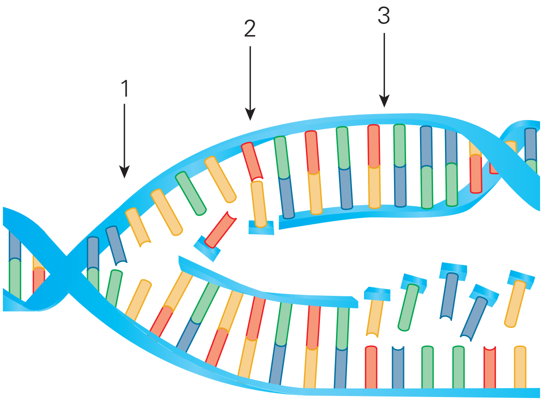


Figure 2.16 DNA replication: (1) the DNA must first unwind and unzip and then (2) the new DNA nucleotides can be added following complementary base pairing rules. (3) This results in two identical strands of DNA.

## Quick check 2.6

1 Explain the purpose of DNA replication.
2 Summarise the steps of DNA replication.

## Mitosis

Growth and repair of damaged tissues requires a form of cell division called mitosis. Mitosis is also important in asexual reproduction to make identical copies of cells. The diploid ($2n$) parent cell divides to form two diploid cells that are genetically identical, called daughter cells. The sequence of steps in mitosis is shown in Table 2.3. Mitosis produces every cell in the human body, except gametes, which are produced by meiosis and result in haploid ($n$) cells.

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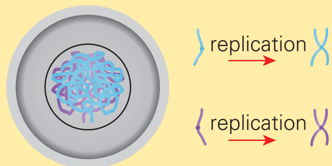
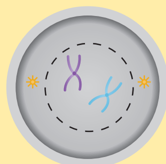
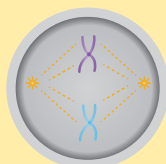
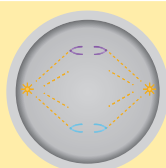
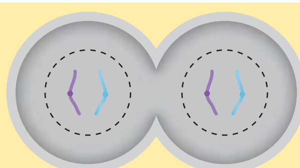
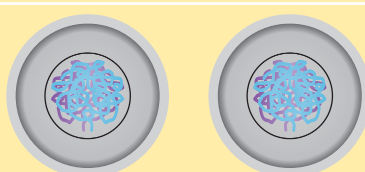
| The stages of mitosis | | |
|---|---|---|
| Interphase 2*n* (before mitosis) |   | • Parent cell is diploid (2*n*).<br>• DNA replication occurs.<br>• Chromosomes are not visible.<br>• The cell gets bigger.<br>• Organelles replicate. |
| Prophase |  | • The nuclear membrane breaks down, DNA condenses and appears as distinct chromosomes.<br>• Spindle fibres begin to form. |
| Metaphase |  | • Chromosomes are arranged along the centre of the cell.<br>• Each chromosome is attached to a spindle fibre by the centromere. |
| Anaphase |  | • The chromatids split at the centromere and are pulled to either end of the cell by the spindle, centromere first.<br>• Spindle fibres then begin to disappear. |
| Telophase |  | • The nuclear membrane re-forms around the two sets of chromosomes, forming two new nuclei.<br>• The chromosomes decondense and are no longer visible. |
| Cytokinesis 2 × 2*n* (after mitosis) |  | • Division of cytoplasm starts.<br>• The cell pinches in half and divides into two genetically identical diploid daughter cells. |

**Table 2.3** The stages of mitosis

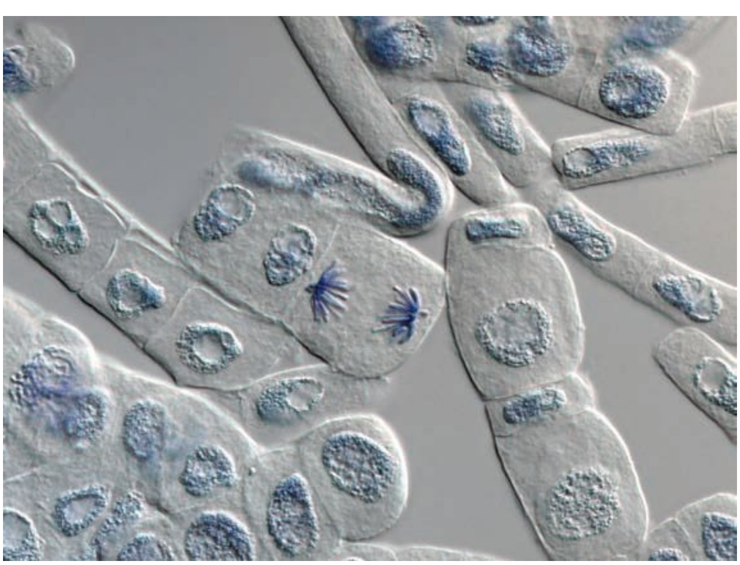


**Figure 2.17** Plant cells in the process of mitosis viewed under a light microscope. The central cell shows the chromosomes moving to each end of the cell in anaphase. Can you identify some of the other stages?

## Quick check 2.7

1 State which cells undergo mitosis.
2 Summarise the steps of mitosis.

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## Practical skills 2.2

### Observing cells in a dividing root tip

**Be careful**

Ensure you carry the microscope appropriately: hold the arm with one hand and place one hand under the base. Ensure you don't make big changes in magnification, so as not to damage the glass slide.

**Aim**

To observe cells carrying out mitosis in a growing onion root tip.

**Materials**

- prepared, stained slide of the growing section of an onion root tip caught at different stages of cell division
- microscope

**Method**

1 Using the lowest magnification, place a prepared slide of a growing onion root tip on the stage of the microscope.
2 Position the slide so that the pointed narrow end of the root tip is clearly visible.
3 Look for a cluster of rapidly growing cells near this region.
4 Observe several different cells at various stages of cell division under the highest magnification of the microscope.

**Results**

Carefully choose one cell with a clearly outlined cell wall and showing chromosomes in a certain stage of cell division. Sketch a copy of what you observed, labelling the cell wall and the chromosomes. Remember to use a sharp pencil and to document the magnification the sketch is taken at.

**Data processing**

1 The mitotic index is a quantitative expression of the amount of cell division that a particular tissue is undergoing. It is the ratio of the number of cells undergoing mitosis to the number of cells that are not undergoing mitosis. It can be calculated using the following equation:

$$\text{Mitotic index} = \frac{\text{number of cells in the field of view undergoing division}}{\text{total number of cells in the field of view}}$$

Calculate the mitotic index for the tissue sample you have observed in your microscope.

2 Using the field of view in your microscope, complete the table and calculate the percentage of cells in each cell cycle stage.

| Cell cycle stage | Number of cells in that stage | Percentage of cells in that stage |
|---|---|---|
| Interphase | | |
| Prophase | | |
| Metaphase | | |
| Anaphase | | |
| Telophase | | |
| **Total** | | |

3 Use the calculated percentages to predict which cell cycle stage is the longest and which is the shortest in your sample of cells. Explain your answer.

**Analysis**

1 Explain how you could tell which cells were dividing.
2 Describe the main features of each stage of cell division. Could you use these to identify the stage of mitosis for a particular cell?
3 List the structures in the cells you could observe. Which structures were present that you could not observe? Why might this be the case?

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## Meiosis

Meiosis is the process by which animals and plants produce gametes for sexual reproduction. The process begins with a diploid ($2n$) parent cell and results in four daughter cells (the gametes), which are haploid ($n$). Because of this reduction in genetic material between the parent and daughter cells, meiosis is also known as a **reduction division**.

**reduction division**
cell division which results in a reduction of genetic material in the daughter cells

The process of meiosis involves two divisions, called meiosis I and meiosis II. These steps are further subdivided into distinct stages, as shown in Table 2.4.

VIDEO
Mitosis and meiosis

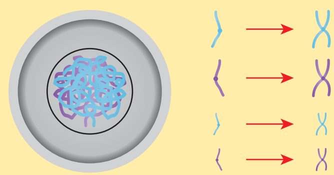
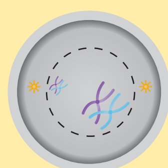
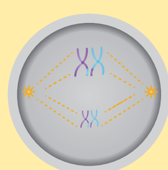
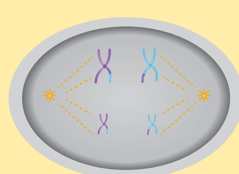
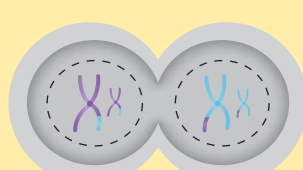
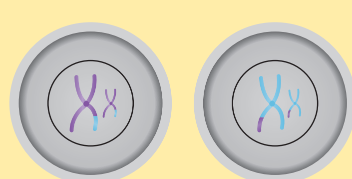
| Meiosis I | | |
|---|---|---|
| Interphase<br>$2n$<br>(before meiosis) |  | • Parent cell is diploid ($2n$).<br>• DNA replication occurs.. |
| Prophase I |  | • The nuclear membrane breaks down, the DNA condenses and chromosomes become visible.<br>• **Homologous chromosomes** pair up and crossing over can occur. |
| Metaphase I |  | • Homologous chromosomes align at the equator. |
| Anaphase I |  | • Paired homologous chromosomes separate from each other and are pulled to opposite ends of the cell by the spindle fibres. |
| Telophase I |  | • The cell membrane pinches in.<br>• The nuclear membranes re-form.<br>• Two separate nuclei form. |
| Cytokinesis<br>(after meiosis I) |  | • Division of cytoplasm starts.<br>• The cell pinches completely into two haploid ($n$) daughter cells. |

**Table 2.4** The stages of meiosis I and meiosis II

**homologous chromosomes**
a matching pair of chromosomes, with one having been inherited from each parent

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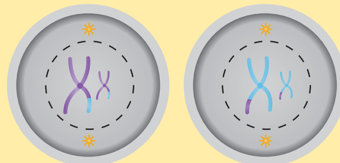
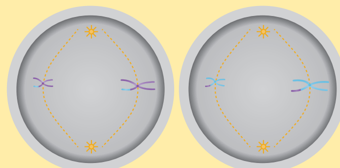
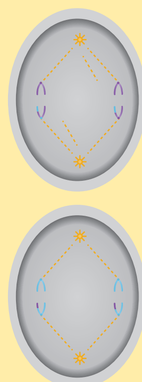
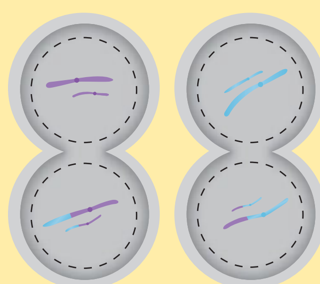
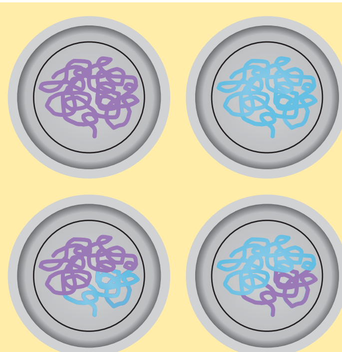
| **Meiosis II** | | |
|---|---|---|
| Prophase II |  | • Nuclear membranes disappear.<br>• Spindle fibres re-form in both cells. |
| Metaphase II |  | • Chromosomes line up at the equator. |
| Anaphase II |  | • The chromosomes are pulled apart, separating the sister chromatids, which are pulled to opposite sides of the cell.<br>• The spindle fibres disappear. |
| Telophase II |  | • The nuclear membrane re-forms.<br>• The chromosomes start to become less visible. |
| Cytokinesis 4 × $n$ (after meiosis II) |  | • Division of cytoplasm starts.<br>• The cells produce four genetically different haploid daughter cells ($n$), each containing half the amount of DNA that was in the parent cell. |

**Table 2.4** (continued)

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## Did you know? 2.3

**Creating variation**

Crossing over can occur in prophase I of meiosis I when homologous chromosomes get so close together that some of their genetic material gets swapped. It results in the chromosomes recombining to form a new combination of **alleles**, increasing the diversity of a species and therefore increasing the ability to respond to changing environments over time. This is how meiosis can increase genetic variation.

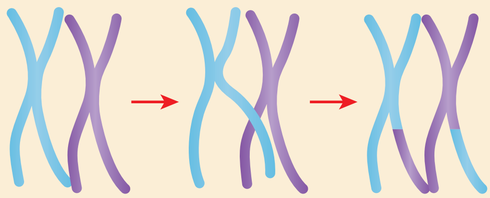

**Figure 2.18** **Recombination** occurs when homologous chromosomes undergo crossing over in prophase I.

**allele**
different form of the same gene

**recombination**
the rearrangement of genetic material, especially by crossing over

## Quick check 2.8

1 Describe why the process of meiosis is also known as 'reduction' cell division.
2 Recall where meiosis occurs in humans.
3 Explain why crossing over is an important process during meiosis.

## Fertilisation

In humans, **fertilisation** occurs when two haploid gametes fuse to form a diploid zygote. For fertilisation to occur, the sperm must complete the acrosome reaction. The acrosome is a structure, located in the head of the sperm, that is filled with enzymes. These enzymes are released to digest their way through the corona radiata, or outer layer of the ovum. Once the sperm penetrate the next layer of the ovum (zona pellucida), the cell membranes of one of the sperm cells and the ovum fuse together, and the sperm nucleus can enter the ovum. The fusing of cell membranes also triggers a reaction that causes the zona pellucida to harden. This is called the cortical reaction, and it prevents any more sperm cells from entering.

**fertilisation**
the fusion of male and female gametes to form a zygote

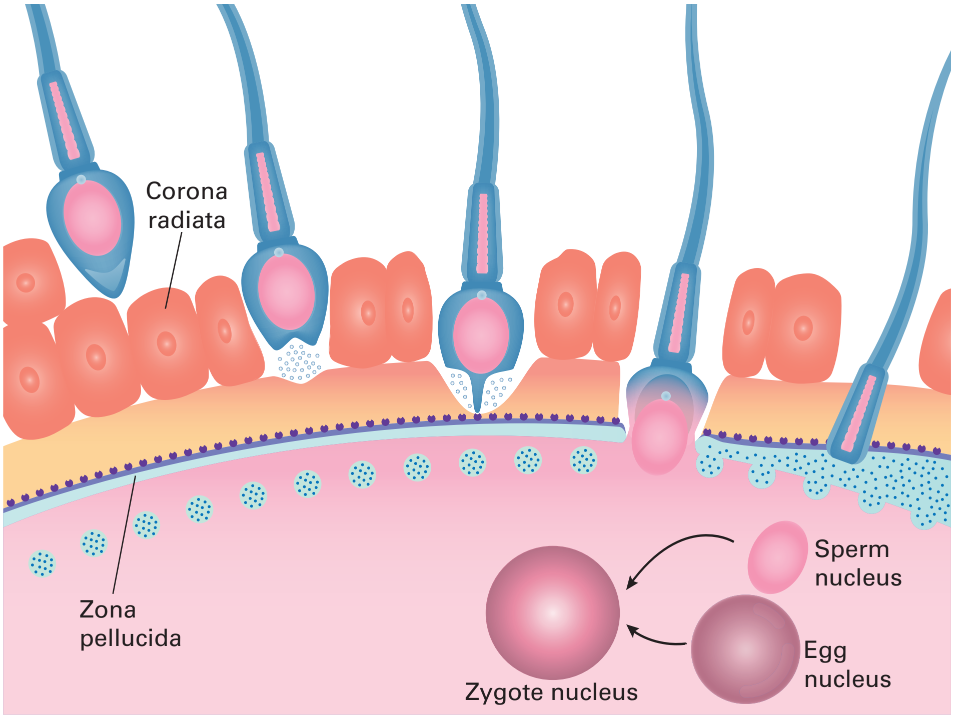


**Figure 2.19** Once a sperm fertilises the egg, the nucleus of the sperm and the egg fuse.

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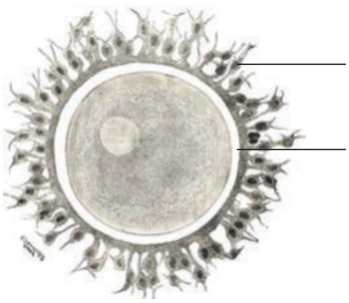


Figure 2.20 A human ovum

## Explore! 2.4

**Types of twins**

You, or someone you know, might have a twin sister or brother. There are two main types of twins: identical (monozygotic) and fraternal (dizygotic). However, there is another, very rare form of twins known as semi-identical (sesquizygotic). Only two cases have ever been recorded, one in the US and one in South East Queensland. Conduct some research and answer the following questions:.

1. Describe how monozygotic and dizygotic twins are formed.
2. Draw a diagram to show how these different types of twins are formed.
3. Discuss why sesquizygotic twins are so rare.

## Quick check 2.9

1. Copy the table below and define the terms.

| Term | Definition |
|---|---|
| Meiosis | |
| Fertilisation | |
| Zygote | |
| Haploid | |
| Diploid | |

2. Identify the missing words in the following sentence.
Male gametes are called ______________, whereas female gametes are called ______________.

## Meiosis versus mitosis

Although the processes of meiosis and mitosis have similarities, there are some differences:

- In meiosis, chromosomes recombine by crossing over, producing chromosomes with new combinations of genes. In mitosis, chromosomes are replicated to make identical copies of themselves.
- Meiosis involves two divisions that produce four haploid ($n$) daughter cells containing unique genetic material that is different to the parent cells. Mitosis involves one division that produces two diploid ($2n$) daughter cells with genetic material identical to the parent cell.

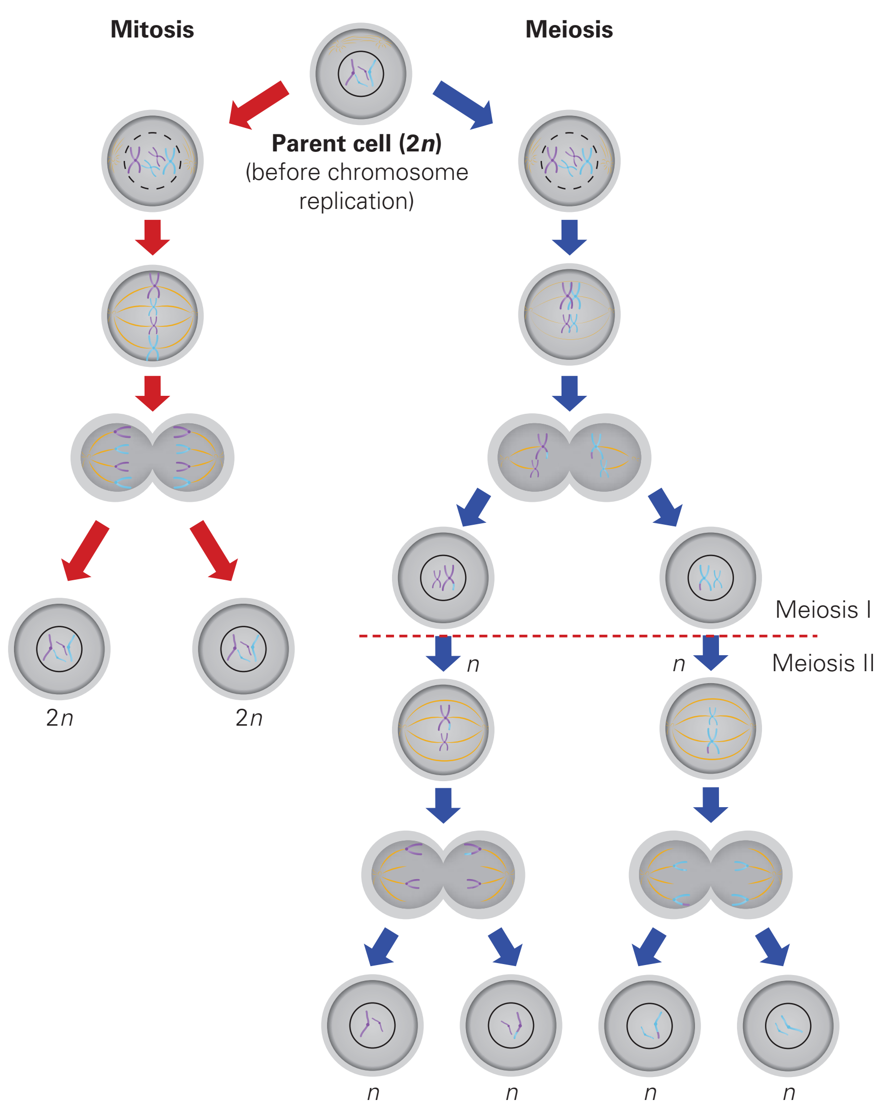


Figure 2.21 A summary of the processes of mitosis and meiosis

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## Karyotypes

The number of chromosomes varies between species, but the chromosomes in each body cell are always present in pairs. For example, humans have a total of 46 chromosomes, or 23 pairs of homologous chromosomes in the nucleus of every body cell. However, within the gametes, there are only 23 chromosomes. We can take a photo of a cell when it has undergone DNA replication and clearly see the chromosomes.

Homologous chromosomes are present in body cells because we receive one from each parent. Homologous chromosomes have the same length, centromere position and gene band patterns and can be displayed in a **karyotype** (Figure 2.23). Chromosomes that do not match (chromosomes from different pairs) are called **non-homologous chromosomes**.

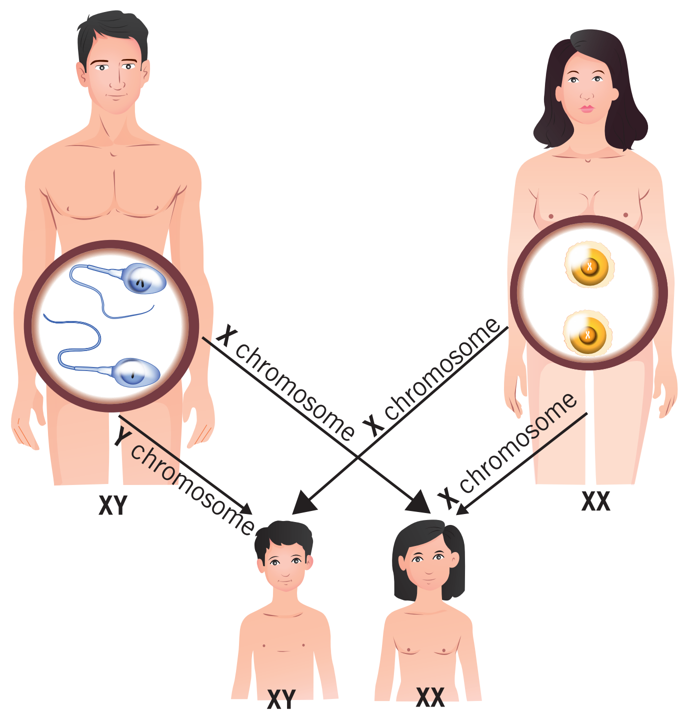


**Figure 2.22** If an egg is fertilised by a sperm carrying an X chromosome, the child will be female. If an egg is fertilised by a sperm carrying a Y chromosome, the child will be male. Therefore, it is the male's sperm that determines the sex of the child.

## Autosomes

Of the 23 pairs of chromosomes, pairs 1 to 22 are known as **autosomes**. These 44 chromosomes are found in both males and females.

**karyotype**
the chromosomes of an individual, often displayed according to size and gene band patterns

**non-homologous chromosomes**
chromosomes that do not belong to the same pair

**autosome**
any chromosome that is not a sex chromosome. In humans, these are chromosome pairs 1 to 22

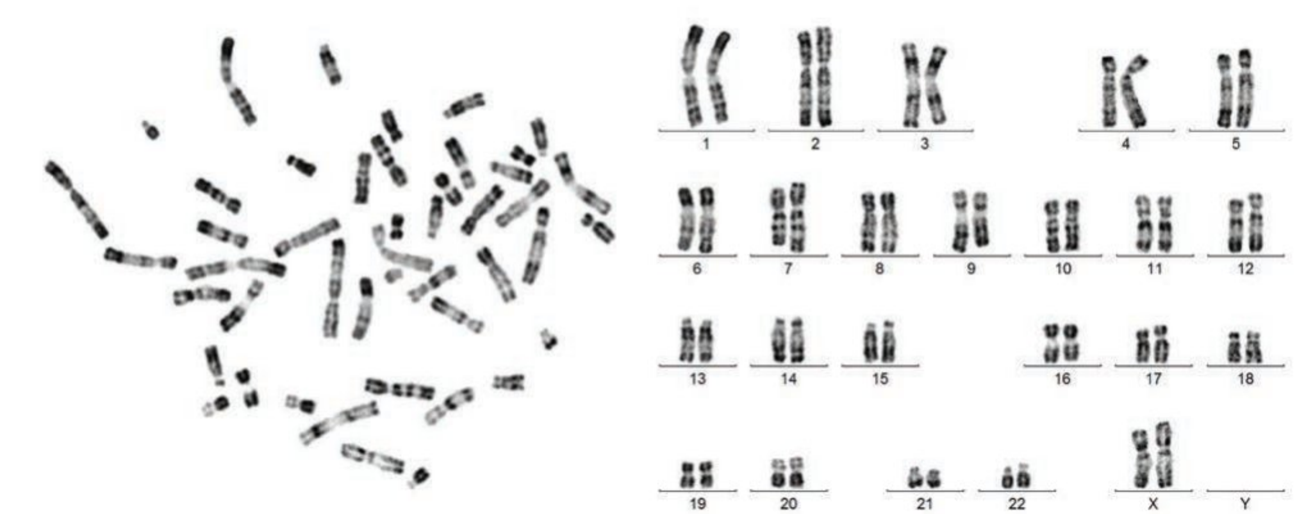


**Figure 2.23** The chromosomes seen under a microscope (left) can be arranged according to size in a karyotype (right). Pairs 1–22 are autosomes while pair 23 is the sex chromosomes..

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## Sex chromosomes

**sex chromosomes** chromosomes that determine the sex of an organism

In humans, the chromosomes making up the 23rd pair are the **sex chromosomes**. They contain genes that determine the sex of the individual. Females receive two X chromosomes (one from each parent), whereas males receive an X chromosome from the mother and a Y chromosome from the father (Figure 2.22).

### Investigation 2.1

**What are the chances?**

**Aim**

To investigate the chances of conceiving a male or female at fertilisation.

**Useful formulas**

$$\text{Theoretical probability (\%)} = \frac{\text{number of a particular outcome (e.g. heads)}}{\text{total number of all possible outcomes (e.g. heads and tails)}} \times 100$$

$$\text{Experimental probability (\%)} = \frac{\text{number of a particular outcome (e.g. heads)}}{\text{total number of all experimental trials (e.g. heads and tails)}} \times 100$$

$$\text{Percentage error (\%)} = \frac{\text{(experimental probability} - \text{theoretical probability)}}{\text{theoretical probability}} \times 100$$

**Materials**

- one coin

**Method**

1. Copy the results table into your science journal.
2. Calculate the theoretical probability of landing heads during a toss.
3. You will now calculate the experimental probability of your own experiment by tossing the coin 50 times, recording the number of heads and tails in the table.

**Results**

1. Calculate the experimental probability of receiving a head and a tail based on both the experimental data for your own and the class results.
2. Calculate the percentage error, comparing the difference between the theoretical and experimental probabilities for both your own data and the class data.
3. Optional: Graph the relationships between the number of trials and percentage error.

| | Individual results | Class results |
|---|---|---|
| Number of heads | | |
| Number of tails | | |
| Total number of trials (throws) | | |
| Experimental probability | | |
| Percentage error | | |

**Analysis**

1. Compare the experimental probabilities of your own and the class results.
2. If a head represents the Y chromosome and a tail represents the X chromosome, explain how accurately this models the process of fertilisation. What would the coin represent?
3. Make a claim about the chances of conceiving a male or female based on this activity.

**Evaluation**

**Reliability**

Discuss whether increasing the number of trials affects the percentage error of the experiment.

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## Did you know? 2.4

**Sex chromosomes in the animal kingdom**

In some animals, such as birds, females have two different sex chromosomes (ZW) while males have two of the same (ZZ). In some reptiles, the temperature of the incubating environment determines the sex of the embryo. In some insects, females are XX and males have one X chromosome (written XO).

Monotremes have a complex sex chromosome system. Female platypuses have five pairs of X chromosomes and males five X and five Y chromosomes. Female echidnas have five pairs of X chromosomes and males five X and four Y chromosomes.

**Figure 2.24** Female platypuses have five pairs of X chromosomes.

## Try this 2.3

**Can you sort chromosomes into a karyotype?**

Go online and find an online karyotype activity. There are many interactives that allow you to sort chromosomes into order and ones that allow you to analyse karyotypes.

## Science as a human endeavour 2.1

**Genetic testing**

When a person is pregnant, their doctor may conduct several tests to screen for genetic and chromosomal abnormalities in the foetus. Creating a karyotype lets the doctor check for abnormalities in the number or length of chromosomes. If anything appears abnormal, the doctor can undertake further genetic tests to check for specific disorders. One such test is chromosomal microarray (CMA) testing, which is much more detailed genetic testing than karyotyping. Chromosomal microarray testing detects around one abnormality in every 70 foetal samples with a normal karyotype. Scientists think that CMA testing will replace karyotyping for prenatal testing.

Genetic testing will identify carriers of genetic mutations and help people make informed decisions, such as in embryo selection. Genetic counsellors work with people who are concerned about having, or have been diagnosed with, a genetic condition.

Many people are also having genetic testing to discover more information about their ancestry or to connect with unknown relatives. Although it is against the law to be discriminated against because of genetic information, there is some concern regarding its use, either personally or by organisations such as insurance companies or medical facilities.

Have a class discussion regarding the ethical issues of non-therapeutic genetic testing performed by commercial companies. You may want to consider privacy concerns, the possible emotional impact, potential lack of medical knowledge and possible exploitation of vulnerable individuals.

The karyotype shows a female with Down syndrome. Note the three chromosomes in position 21.

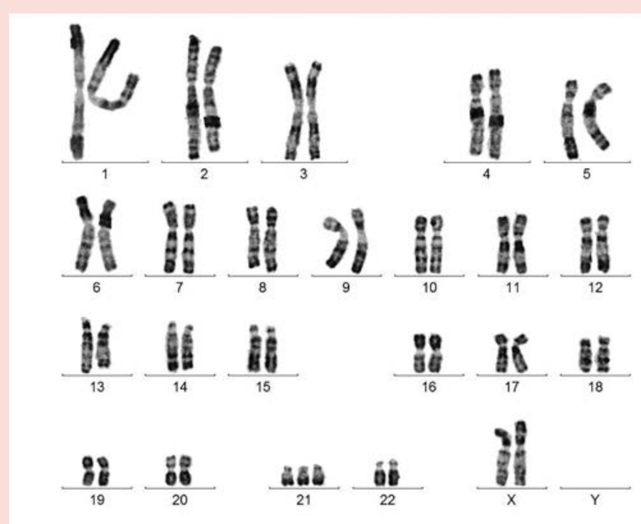


**Figure 2.25** A well-known chromosomal abnormality is trisomy 21 or Down syndrome, where the foetus has three copies (instead of two) of chromosome 21.

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## Quick check 2.10

1 Compare mitosis and meiosis in a Venn diagram.
2 Explain what karyotypes can show and why this is useful.

QUIZ

## Section 2.2 questions

### Retrieval

1 **State** one key difference between mitosis and meiosis.
2 **Recall** the phase of meiosis when pairs of matching chromosomes separate.
3 **State** the name of the syndrome that arises from trisomy 21.
4 **State** what the term 'homologous chromosomes' means.

### Comprehension

5 **Explain** why gametes need to be haploid.
6 **Explain** what is meant by the term 'reduction division'.
7 **Explain** why a chromosome missing a part may lead to a disorder or syndrome.
8 **Explain** why the cells produced during meiosis are genetically unique.

### Analysis

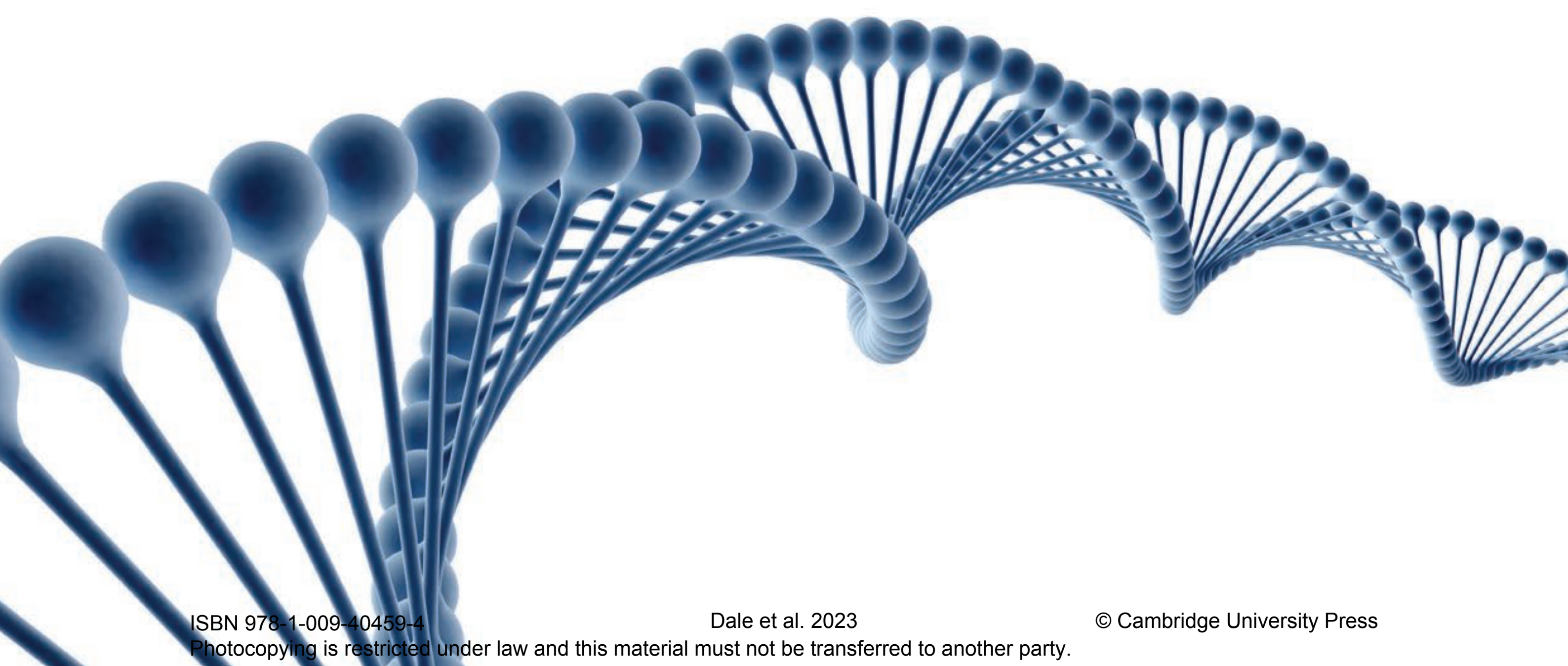
9 Complete the following table to **differentiate** between mitosis and meiosis.

| | Where it occurs | Purpose | Features of daughter cells |
|---|---|---|---|
| Mitosis | | | |
| Meiosis | | | |

10 **Contrast** the daughter cells produced in mitosis versus meiosis.
11 **Illustrate** a diagram to represent the steps of mitosis for a cell with two pairs of chromosomes. Be sure to use a different colour for each pair of chromosomes.
12 **Contrast** anaphase I in meiosis and anaphase in mitosis.
13 **Contrast** prophase I and prophase II in meiosis.

### Knowledge utilisation

14 **Critique** the following claim: It is the male that determines the sex of the child.
15 **Predict** the chances of a woman giving birth to a girl if she has already given birth to three boys, giving reasons for your response.



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# 2.3 Patterns of inheritance

**Learning goals**

1. To be able to define the terms 'homozygous', 'heterozygous', 'dominant' and 'recessive' with respect to genetic inheritance.
2. To be able to use and interpret Punnett squares to identify possible genotypes and phenotypes of offspring.
3. To be able to use pedigree diagrams to determine the type of inheritance that is occurring.
4. To be able to explain codominance, incomplete dominance and sex linkage.

DOC
WORKSHEET
Inheritance

Many First Nations Australian communities have understood inheritance patterns for a long time. They recognise how traits can be passed down to the next generation and how negative traits and illnesses often appear in the children of closely related parents. Their knowledge of heredity created complex and sophisticated kinship systems which allow individuals to understand who they are and how they fit into the social structure and even the universe. These kinship systems are strictly adhered to and dictate who can or cannot marry through marriage laws. Kinship and family structures also determine how individuals behave towards others and the responsibilities each person has towards others, natural resources and the land.

For example, a person may be obliged to care for their sibling's offspring. These children might address their aunt or uncle as 'mother' or 'father' and their cousins as 'brothers' or 'sisters'. Although they are aware of their biological parents, the societal (kinship) laws assign equal importance to other relatives. When conversing with one another, First Nations Australians frequently use the terms 'brother' or 'sister', which are derived from the kinship terminology and connections.

**Figure 2.26** This artwork from Kakadu National Park shows Namondjok, a Creation ancestor who broke kinship laws.

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## Inheriting traits from our parents

Each characteristic or trait that we inherit is controlled by one or more pairs of genes. Members of each gene pair are found at the same location on their respective homologous chromosomes. This is called the **locus** of a gene.

**locus**
the location of a gene on a chromosome

**genome**
the complete set of genetic material in an organism

**genotype**
the combination of alleles an organism has for a particular gene

**homozygous**
having two identical alleles at a particular gene locus

**heterozygous**
having two different alleles at a particular gene locus

**dominant**
a characteristic in which the allele responsible is expressed in the phenotype, even in those with heterozygous genotypes

**recessive**
a characteristic in which the allele responsible is only expressed in the phenotype if there is no dominant allele present

Genes are sections of DNA that code for a particular protein which contributes to our characteristics, such as a gene for eye colour. However, not all forms of a gene are the same; for example, different people can have different eye colours. We use the term 'allele' to describe the different forms of a gene. We get one copy of each chromosome from each parent, so although we inherit the same genes, we don't necessarily inherit the same alleles. The combination of alleles an organism has for a particular gene is known as the organism's **genotype**. If two identical alleles are present in a person's genotype, they are known as **homozygous** for that particular trait. However, if there are two different alleles present for the same trait, then the person is **heterozygous** for that trait.

For example, consider the trait of freckles. This trait is controlled by a single gene that is represented using two alleles. The allele of the dominant trait is the presence of freckles (we assign it the capital letter 'F' to show it is dominant), and the allele for the recessive trait is the lack of freckles (assigned a lower case 'f' to show it represents the recessive trait). A trait or characteristic is described as **dominant** if you need only one allele for it to be expressed (FF or Ff). For a **recessive** characteristic, the allele needs to be inherited from both parents for it to be expressed (ff).

If you inherit the freckles allele from both parents, you are homozygous dominant for that trait and your genotype will be FF. If you inherit the no-freckles allele from both parents, you are homozygous recessive for that trait and your genotype will be ff. If you inherit a freckles allele from one parent and

### Did you know? 2.5

**The genome**

The **genome** refers to all the genetic material in the chromosomes of an organism, including its genes and DNA sequences. The human genome is made of approximately 3.2 billion nitrogenous base pairs, which make up about 20 000 genes on 23 pairs of chromosomes. Other organisms have different genome sizes.

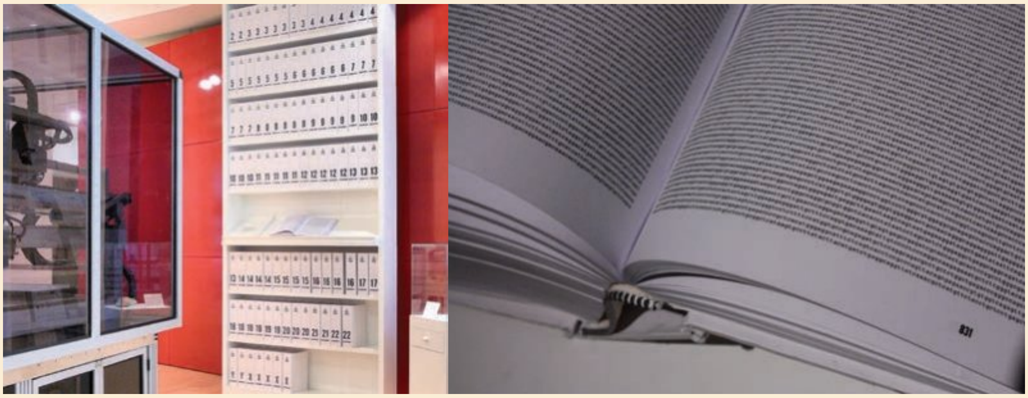

**Figure 2.27** The first publication of the human genome was printed as 109 books in 23 volumes. The around three billion units of human DNA code are printed in a small font, and each book is a thousand pages long.

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Figure 2.28 The presence of freckles is an example of a dominant trait.

a no-freckles allele from the other parent, you are heterozygous for that trait and your genotype will be Ff.

The interaction of an organism's genotype with the environment results in its **phenotype**, or its physical appearance. In the example in Figure 2.28, the presence of freckles is the person's phenotype for that trait. The freckles are present due to the person's genotype and their environmental exposure to UV light.

**phenotype** the observable characteristics of an organism, resulting from both genotype and the environment

To determine whether an allele represents a trait that is dominant or recessive, scientists look at the phenotype of a heterozygous organism. If the trait is expressed in this phenotype, it must be the dominant trait.

## Quick check 2.11

1 Copy the table below and define the terms.

| Term | Definition |
|---|---|
| Locus | |
| Allele | |
| Genotype | |
| Phenotype | |
| Dominant | |
| Recessive | |
| Heterozygous | |
| Homozygous dominant | |
| Homozygous recessive | |

2 Explain why a genotype can indicate that a person will have freckles, but there are not many on their face.

## Investigation 2.2

### Inherited features

#### Aim

To use data to determine whether some key characteristics are dominant or recessive traits.

#### Materials

- mirror

Optional extension: Collect information from other students or family members for further validity analysis.

#### Method

**Part 1: Prepare the results table**

Copy the results table into your science journal.

*continued …*

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*continued …*

**Part 2: Collect data on the variables**

1 Identify whether you possess each of the inheritable features described below.
2 Record your results in the table.
3 Find out how many members of your class share the same features as you do. Record your results in the table.
Optional: Find out how many members of your family display the traits.
  a Attached ear lobes: are your earlobes attached or unattached to the side of your head?
  b Widow's peak: do you have a V-shaped peak in the centre of your hairline as shown in Figure 2.29?
  c Tongue roll: can you roll your tongue as shown in Figure 2.30?
  d Front tooth gap: is there a definite gap between your two top front teeth as shown in Figure 2.31?
  e Mid-digital hair: is there any hair on the second joint of at least one of your fingers?
  f Long second toe: is your second toe longer than your big toe as shown in Figure 2.32?

**Figure 2.29** This girl has a widow's peak (V-shaped peak) in the centre of her hairline.

**Figure 2.30** This woman is able to roll her tongue.

**Figure 2.31** This man has an obvious gap between his top front teeth.

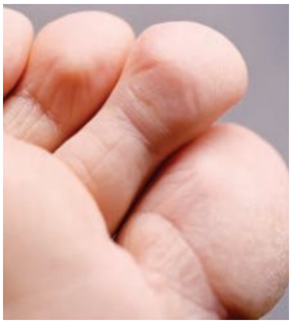

**Figure 2.32** The second toe is longer than the big toe on this foot.

**Results**

1 Calculate the total number of people sampled in this survey.
2 Calculate the percentage presence of the trait in your family and within the class.
3 Draw an appropriate graph (or graphs) to compare the percentage presence of each trait within your family with the percentage presence in the whole class.

| Feature | Trait present in you? (Y/N) | Number of family members with trait | Presence of trait in family (%) | Number of class members with trait | Presence of trait in class (%) | Presence of trait in total sample (%) |
|---|---|---|---|---|---|---|
| Attached ear lobes | | | | | | |
| Widow's peak | | | | | | |
| Tongue roll | | | | | | |
| Front tooth gap | | | | | | |
| Mid-digital hair | | | | | | |
| Long second toe | | | | | | |
| Sample size (*Total number of people surveyed*) | 1 | | | | | |

*continued …*

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*continued …*

**Analysis**

1 Describe which traits were commonly found in your family.
2 Describe which traits were commonly found in the class.
3 Describe which traits were commonly found in the whole sample.
4 Do your findings support the idea that a feature such as tongue-rolling is inherited? Explain your answer.
5 Predict from the data which traits are likely to be recessive and dominant. Justify your answer with data.

**Evaluation**

**Reliability**

1 If you repeated the survey on the same people, would you get a similar result? Support your answer relating back to the theory behind inheritance of traits.
2 Can reliable conclusions and predictions be drawn from the results?

**Limitations**

3 Compare the values from your family with those from the class. Were there any significant differences with some traits? Justify your answer with data.
4 Compare the values from your family with results from several other student families. Were there any significant differences with some traits? Justify your answer with data.
5 Can you draw valid conclusions as to which traits are dominant and recessive from this data? Justify your response.
6 Sample size is a factor that commonly affects data in small surveys. Discuss how this relates to the activity.
7 Can you identify possible limitations of this method? Justify your answer.

**Improvements**

8 Suggest any changes that could be made to the method to improve the quality of the data in future surveys. Justify your suggestions by explaining how each change will improve the data quality.

## Determining chances of inheritance

### Gregor Mendel

Gregor Mendel is known as the father of genetics. Born in 1822, he was an Austrian monk who carried out experiments in his garden using pea plants and discovered some of the fundamental laws of heredity we still rely on today.

Mendel looked at the features of pea plants, which could be tall or short (dwarf). He assigned the following letters to represent these alternative characteristics (known today as alleles): T = tall and t = dwarf. Mendel bred the plants and observed the height of the plants in the next generation. He discovered that tall pea plants could be either pure breeding (TT or homozygous dominant) or hybrid (Tt or heterozygous). The dwarf plants could only be tt (homozygous recessive). Today, we call this the plant's genotype.

Mendel also used the following notation to represent different levels of generations:

- P = parent generation
- $F_1$ = first filial generation (first generation of offspring)
- $F_2$ = second filial generation (second generation of offspring).

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**Figure 2.33** Gregor Johann Mendel was the founder of the science of genetics, using pea plants to show dominant and recessive traits. He produced large amounts of data which all supported his theory, but later statistical analysis suggests that he may have falsified his data – it was simply too good to be true! Large data sets and statistical analyses are vital for validating scientific findings.

**Punnett square**
a specialised grid to show genetic crosses

**monohybrid cross**
a type of genetic cross or breeding experiment that considers the inheritance of a single trait or characteristic, typically controlled by a single gene with two alleles

An easy way to predict the outcome of crossbreeding plants with certain traits is to use a **Punnett square**, a specialised grid invented by Reginald Punnett. A Punnett square is a visual representation of a **monohybrid cross**, which is a breeding experiment involving two individuals that differ in a trait of interest. In a monohybrid cross, the parents are typically represented by letters to denote their respective alleles for the trait being studied.

To use a Punnett square, you need to know the genotype of the parents to work out what genetic information they could pass on to their offspring via the gametes. For example, we know a heterozygous, tall pea plant has the genotype Tt. This means that when the plant makes its gametes, they could contain either a T or a t, as gametes only carry one of the alleles from the parent. In contrast, a homozygous tall pea plant has the genotype TT, so its gametes will all contain a T.

### Worked example 2.1

**Cross between a pure-breeding tall plant and a pure-breeding dwarf plant**
Parents: TT × tt

| gametes | T | T |
|---|---|---|
| **t** | Tt | Tt |
| **t** | Tt | Tt |

You will notice that all the predicted $F_1$ offspring (shaded) have the genotype Tt. We can write this as:
$F_1$ genotype: 100% Tt
We can also see that offspring with Tt would all physically appear tall, as T stands for the tall allele which is dominant over the dwarf allele (t). So, we can write this as:
$F_1$ phenotype: 100% tall plants

### Worked example 2.2

**Cross between two of the hybrid $F_1$ plants from worked example 2.1**
$F_1$: Tt × Tt

| gametes | T | t |
|---|---|---|
| **T** | TT | Tt |
| **t** | Tt | tt |

$F_2$ genotype: 25% TT; 50% Tt; 25% tt
$F_2$ phenotype: 75% tall plants; 25% dwarf plants
We can also write the predicted outcomes as ratios. In this case, when two heterozygous tall pea plants were crossed, there was a genotypic ratio of 1TT : 2Tt : 1tt and a phenotypic ratio of 3 tall : 1 dwarf.

## Huntington's disease

Huntington's disease is inherited as a dominant trait on an autosome. It usually appears in an affected person as neurological symptoms that develop around 30–50 years of age resulting from an abnormal protein being made. The disease is lethal in the womb if an offspring is homozygous for the abnormal protein.

If we let H = abnormal Huntington's protein allele (Huntington's disease) and h = 'normal' protein allele (unaffected), then we can use these notations to help work out probable outcomes in the offspring.

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## Worked example 2.3

**Cross between two individuals unaffected by Huntington's disease**

Parents: hh × hh

| gametes | h | h |
|---|---|---|
| h | hh | hh |
| h | hh | hh |

$F_1$ genotype: 100% hh

$F_1$ phenotype: 100% unaffected

## Worked example 2.4

**Cross between an individual with Huntington's disease and an unaffected individual**

Parents: Hh × hh (Someone with two H alleles will not survive birth so the individual with Huntington's disease must be Hh).

| gametes | H | h |
|---|---|---|
| h | Hh | hh |
| h | Hh | hh |

$F_1$ genotype: 50% Hh; 50% hh

$F_1$ phenotype: 50% with Huntington's disease; 50% unaffected

## Try this 2.4

**Punnett squares**

1 A black mouse mates with a brown mouse. There is a large number of offspring and all of them are black.
   a Which trait is dominant?
   b Draw a Punnett square and determine the genotypes of the offspring.

2 A recessive gene causes a condition called cystic fibrosis. If a homozygous recessive individual mates with a heterozygous individual, what are their chances of producing offspring with cystic fibrosis?

## Quick check 2.12

1 Contrast genotype and phenotype.

2 Brown eyes are dominant to blue eyes.
   a Select letters for the brown eye and blue eye alleles.
   b Create a Punnett square for a couple who are both heterozygous.
   c State the genotypic and phenotypic ratios of the offspring.
   d State the chances of this couple producing a blue-eyed child.

## Test cross

A **test cross** can be used to discover whether an organism showing a dominant trait is homozygous dominant or heterozygous. It involves observing the offspring of the individual in question if it mates with a homozygous recessive individual (for example, aa). This means the individual of unknown genotype mates with an individual of known genotype. By looking at the offspring ratio, we can deduce the unknown genotype of the individual in question.

For example, in mice, coat colour may be black (B) or white (b). You can find out if a black mouse is homozygous black (BB) or heterozygous black (Bb) by doing a test cross between the black mouse and a white mouse (bb).

**test cross**
a genetic cross between a homozygous recessive individual and an individual of unknown genotype showing the dominant trait to determine the unknown genotype

If the unknown black mouse is BB, the cross would look like this:

Parents: BB × bb

| gametes | B | B |
|---|---|---|
| b | Bb | Bb |
| b | Bb | Bb |

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$F_1$ genotype: 100% Bb
$F_1$ phenotype: 100% black
This means if all the offspring are black, the unknown black mouse is probably BB (or homozygous dominant).

If the unknown black mouse is Bb, the cross would look like this:

Parents: Bb × bb

| gametes | B | b |
|---|---|---|
| b | Bb | bb |
| b | Bb | bb |

$F_1$ genotype: 50% Bb; 50% bb
$F_1$ phenotype: 50% black; 50% white
This means if roughly half the offspring are black and half are white, the unknown black mouse is probably Bb (or heterozygous). Note that these expectations are only true when based on large numbers of offspring because they are probabilities. However, if even one white offspring is born, the black mouse must be heterozygous in order to have passed on a recessive b gene.

### Quick check 2.13

1 Explain the importance of a test cross.
2 Silky feathers in a bird species are caused by a gene with a trait recessive to normal feathers. If you had a normal-feathered bird, describe a way to determine whether it is heterozygous or homozygous. Use Punnett squares to help with your answer.

### Try this 2.5

**Positive or negative**
One vital gene located on chromosome 1 in humans is the gene controlling for Rhesus (Rh) blood type. Rh positive blood is dominant to Rh negative blood, so we can assign the alleles D (Rh positive) and d (Rh negative). Therefore, an Rh positive person can be either DD or Dd with respect to this gene, but an Rh negative blood type can only be homozygous, dd.

**Instructions**
In this activity, we will use coloured counters and felt-tipped pens to model the passing of Rh alleles from heterozygous individuals to their offspring.
1 Copy the results table into your science journal.
2 Choose one coloured counter. Print D on one side and d on the other to represent the alleles of the chromosomes. This counter represents an individual who is Dd for Rh blood type, that is, able to produce gametes (eggs or sperm) of the type D and d in equal proportions.
3 Find a partner in the room with a different coloured counter.
4 Make an unbiased toss of your two counters to produce an offspring. The labels facing up on the counters will represent the alleles of the gametes produced by the parents. Record the genotype of the offspring in the Family 1 row of the following table. Repeat this step three more times to produce a total of four children.
5 Generate a total of four families (by pairing up with three different students) with each having produced four children.
6 Record the number of each type of genotype found in the children of each family in the table following table. Pool your total results with those of the class.

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*continued …*

**Results**

| | Genotype of children | | |
|---|---|---|---|
| | DD | Dd | dd |
| Family 1 | | | |
| Family 2 | | | |
| Family 3 | | | |
| Family 4 | | | |
| **Total numbers across the class** | | | |

**Analysis**

1 Using the class data, calculate the probability of obtaining the offspring genotypes:
 a DD
 b Dd
 c dd
2 What are the proportions of the different genotypes in your group of 16 children compared to those generated across the whole class? Discuss whether this is expected.
3 A woman with Rh positive blood insisted that she was the daughter of a rich, elderly couple who both had Rh negative blood. Use a Punnett square to show your working out to explain whether this woman's statement could be valid.

## Sex linkage

As we have seen, in humans the sex chromosomes are the 23rd pair. Human females are homozygous for the X chromosome while males are heterozygous with one X and one Y chromosome.

The X chromosome also contains many genes not related to sex determination (in contrast, the Y chromosome has very few). Characteristics that are not related to determining the sex of the individual but are coded for by X chromosome genes are termed X-linked. When we predict X-linked traits using a Punnett square, we must use the sex chromosomes and superscripted letters above the sex chromosomes to represent the trait.

For example, Duchenne muscular dystrophy (DMD), a disorder where the muscles progressively degenerate, is inherited as an X-linked recessive trait. The genotype for an unaffected female would be $X^DX^D$, a **carrier** female (who has a recessive allele for the disease but is heterozygous so does not have the disease) would be $X^DX^d$, and a female with DMD would be $X^dX^d$. On the other hand, an unaffected male would be $X^DY$ and a male with DMD would be $X^dY$. As there is no gene for this condition found on the Y chromosome, we do not write $^D$ or $^d$ next to the Y. Because males have only a single copy of the X chromosome, they are more likely to be affected by sex-linked disorders. A single allele of a mutated gene on an X chromosome will cause the disease in a male but not in a female (who would need two DMD alleles).

**carrier**
an individual with a recessive allele for a disease but who does not have the disease due to being heterozygous

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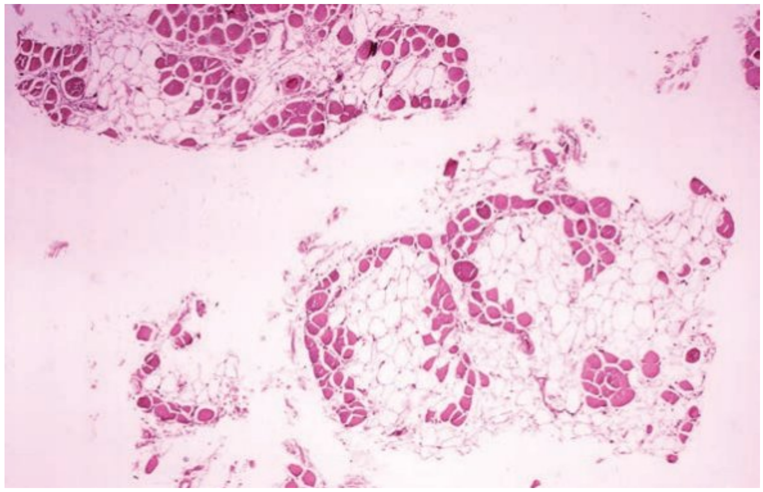

Figure 2.34 In Duchenne muscular dystrophy, muscle fibres (red) are replaced by fat cells (white).

## Worked example 2.5

**Cross between a heterozygous normal-vision female (carrier) and a normal-vision male**

Colour blindness is inherited as an X-linked recessive trait. The genotype of a heterozygous normal-vision (carrier) female is $X^BX^b$ and of a colour-blind male is $X^bY$.

Parents: $X^BX^b \times X^bY$

| gametes | $X^B$ | $X^b$ |
|---|---|---|
| $X^B$ | $X^BX^B$ | $X^BX^b$ |
| Y | $X^BY$ | $X^bY$ |

$F_1$ genotype: 25% $X^BX^B$; 25% $X^BY$; 25% $X^BX^b$; 25% $X^bY$

$F_1$ phenotype: 25% normal-vision female; 25% normal-vision male; 25% carrier normal-vision female; 25% colour-blind male

## Try this 2.6

**Sex-linked inheritance**

Now it is your turn to practise. Remember that the gametes need to include the sex chromosomes, and the genotype and phenotype both need to include the sex chromosomes as well.

1 Using a Punnett square, cross a normal-vision female (homozygote) with a colour-blind male.
2 Using a Punnett square, cross a colour-blind female with a normal-vision male.
3 Explain why more males than females have colour blindness.

VIDEO
An example of codominance

## Codominance

When there are two equally dominant alleles for a trait, they will both be expressed in the phenotype of a heterozygote. This is **codominance**. Look at the picture of the chickens in Figure 2.35. The colours black and white are equally dominant (their alleles are both given capital letters), so when you cross a pure black chicken with a pure white chicken, you get a heterozygote. In the heterozygote, both colours are expressed equally, so you get a speckled chicken with black feathers and white feathers!

**codominance**
both alleles are expressed equally in the phenotype

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| Genotype | WW | BB | BW |
|---|---|---|---|
| Phenotype | White | Black | Speckled |

**Figure 2.35** White and black are equally dominant alleles and are said to be codominant. The evidence of this is their heterozygote offspring that has a mix of black and white feathers.

## Blood types

In humans, our blood type is a codominant trait. Our red blood cells have proteins on the surface called antigens, and these determine whether our blood is A, B, AB or O.

Each person has two copies of the ABO blood type gene, one from their mother and one from their father. The blood type gene is found on chromosome 9, and there are three possible alleles:

- $I^A$ = production of antigen A (type A blood) is dominant.
- $I^B$ = production of antigen B (type B blood) is dominant.
- i = production of neither antigen (type O blood) is recessive.

As we have two copies of chromosome 9, there can be six different allele combinations:

- Type A blood can have genotypes $I^A$ $I^A$ or $I^A$ i.
- Type B blood can have genotypes $I^B$ $I^B$ or $I^B$ i.
- Type AB blood can only have the genotype $I^A$ $I^B$.
- Type O blood can only have the genotype ii.

$I^A$ an $I^B$ are both dominant over i, but are codominant to each other.

VIDEO
Blood types

### Worked example 2.6

**Cross between heterozygous blood type A and heterozygous blood type B**

Parents: $I^Ai \times I^Bi$

| gametes | $I^A$ | i |
|---|---|---|
| $I^B$ | $I^AI^B$ | $I^Bi$ |
| i | $I^Ai$ | ii |

$F_1$ genotype: 25% $I^A$ $I^B$; 25% $I^B$ i; 25% $I^A$ i; 25% ii

$F_1$ phenotype: 25% AB blood type; 25% B blood type; 25% A blood type; 25% O blood type

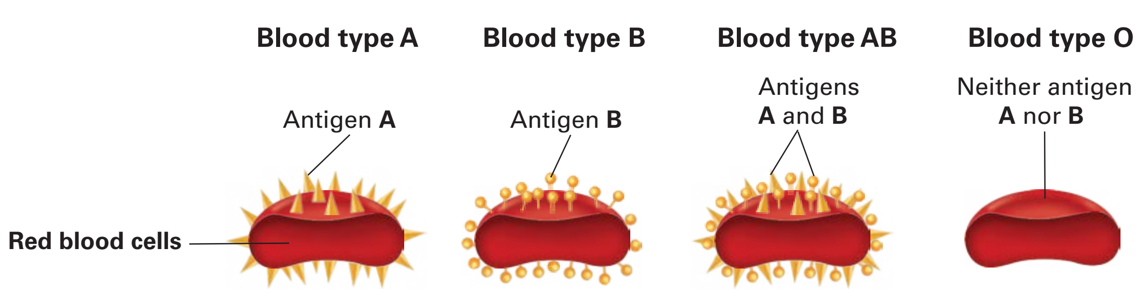


**Figure 2.36** Illustration of the different antigens on the surface of red blood cells

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## Explore! 2.5

### Incomplete dominance

**incomplete dominance** a form of inheritance in which both alleles are partially expressed, producing a third intermediate phenotype

**Incomplete dominance** occurs when neither of the alleles is dominant over the other, resulting in a third phenotype which is an intermediate form of both alleles. Wavy hair is an example of incomplete dominance. A person with two curly hair alleles will have curly hair. A person with two straight hair alleles will have straight hair. However, a person with one curly and one straight allele will have wavy hair.

1 The flower colour of snapdragons is an example of incomplete dominance. Draw an example of a cross for a white flower ($C^WC^W$) and a red flower ($C^RC^R$).
2 Eggplant colour is another example of incomplete dominance. Explain how the three colours of eggplant shown in Figure 2.38 are possible.

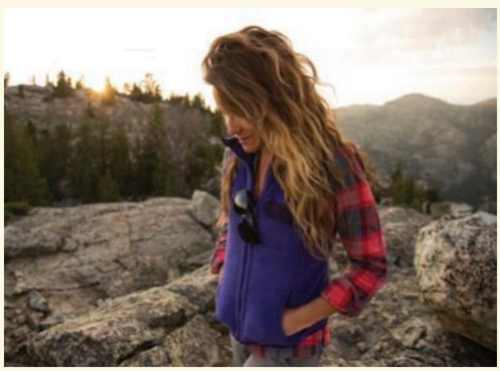


**Figure 2.37** Wavy hair is an example of incomplete dominance.

**Figure 2.38** Deep purple (left), violet (middle) and light green (right) eggplants

## Quick check 2.14

1 Explain why males are more likely to be affected by recessive X-linked disorders than are females.
2 Describe codominance.

DOC WORKSHEET Pedigrees

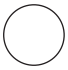
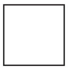
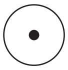
## Pedigrees

**pedigree** a chart that shows relationships between family members and indicates which individuals have certain genetic traits

One way of finding out how a trait is inherited is to follow the inheritance pattern over two or more generations. This technique is called pedigree analysis. To study patterns of inheritance in humans, geneticists investigate the frequency and occurrence of a particular gene over many generations to determine whether the traits are dominant or recessive. The chart formed is called a **pedigree** and it is like a family tree.

Each generation is numbered in Roman numerals and forms a row on the pedigree.

Individuals are numbered using Arabic numerals (1, 2, 3 etc.) from left to right on each row. The symbols used are:

- Unaffected female 
- Unaffected male 
- Female with the trait being investigated 
- Male with the trait being investigated 
- Carrier of trait  or 

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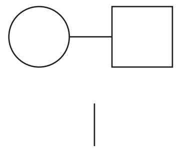
- Mating is represented by a horizontal line
- A vertical line connects offspring to parents



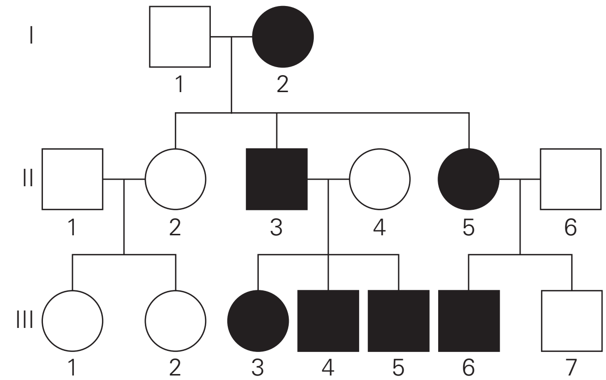



**Figure 2.39** An example of a pedigree showing three generations of a family. Individuals affected by a particular trait are shown in black. Note how male I-1 and female I-2 had three children, and their eldest is an unaffected female (II-2).

## Reading a pedigree

There are some points to keep in mind when reading a pedigree and determining inheritance:

- A trait that is common in a population is not necessarily dominant.
- When asked to determine a genotype in a pedigree, you will need to establish the mode of inheritance. You can use Punnett squares to help you.

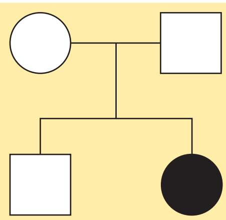
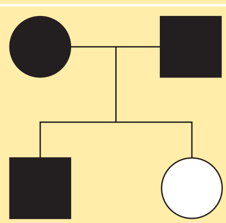
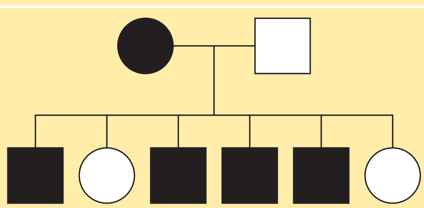
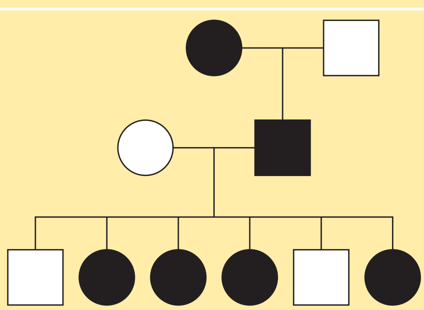
| Mode of inheritance | Pedigree chart | What to look for | Examples |
|---|---|---|---|
| Autosomal recessive |  | Two unaffected parents can have an affected child.<br>Males and females are equally affected.<br>The trait may disappear from a branch of pedigree and then reappear in later generations.<br>Two affected recessive parents must have all affected recessive children. | Albinism, cystic fibrosis, sickle cell anaemia and thalassaemia |
| Autosomal dominant |  | Two affected parents can have an unaffected child.<br>Males and females can be equally affected, yet all of the affected individuals must have at least one parent affected. | Huntington's disease and haemochromatosis |
| X-linked recessive |  | Affected mothers produce affected sons.<br>Affected fathers *cannot* pass the trait to their sons. | Colour blindness, haemophilia and Duchenne muscular dystrophy |
| X-linked dominant |  | Affected fathers produce daughters that are all affected.<br>Affected fathers *cannot* pass the trait to their sons, but affected homozygous females will pass the trait on to all of their daughters and sons. | X-linked hypophosphatemic rickets |

**Table 2.5** Different modes of inheritance and how to identify them in a pedigree chart

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## Did you know? 2.6

**Famous people have genetic disorders too!**

Megan Fox has a condition called brachydactyly. This is an autosomal dominant condition that causes shortened fingers or toes. Jessie J has Wolff–Parkinson–White Syndrome, an autosomal dominant condition that causes a very fast heart rate.

**Figure 2.40** Megan Fox and Jessie J both have genetic disorders.

## Quick check 2.15

1 Study the pedigree chart in Figure 2.41. It illustrates the inheritance of achondroplasia (dwarfism) in humans.

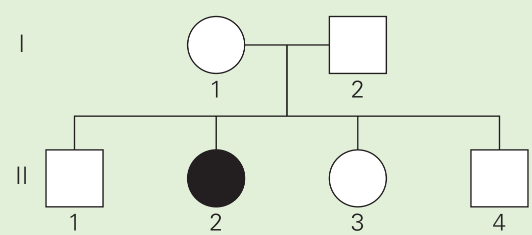


**Figure 2.41** Pedigree chart

a Identify a piece of evidence that suggests that this condition is recessive and not dominant.

b Identify the genotype of individuals I-1, I-2, II-1 and II-2.

c Suppose individual II-2 has children with a man who does not have achondroplasia but is a carrier for the condition. Determine the chance of having a child with achondroplasia and the chance of having a child without achondroplasia. Use a Punnett square to show how you arrived at your answer.

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## Section 2.3 questions

QUIZ

### Retrieval

1 **State** how many copies of each gene we have and where they come from.
2 **Recall** the name of the person known for being the father of genetics.
3 **Name** an example of codominance and of incomplete dominance.
4 The pedigree chart in Figure 2.42 shows the inheritance pattern of a disease that is caused by a single gene.
  a **Identify** the sex of the person labelled II-5.
  b **State** whether the disease is dominant or recessive, giving reasons for your answer.
  c **State** the genotype of individual II-5, giving reasons for your response.

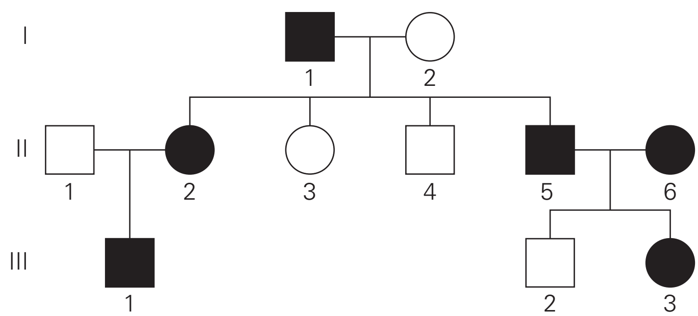


**Figure 2.42** Pedigree chart

5 Dimples are dominant to no dimples.
  a **Select** appropriate letters for these alleles.
  b **Identify** the genotype and phenotype of a person who is:
    i homozygous recessive for dimples
    ii heterozygous for dimples
    iii homozygous dominant for dimples.

### Comprehension

6 **Describe** what pedigrees are useful for.
7 **Explain** how sex linkage is different from other types of inheritance.
8 **Explain** why, for a particular characteristic, two homozygous recessive individuals can only produce homozygous recessive children.
9 **Explain** what is meant by the term 'carrier'.
10 **Explain** why a test cross is useful.

### Analysis

11 **Contrast** codominance and incomplete dominance.

### Knowledge utilisation

12 In fruit flies, eye colour is determined by an autosomal gene. The red eye allele is dominant over the white eye allele.
  a **Select** appropriate letters for the alleles.
  b Using a Punnett diagram, **determine** the offspring a male heterozygous fly that mates with a female homozygous recessive fly will produce.
  c **Decide** the genotypic and phenotypic ratios of the offspring.
13 In mice, black hair is dominant to brown hair. Mice with black hair can be either homozygous or heterozygous.
  **Propose** how you would find out if a mouse with black hair was homozygous or heterozygous. Support your response with a Punnett square.

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**14** The pedigree chart in Figure 2.43 shows the inheritance patterns for haemophilia. Haemophilia is an X-linked recessive disorder.
Use evidence from the pedigree to **justify** that haemophilia is recessive..

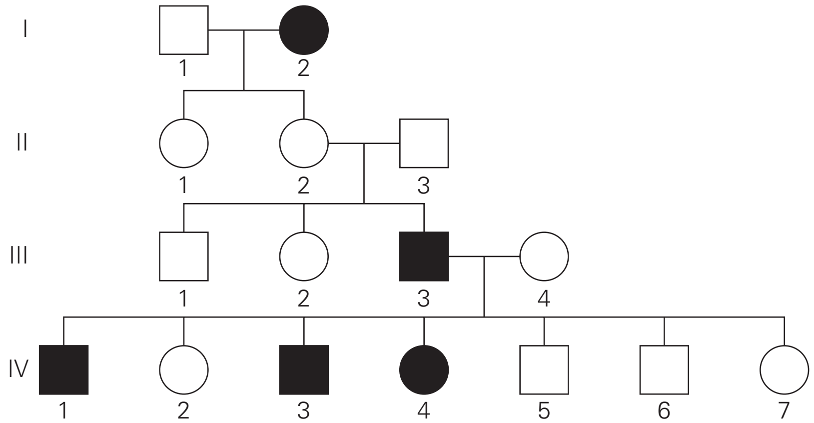


**Figure 2.43** A haemophilia pedigree

**15** A brown-eyed male and a blue-eyed female produced all blue-eyed children. **Discuss** whether that means blue eyes is the dominant trait.

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# 2.4 Changes in DNA

**Learning goals**

1. To be able to distinguish germline and somatic mutations.
2. To be able to recall types of point and chromosome mutations.
3. To explore the applications of DNA manipulation.

WORKSHEET Changes in DNA

Sometimes, the process of DNA replication makes errors, which cause changes to the genetic code. Often these errors are repaired, but when they are not, they become permanent changes in the genome of the cell. This is known as a mutation. Mutations may be small, such as a change in a single nucleotide (**point mutation**), or large, involving entire segments of DNA within a chromosome (**chromosome mutation**). Mutation is the only way that new alleles can be created within a population.

A mutation can be described as **spontaneous** (naturally occurring) or **induced**. Induced mutations are caused by exposure to **mutagenic** agents in the environment like radiation (X-rays, ultraviolet rays or nuclear radiation) or chemicals. Mutations that occur within the gametes are called **germline mutations**. These can be inherited and will influence the next generation. Mutations that occur within somatic cells will only affect the individual and will not be passed down to future generations. This form of mutation is known as a **somatic mutation**.

## Beneficial, harmful, and neutral mutations

Mutations have three possible consequences:

- **No effect – neutral**. Neutral mutations are non-lethal and make no difference to the organism's ability to survive and reproduce in its environment.
- **Negative effect – harmful**. Harmful mutations produce proteins that malfunction or cause proteins not to be produced at all. They can cause genetic

**point mutation**
a mutation in which a single nucleotide is changed

**chromosome mutation**
a mutation involving large segments of DNA

**spontaneous mutation**
a naturally occurring mutation

**induced mutation**
a mutation produced by environmental factors

**mutagenic**
causing mutations in DNA

**germline mutation**
a mutation of DNA in gametes which can be inherited

**somatic mutation**
a mutation that occurs in somatic (body) cells which cannot be inherited

**Explore! 2.6**

**Mutagens**

Many factors in the environment are known as 'mutagens' – that is, they cause mutations.

1. Research some environmental mutagens.
2. From the list created in Question **1**, divide your mutagens into categories according to their source, such as chemical mutagens, radiation and mutagens in food.

**Figure 2.44** Melanoma is linked to UV light exposure as well as gene changes. A mole may be a sign of skin cancer if it has irregular borders, an asymmetrical shape or if it changes in colour, shape, size or height.

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## Did you know? 2.7

**The Black Death left a genetic mark**

Many individuals with European ancestry carry genetic mutations that protected their ancestors from the bubonic plague, a disease caused by *Yersinia pestis*, a species of bacterium spread by fleas. When plague struck Europe in 1348 and again in 1665, millions of people were killed. However, some people had mutations that made them more likely to survive.

By examining the DNA of people who died before, during and after the Black Death, researchers have found that carrying two copies of a mutated ERAP2 gene improved a person's survival by 40%. The allele codes for a protein that is involved in the immune response, and the mutation produced a heightened response. This meant that the survivors of bubonic plague passed on this beneficial trait to their offspring. However, this mutation is also problematic. Individuals who carry the mutated ERAP2 gene are at an increased risk of autoimmune diseases.

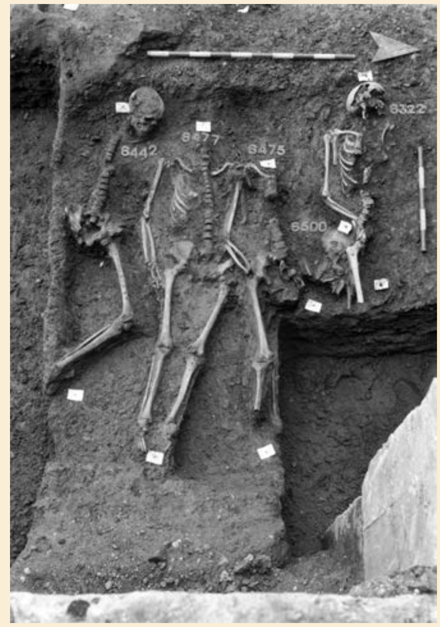

**Figure 2.45** A small mass burial pit of plague victims excavated in East Smithfield, London. The significant number of deaths during plague outbreaks resulted in many similar mass burials across Europe.

disorders or cancer and result in organisms that are less likely to survive, reducing the likelihood that the genetic material will be passed on to the next generation.

- **Positive effect – beneficial**. Beneficial or advantageous mutations give rise to new versions of proteins that increase the chance that the organism will survive and reproduce to pass its genetic material to the next generation. Beneficial mutations increase genetic variation in a population and are essential for evolution to occur.

**gene mutation**
a permanent alteration in the DNA sequence that makes up a gene

**substitution**
where one nucleotide is swapped for another

## Quick check 2.16

1. If a mutation is to be passed on to the next generation, recall where it must occur.
2. Summarise the possible effects of mutations that occur in somatic cells.

## Gene mutations

**Gene mutations** refer to changes in the DNA sequence that make up a gene. This involves changes to any of the four nitrogenous bases in the nucleotides that make up the genes.

There are several types of gene mutations, including point mutations, insertions, deletions and inversions.

Changing the nucleotides could change the message carried by the gene, which may change the order of amino acids making up the protein.

- A point mutation is the most common type of gene mutation, and involves the **substitution** of one nucleotide for another (for example, ATG becomes ACG). This mutation only changes the DNA code for a single amino acid. If the new sequence codes for the same amino acid, it is called

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a silent mutation. An example of a disease caused by a substitution mutation is sickle cell anaemia.

- An **insertion** mutation occurs when an extra nucleotide (or more than one) is inserted into the DNA sequence (for example, ATG becomes ATCG). This type of mutation changes the DNA code for all amino acids that follow and is called a frameshift mutation. An example of a disease caused by an insertion mutation is fragile X syndrome.
- A **deletion** mutation occurs when a nucleotide is deleted from the sequence (for example, ATG becomes AG). This type of mutation changes the DNA code for all amino acids that follow and is also a frameshift mutation. An example of a disease caused by a deletion mutation is Duchenne muscular dystrophy.
- An **inversion** mutation occurs when two nucleotides reverse their order in the DNA (for example, ATG becomes AGT). This mutation only changes the DNA code for a single amino acid, and it could code for the same amino acid (silent mutation). An example of a disease caused by an inversion mutation is haemophilia.

**Try this 2.7**

**Remembering deletions**

Find a way to remember the different types of mutations using normal words. For example:

- Normal code – WING
- Deletion – WIG
- Substitution – WIND
- Insertion – WRING.

## Chromosomal changes

### Chromosome mutations

If a mutation occurs in a gene on one of the pair of homologous chromosomes, there will still be a normal copy of the gene on the other chromosome. The same applies with chromosome mutations. As chromosomes occur as homologous pairs, if one chromosome is abnormal, the other is still likely to be normal. The different types of chromosome mutations are illustrated in Figure 2.46.

**insertion**
where one or more extra nucleotides are inserted into the DNA

**deletion**
where a nucleotide is deleted from the sequence

**inversion**
where two nucleotides reverse their order

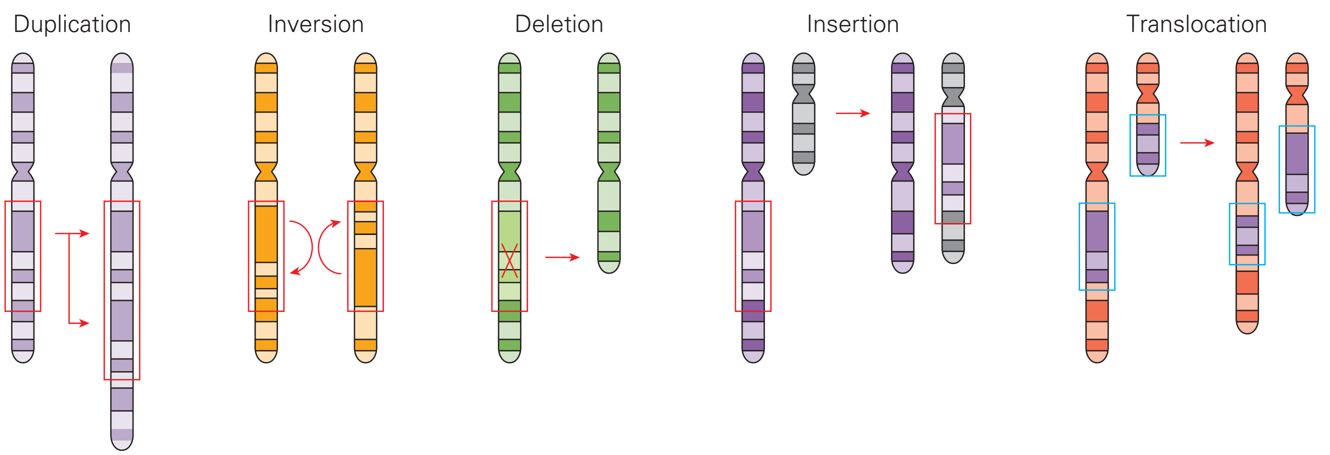


**Figure 2.46** The five different types of chromosome mutation. Can you identify what is changing in each type?

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## Explore! 2.7

### Sickle cell anaemia

Sickle cell anaemia is a disease caused by a mutation in a gene that codes for a subunit of haemoglobin, a protein found in red blood cells. The mutation causes the red blood cells to be misshapen and block blood vessels. Despite this, the sickle cell trait protects against the development of malaria. Research the following questions.

1. Which amino acid is changed in sickle cell anaemia?
2. Sickle cell anaemia is an example of both a harmful and a beneficial mutation. Explain what these terms mean.
3. What is the correlation between the distribution of the mutated gene and the distribution of malaria in Africa?
4. Why is sickle cell anaemia harmful in a non-malarial zone and beneficial in a malarial zone?

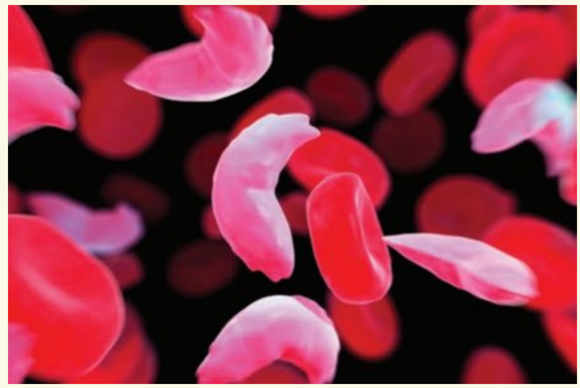

**Figure 2.47** Red blood cells are misshapen and resemble sickles in people with sickle cell anaemia.

**non-disjunction**
the failure of homologous chromosomes or sister chromatids to separate correctly in meiosis

**aneuploidy**
the presence of an abnormal number of chromosomes in a cell

**trisomy**
when an organism has a third copy of a chromosome

## Chromosome number abnormalities

Certain individuals may have one more or one fewer chromosome because of **non-disjunction** during meiosis. Non-disjunction means that the chromosomes failed to separate correctly when making gametes, so the gametes end up with an abnormal number of chromosomes (**aneuploidy**).

**Trisomy** occurs when an organism has a third copy of a chromosome that should only be present in two copies. Trisomy is therefore an example of aneuploidy. The most common trisomy among embryos that survive to birth is Down syndrome, or trisomy 21. People with this inherited disorder have distinct facial characteristics and experience developmental delays.

## Did you know? 2.8

### Sex chromosome abnormalities

Sex chromosome abnormalities occur when a person is missing a whole sex chromosome or has an extra sex chromosome due to non-disjunction. Problems can also occur when a person is missing part of a sex chromosome. Some disorders of sex chromosome are Klinefelter syndrome, XX male, XYY male, Turner syndrome, XXX female and XY female. Some of these disorders are surprisingly common. For example, many men with Klinefelter syndrome (who have two X chromosomes and one Y) have no signs or symptoms, and it is estimated that only one in six are ever diagnosed.

**Figure 2.48** A karyotype of a male with Klinefelter syndrome

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## Quick check 2.17

1 Describe a substitution mutation.
2 Recall what the term 'aneuploidy' means.


**Figure 2.49** There are other types of trisomy apart from trisomy 21. Trisomy 13 and 18 result in more severe conditions. Which trisomy is depicted in this karyotype?

## Did you know? 2.9

**Madeline Stuart**

Madeline Stuart is the first professional model with Down syndrome, and she is Australian! Although the fashion industry has a long way to go in terms of diversity, Madeline is one of the women who are changing the game. As well as being a model, she has also represented Queensland at the Special Olympics in cricket and basketball.

**Figure 2.50** Madeline Stuart models at the New York Fashion Week.

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## DNA testing

A person's DNA can provide information relating to their ancestry or parentage, confirm if they have a hereditary disease, and inform whether they are a carrier for genetic disorders that may affect their children.

**genetic screening** genetic tests carried out across the population to identify people at risk of genetic disorders

**Genetic screening** is a type of genetic testing, but instead of identifying a genetic condition, it is used to evaluate an individual's risk of developing a certain disease. These tests are routinely done for anyone in the population, even if they have not shown a family history of the disease. Genetic screening is usually done during pregnancy and at birth. In Australia, about 99% of babies are screened every year. Of the babies screened, around one in every thousand has a condition that would otherwise have gone undetected. Genetic screening provides an opportunity for preventive measures and early treatment.

**Figure 2.51** In Queensland, the newborn bloodspot screening test screens for cystic fibrosis, phenylketonuria, hypothyroidism, galactosaemia and congenital adrenal hyperplasia.

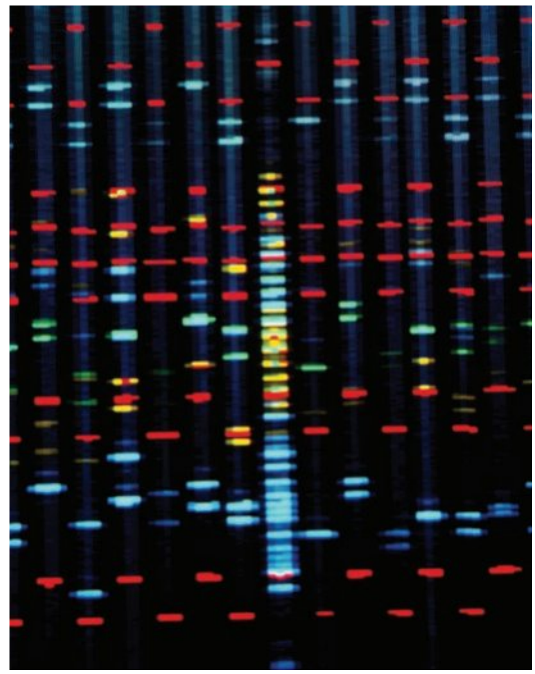

**Figure 2.52** A DNA sequence or 'genetic fingerprint' on a computer monitor. The development of fast computers made the analysis of DNA sequences possible.

### Making thinking visible 2.2

**Think, feel, care: Genetic screening**

In your class, divide into teams and engage in a discussion about perspectives within a scenario about genetic testing. You may wish to consider the following scenario, although your teacher may provide you with an alternative.

A woman who is 12 weeks pregnant attends a clinic and expresses her concern about her husband's family history of Huntington's disease (HD). Her sister-in-law tested positive last year, although she is not yet showing symptoms of the disease, but the woman's husband refuses to be tested. Due to this, the woman is asking for her unborn baby to be screened to determine whether it carries the HD gene. If the test comes back positive, which means that her husband carries the HD gene, the woman will discuss terminating the pregnancy with her husband.

Step inside each person's point of view in this scenario. As you think about what you know, consider what each person might understand, respond to and value in the issues raised. Don't forget to consider the legal and ethical issues.

The *Think, feel, care* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

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## Science as a human endeavour 2.2

**Precision medicine**

Pharmacogenomic tests look for genetic variants that are associated with an individual's response to specific medicines, by testing genes that affect drug metabolism. Its goal is to help doctors to select the drugs and doses that are best suited to each person.

**Figure 2.53** Research has shown that people with red hair tolerate pain differently to people with other hair colours. Due to a mutation on the MC1R gene, they require more anaesthesia but need lower doses of opioids as they are more responsive to those painkillers.

## Quick check 2.18

1 Explain why an individual might choose to be screened for genetic diseases.
2 Identify some ethical issues with genetic testing.

## Manipulating DNA

**Genetic engineering** technology allows scientists to manipulate genetic material and transfer genes between different organisms.

One of the most exciting developments of the last decade is CRISPR, a technology that can edit genetic material quickly and cheaply. Developed by Jennifer Doudna and Emmanuelle Charpentier, the CRISPR tool lets scientists change or delete DNA bases and insert entirely new genes. The gene editing technology has almost endless potential, including editing crops so they're more nutritious or able to survive in different conditions, curing genetic diseases, producing powerful new drugs or even resurrecting extinct species. In 2022, a New Zealand woman became the first to receive CRISPR treatment to treat heart disease by permanently lowering her cholesterol.

**genetic engineering** deliberately modifying genetic material to manipulate the characteristics of an organism

VIDEO CRISPR

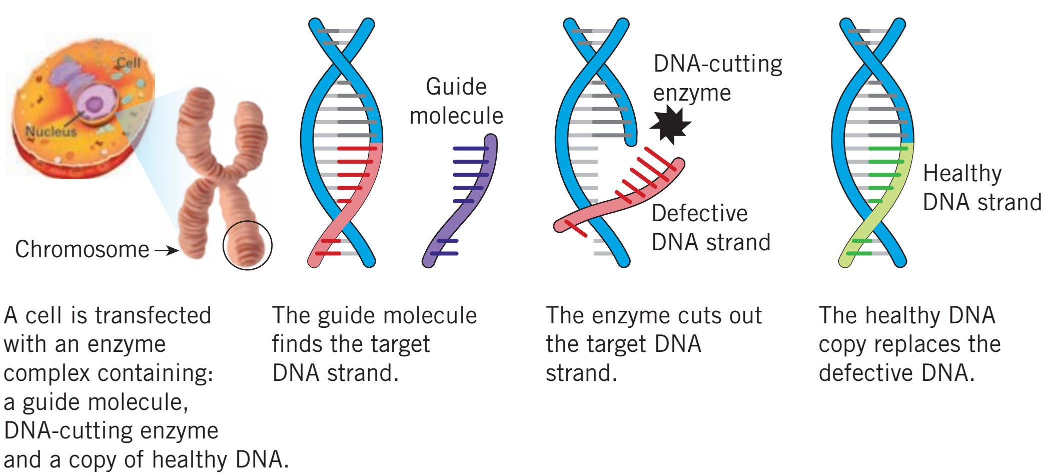


**Figure 2.54** CRISPR gene editing technology allows DNA to be manipulated in a highly precise way.

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## Genetically modified organisms

**genetically modified organism** an organism that has had its genome altered using genetic engineering techniques

A **genetically modified organism** (GMO) is an organism whose genome has been altered by humans. Commonly, they are crop species that have been modified to improve growth rates, yield, quality and nutritional value. Genetic modification can decrease pest and disease susceptibility, reducing the need for pesticides.

Agricultural practices have changed to include the widespread use of genetically engineered crops. Crop plants are modified to have a greater tolerance to environmental stressors such as drought or heavy metals, allowing plants to grow in new areas. For example, some plants have been genetically engineered to grow with less water so that they are more resistant to climate change. Until recently, only three GM crops were approved to be grown in every mainland Australian state: canola (oilseed rape), cotton and safflower. After a ban was lifted, a wider range of GM crops can now be grown in every mainland state.

### Try this 2.8

**GM food**

A great debate continues to rage within society regarding the health risks associated with eating GM food. Research two advantages and two disadvantages of the use of GM food and be prepared to debate with your classmates.

**Figure 2.55** Cassava root has been genetically modified to have increased levels of beta carotene (right). This decreases post-harvest deterioration and also improves the nutritional value of the crop.

### Did you know? 2.10

**De-extinction**

De-extincting is the process of bringing an extinct species back to life through genetic engineering by using fragments of DNA from preserved specimens. De-extincting species is a controversial idea, and many scientists argue that funding would be better spent conserving existing species and their habitats. A start-up biotechnology company called Colossal Biosciences quickly raised millions of dollars after announcing plans to de-extinct the woolly mammoth, the thylacine and the dodo.

**Figure 2.56** A model reconstruction of a dodo on display in the Birds gallery at the Natural History Museum in London.

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**Figure 2.57** Golden rice and normal rice

**Figure 2.58** Mosquitoes have been genetically modified to slow the growth of malaria-causing parasites in their gut, preventing transmission of the disease to humans.

Genetic engineering is also helping to alleviate global malnutrition and disease. A type of rice called golden rice has been engineered to prevent blindness in children caused by vitamin A deficiency. Another type of GM rice has been developed that has four times more iron than normal rice.

## Explore! 2.8

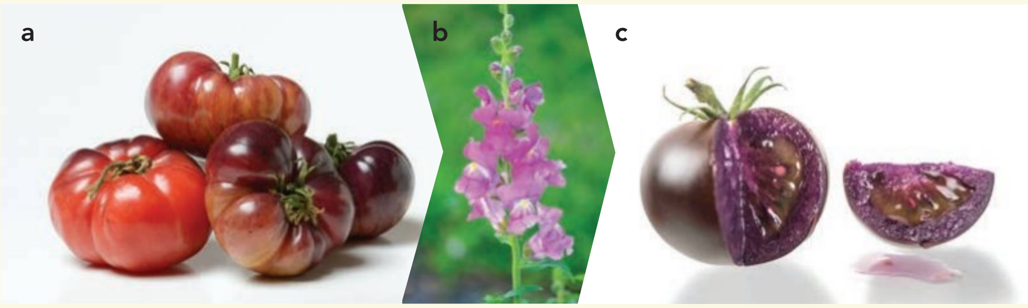
### Genetically modified tomatoes

Many foods come from genetically modified organisms, and we call them GM foods. The Flavr Savr tomato was the first commercially grown GM food that was granted a licence for human consumption. Released in 1994, the tomato had an improved shelf life and was developed for long-distance shipping. Recently, a GM tomato has been developed that contains higher levels of anthocyanins, a pigment that occurs naturally in purple or blue fruits and vegetables such as blueberries or red cabbage. By transferring a snapdragon gene into a tomato's genome, they have produced a purple tomato that has the same levels of anthocyanins as blueberries.

1 Research why the team chose to genetically modify a tomato.

2 The high levels of anthocyanins in the purple tomatoes are beneficial for several reasons. Research the effect of anthocyanins on:

  a shelf life
  
  b plant reproduction and survival
  
  c human health.




**a** Existing purple-skinned tomatoes do not contain useful levels of anthocyanins.

**b** Genes from purple snapdragon flowers were added to the tomato. The snapdragon genes act like 'on switches', causing the purple pigment to be expressed throughout the tomato, instead of just in the skin.

**c** The resulting purple tomato is high in anthocyanins, which have a range of benefits for human health.

**Figure 2.59** The process by which the John Innes Centre and the Sainsbury Laboratory created a GM purple tomato, which was approved for growing and breeding in the US in 2022

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**Figure 2.60** Transgenic C5 plums contain a gene that makes them resistant to plum pox virus.

**transgenic organism**
an organism that possesses a foreign gene or segment of foreign DNA in its genome because of human experimentation

**Transgenic organisms** (TGOs) are the result of a type of genetic modification where a 'foreign' gene, or a segment of 'foreign' DNA is inserted into an organism's genome. A foreign gene is one that is taken from another species. All transgenic organisms are GMOs, but not all GMOs are transgenic.

By inserting human genes into mice, human diseases can be mimicked, particularly as the genome and physiology of mice are so similar to humans. Transgenic mice are being used to study conditions such as obesity, heart disease, diabetes and Alzheimer's disease. Transgenic pigs are being investigated as a source of organs for transplants, which could address severe donor organ shortages. CRISPR technology has greatly reduced the complexity of the creation of transgenic animals, making the process faster and cheaper.

Human genes have been engineered into other mammals to supply the protein products of those genes, usually for medical purposes. For example, transgenic goats have been genetically engineered to produce milk that contains human antithrombin III. This is a protein that is used to prevent clots in patients with hereditary antithrombin deficiency when they are in surgery or giving birth. A herd of approximately 80 goats could supply enough human antithrombin III for all of Europe.

**Figure 2.61** A CSIRO study found that genetically modified sheep grow bigger and faster and can produce more milk and wool. However, they required more care than non-GM sheep.

## Making thinking visible 2.3

**I used to think … now I think … : Xenotransplantation**

Xenotransplantation is the transplantation of living cells, tissues or organs from one species to another. Transgenic pigs are promising xenotransplantation donor organisms as they share many anatomical and physiological characteristics with humans. In 2022, the first pig-to-human heart transplant took place. The operation was successful and, due to genetic modification, the heart was not rejected by the patient's immune system. Unfortunately, he died 60 days later; scientists are still investigating why this happened. Scientists have also been successful in transplanting genetically modified pig kidneys into a brain-dead patient, with them functioning normally throughout the study period.

Think about what you have learned about transgenic organisms and xenotransplantation and complete the following sentence stems.

In the past, my viewpoint was …

Currently, my viewpoint is …

The *I used to think … now I think …* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

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## Gene therapy

**Gene therapy** is a process by which a copy of a functional gene is introduced into an organism. The gene is then switched on to produce the functional protein that is missing. This technique aims to treat inherited disorders like cystic fibrosis by directly targeting the genotype (unlike treatments that target the symptoms). Technical difficulties may arise when trying to specifically target the cells of affected tissue, and when targeting one specific gene without interfering with the function of other essential genes. Ethical issues also arise. Some people argue that gene therapy should be restricted to somatic tissue only, so the introduced gene is not transmitted through to the next generation. What do you think about this issue?

**gene therapy**
a process by which a copy of a functional gene is introduced into an organism

### Science as a human endeavour 2.3

**DNA data storage**

Digital technology currently works on the binary system, which only uses the digits 0 and 1. Any information that is input digitally is converted to this system, and digital devices will change those values to the necessary form of information. It's predicted that by 2035 the total volume of digital data generated by humans is expected to reach 2142 zettabytes (a zettabyte is equivalent to 1 000 000 000 000 000 000 000 bytes). Currently, most data is stored in the 'cloud', but the cloud is actually huge data centres stored in warehouses that require large amounts of energy to run.

However, by translating binary (0 or 1) values into one of the four DNA bases, it is possible for DNA to be reliably used to store huge amounts of digital data. Some scientists say that the entire world's data could be stored in DNA that would fill a shoebox.

Rather than storing 0s and 1s individually, DNA allows them to be stored in pairs such as this:

- 00 A
- 01 T
- 10 C
- 11 G.

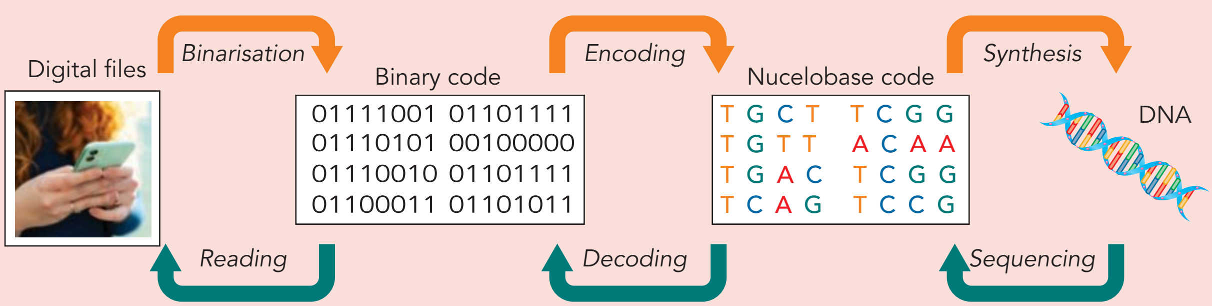


**Figure 2.62** Encoding data into DNA code might be the future of efficient data storage.

After storing data in DNA, it can then be read using a DNA sequencer. This reads all of the bases and then converts it to binary. Improvements in sequencing techniques allow for billions of DNA sequences to be easily read at once and, when kept in suitable conditions, DNA can be preserved for hundreds of thousands of years without any energy input.

New sequencing techniques are also allowing sections of DNA to be used as identification tags. This DNA barcoding is accelerating the pace of research in fields such as chemical engineering, materials science and nanotechnology.

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## Quick check 2.19

1 Recall what GMO stands for.
2 Describe the process of gene therapy.
3 State an example of the application of genetic screening.
4 Discuss the reasons for the adoption of genetic screening by groups in society.
5 State five conditions that are screened for in Queensland through the newborn bloodspot screening tests.

## Section 2.4 questions

QUIZ

**Retrieval**

1 If a mutation is to be passed on to the next generation, **state** where it must have occurred.
2 **Define** the term 'mutagen'.
3 **Recall** the definition of a genetically modified organism.
4 Using the table below, answer the following questions.

Second letter in the codon

| First letter in the codon | U | | C | | A | | G | | Third letter in the codon |
|---|---|---|---|---|---|---|---|---|---|
| U | UUU | Phe (F) | UCU | Ser (S) | UAU | Tyr (Y) | UGU | Cys (C) | U |
| | UUC | | UCC | | UAC | | UGC | | C |
| | UUA | Leu (L) | UCA | | UAA | STOP | UGA | STOP | A |
| | UUG | | UCG | | UAG | STOP | UGG | Trp (W) | G |
| C | CUU | Leu (L) | CCU | Pro (P) | CAU | His (H) | CGU | Arg (R) | U |
| | CUC | | CCC | | CAC | | CGC | | C |
| | CUA | | CCA | | CAA | Gin (Q) | CGA | | A |
| | CUG | | CCG | | CAG | | CGG | | G |
| A | AUU | Ile (I) | ACU | Thr (T) | AAU | Asn (N) | AGU | Ser (S) | U |
| | AUC | | ACC | | AAC | | AGC | | C |
| | AUA | | ACA | | AAA | Lys (K) | AGA | Arg (R) | A |
| | AUG | Met (M) START | ACG | | AAG | | AGG | | G |
| G | GUU | Val (V) | GCU | Ala (A) | GAU | Asp (D) | GGU | Gly (G) | U |
| | GUC | | GCC | | GAC | | GGC | | C |
| | GUA | | GCA | | GAA | Glu (E) | GGA | | A |
| | GUG | | GCG | | GAG | | GGG | | G |

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The original DNA strand is GTC GGG ATA CGG CTC.
A gene mutation occurs, whereby the C in the first codon is replaced with a T, resulting in GTT GGG ATA CGG CTC.

a **State** the name of this gene mutation.
b **State** the mRNA strand that was copied from the original DNA strand.
c **State** the new mRNA strand produced from the mutated DNA strand.
d **State** whether the amino acids stay the same or change.
e Another mutation occurs, whereby a C was added to the beginning of the above original DNA strand, giving CGTC GGG ATT CGG CTC.
**State** the name of this mutation and describe how it would affect the subsequent amino acids that it codes for.
f Write out the mRNA code for this mutation and **identify** the corresponding amino acids.

**Comprehension**

5 **Explain** what will happen if a nucleotide is deleted from the sequence of nucleotides within a gene.
6 **Explain** what usually results when mutations occur in non-germ (somatic) cells.
7 **Explain** whether or not all mutations are detrimental (harmful).
8 **Explain** how a mutated gene can lead to a genetic disorder.
9 **Illustrate** a diagram to outline how non-disjunction may occur and cause aneuploidy.

**Analysis**

10 **Contrast** a genetically modified organism and a transgenic organism.
11 **Contrast** a spontaneous mutation and an induced mutation.

**Knowledge utilisation**

12 Using the DNA sequence ACAATTGGTAGCTGAGTTGGCCCGTA, **create** an example of the following mutations.
a substitution b inversion c deletion d insertion.
13 **Discuss** why the substitution of one nucleotide may not be as critical to the functioning of the protein as the deletion or insertion of a nucleotide.
14 **Propose** an explanation for the relationship between increased rates of skin cancer and the thinning of the ozone layer.
15 **Construct** a mind map that shows the different types of mutations that may occur.

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# Chapter review

## Chapter checklist

You can download this checklist from the Interactive Textbook to complete it.

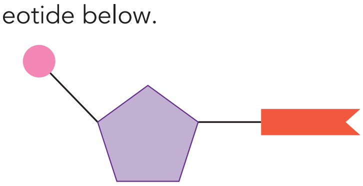
| Success criteria | | Linked questions | Check |
|---|---|---|---|
| **2.1** | I can recall the components that make up the structure of DNA and RNA molecules. | 6, 13 | |
| **2.1** | I can describe the relationship between genes, DNA and chromosomes. | 1 | |
| **2.1** | I can describe the steps in which DNA is used to synthesise proteins. | 7, 18 | |
| **2.2** | I can recall the steps involved in DNA replication. | 3, 4, 15 | |
| **2.2** | I can describe the stages of cell division in mitosis. | 17 | |
| **2.2** | I can describe the stages of cell division in meiosis. | 17 | |
| **2.2** | I can use a karyotype to determine information about an individual. | 10 | |
| **2.3** | I can define the terms 'homozygous', 'heterozygous', 'dominant' and 'recessive' with respect to genetic inheritance. | 5 | |
| **2.3** | I can use and interpret a Punnett square to identify possible genotypes and phenotypes of offspring. | 20, 23 | |
| **2.3** | I can explain sex linkage. | 11, 19 | |
| **2.3** | I can distinguish between codominance and incomplete dominance. | 22 | |
| **2.3** | I can use a pedigree diagram to determine the type of inheritance that is occurring. | 19 | |
| **2.4** | I can explain the different types of mutations, including their causes and effects. | 16 | |
| **2.4** | I can describe some ways in which DNA can be manipulated. | 25 | |

## Review questions

SCORCHER

### Retrieval

1 **State** the name of the position on a chromosome where a particular gene is located.
2 **Recall** two autosomal recessive inheritable traits.
3 **Recall** the name of the enzyme that unwinds the DNA double helix during DNA replication.
4 **Name** the structure formed when DNA condenses and becomes visible before cell division.
5 **Define** the terms 'homozygous', 'heterozygous', 'dominant' and 'recessive'.
6 **Identify** the parts of the nucleotide below.



7 **State** where transcription and translation occur.
8 **State** how many chromosomes you would expect to find in a:
   a human somatic cell
   b human gamete
   c human somatic cell with Down syndrome.

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**9** The table below shows several different organisms with their chromosome number.

| Organism | Chromosome number |
|---|---|
| Chimpanzee | 48 |
| Human | 46 |
| Horse | 64 |
| Onion | 16 |
| House fly | 12 |
| Worm | 20 |

a **Identify** the organism with the highest number of chromosomes in its gametes.
b **State** the haploid number of the onion.

**10** **Identify** what information can be gained from the following karyotype.

## Comprehension

**11** **Explain** why males have more chance than females of inheriting an X-linked recessive trait.

**12** Assuming eye colour in humans is controlled by a single pair of genes, and that brown eyes are dominant to blue eyes, **determine** the genotype of a brown-eyed man if he and a woman with blue eyes produce a baby with blue eyes.

**13** **Illustrate** a diagram to show how two nucleotides join together with hydrogen bonds.

**14** **Explain** why chromosomes are not always visible.

**15** When cells reproduce themselves, the DNA is replicated. **Explain** why this is necessary.

**16** **Explain** how aneuploidy occurs.

**17** **Contrast** meiosis and mitosis.

**18** **Illustrate** a diagram to show the processes of transcription and translation.

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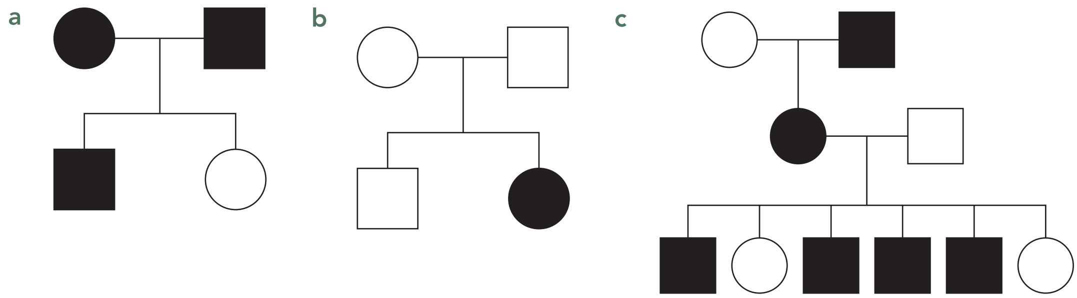
### Analysis

**19** Use information from the following pedigrees to **infer** the inheritance pattern shown.




### Knowledge utilisation

**20** Using a Punnett square, **determine** the genotypes and phenotypes of the children if a normal-vision female carrier of colour blindness has children with a normal-vision male.

| | gametes | Normal-vision carrier female ($X^B$ $X^b$) | |
|---|---|---|---|
| | | $X^B$ | $X^B$ |
| Normal-vision male ($X^BY$) | $X^B$ | | |
| | Y | | |

**21** **Construct** a pedigree with the following information.
A woman with Huntington's disease marries a man who does not have Huntington's disease. They have three children. The first child is a male, the second child is a female, and both do not have the disease. The third child, a male, does develop the disease. Remember that Huntington's disease is an autosomal dominant genetic disorder.

**22** An abandoned baby was handed in at the police station. Later, two women claimed to be the baby's mother. Blood studies revealed that woman 1 had blood type A, and that woman 2 was blood type AB. The baby was blood type O. **Deduce** which woman could possibly be the baby's mother and which woman can be ruled out completely. Show your working.

**23** Chondrodystrophy is an autosomal recessive condition that is governed by a single gene with two alleles. In turkeys, affected embryos die approximately 16 days after fertilisation, so they do not survive long enough to hatch. Two turkeys that are heterozygous for the condition are crossed. Show your working to **determine** the phenotypic and genotypic ratios of the offspring.
Let C = normal allele and c = allele with chondrodystrophy.

**24** Personal genome screening can be readily ordered over the internet. **Evaluate** the pros and cons of having DNA testing so readily available at an affordable cost.

**25** You had genome screening and found out that your genes conferred a 25% chance of developing a disease. However, you also know that environmental and lifestyle factors play a large role in whether you develop the disease.

a **Evaluate** how this information would affect your life.

b **Discuss** how this scenario is different from knowing about a disease that is not influenced by lifestyle factors.

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## Data questions

A student prepared an onion root tip slide and examined the cells using a light microscope. She recorded the number of cells in each stage of the cell cycle.

The table shows her results.

| Stage of cell cycle | Number of cells recorded |
|---|---|
| Interphase | 340 |
| Prophase | 13 |
| Metaphase | 4 |
| Anaphase | 3 |
| Telophase | 6 |

She then calculated the mitotic index for different areas of the root tip. The graph shows her results.

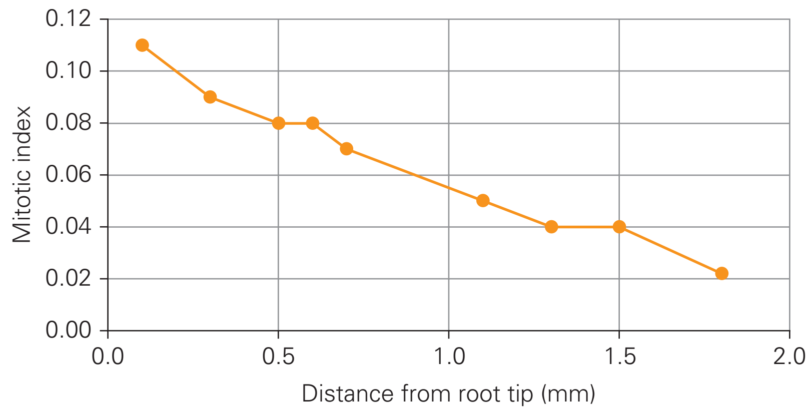


**Figure 2.63** Mitotic index plotted against distance from root tip

### Apply

1 The mitotic index of dividing tissue is calculated with the following formula:

$$\text{Mitotic index} = \frac{\text{number of cells seen that were undergoing mitosis}}{\text{total number of cells seen}}$$

**Calculate** the mitotic index of the tissue shown in the table.

2 The duration of any phase of the cell cycle can be calculated with the following formula:

$$\text{Phase duration (minutes)} = \frac{\text{number of cells seen in that phase}}{\text{total number of cells seen}}$$

$$= \text{cell cycle duration of the organism.}$$

The cell cycle duration for the onion is 24 hours.

**Calculate** the duration of metaphase.

### Analyse

3 **Identify** the trend shown in the graph.

### Interpret

4 **Extrapolate** the data in the graph to estimate the mitotic index of the cells found 2 mm from the root tip.

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# STEM activity: Designing and prototyping an assistive device for individuals with a genetic disease

## Background information

When a mutation occurs that is not beneficial, complications occur. An example of a disease with genetic causes is scoliosis. Scoliosis is a sideways curvature of the spine that usually occurs before puberty. Genetic diseases such as cerebral palsy and muscular dystrophy can cause scoliosis, but the cause of most scoliosis is unknown.

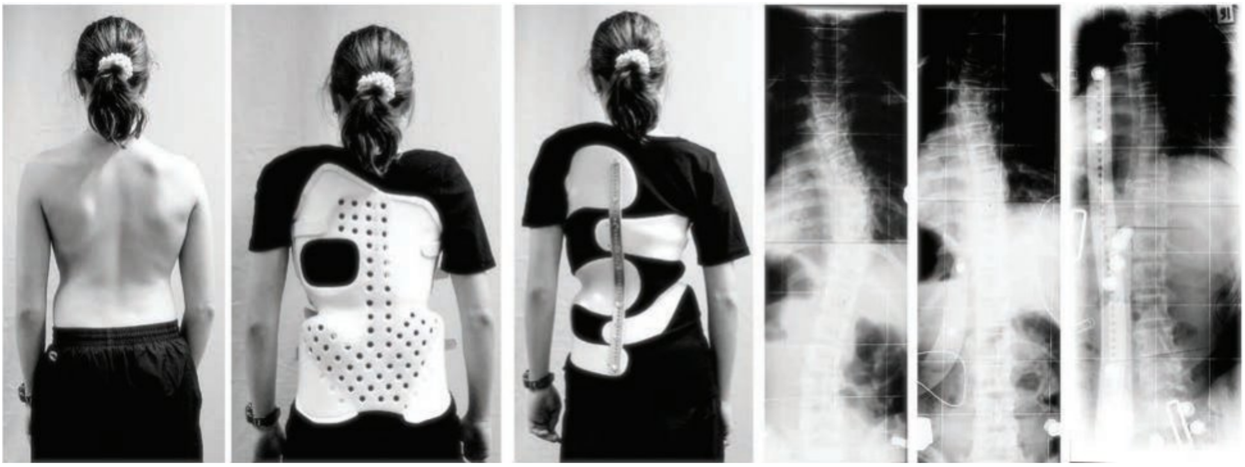

**Figure 2.64** Various brace designs can be used for the treatment of scoliosis.

**Design brief:** Research a genetic disease. Design and build an apparatus that can help to improve the quality of life for people with the selected disease.

## Activity instructions

In groups of three or four, conduct basic research on a genetic disease. Then design an apparatus that will improve the quality of life for people with that condition. Consider how the product would be built and marketed. Each team member needs to have a clear role but must be able to contribute to all aspects of the project.

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## Suggested materials

- computer
- pencil
- paper
- ruler
- balsa wood
- plaster
- papier mâché
- chicken wire
- 3D printer
- cardboard
- poster paper

## Research and feasibility

1 Research genetic diseases and as a group decide which genetic disease will be the focus.
2 Create a table of the causes and effects of the disease.

| Genetic disease cause | Effects on part of body | Ideas to help |
| --- | --- | --- |
| e.g. Muscular dystrophy<br>Muscle loss | Reduced joint movement | Brace and orthotics for feet |
| e.g. Haemophilia<br>Blood doesn't clot effectively | Whole body can be bruised easily | 1 Creation of children's play suit<br>2 Creation of some type of buffing edging that could be applied to furniture |

3 Find pictures or diagrams of current equipment used, and annotate them with features and characteristics that relate to assisting people living with this disease.

## Design and sustainability

4 Sketch potential design solutions (at least two) and annotate the purpose of the apparatus and what it is made of. Describe how it will improve the quality of life for people with this disease. How will it improve on current aids or tools (if any)?
5 Reflect on the materials you would use in real-world construction and comment on the durability and sustainability of the materials.

## Create

6 Build a prototype of your design using available construction materials.

## Evaluate and modify

7 Reflect on the prototype you have created and its effectiveness to help people with your chosen genetic disease.
8 Discuss as a group the modifications you would make in your solution to increase the effectiveness of design.
9 Present your prototype to the class. Outline the effectiveness of the prototype and demonstrate supporting ideas that show how the prototype would improve the quality of life of a person with this genetic disease.

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# Chapter 3
# Evolution

## Chapter introduction

Life on Earth has been evolving for billions of years, resulting in an enormous diversity of organisms. But despite the differences, there are also similarities. While koalas, quolls, frogs and dolphins all look different, their skeletons are organised in the same way. This can be explained by evolution: the idea that all organisms on Earth are the living descendants of common ancestors that have changed over a long period. The evidence we see in the fossil record, genetics and other fields of science supports the theory of evolution. In this chapter, we will look at the evidence that supports the theory for evolution and evaluate the key processes involved.

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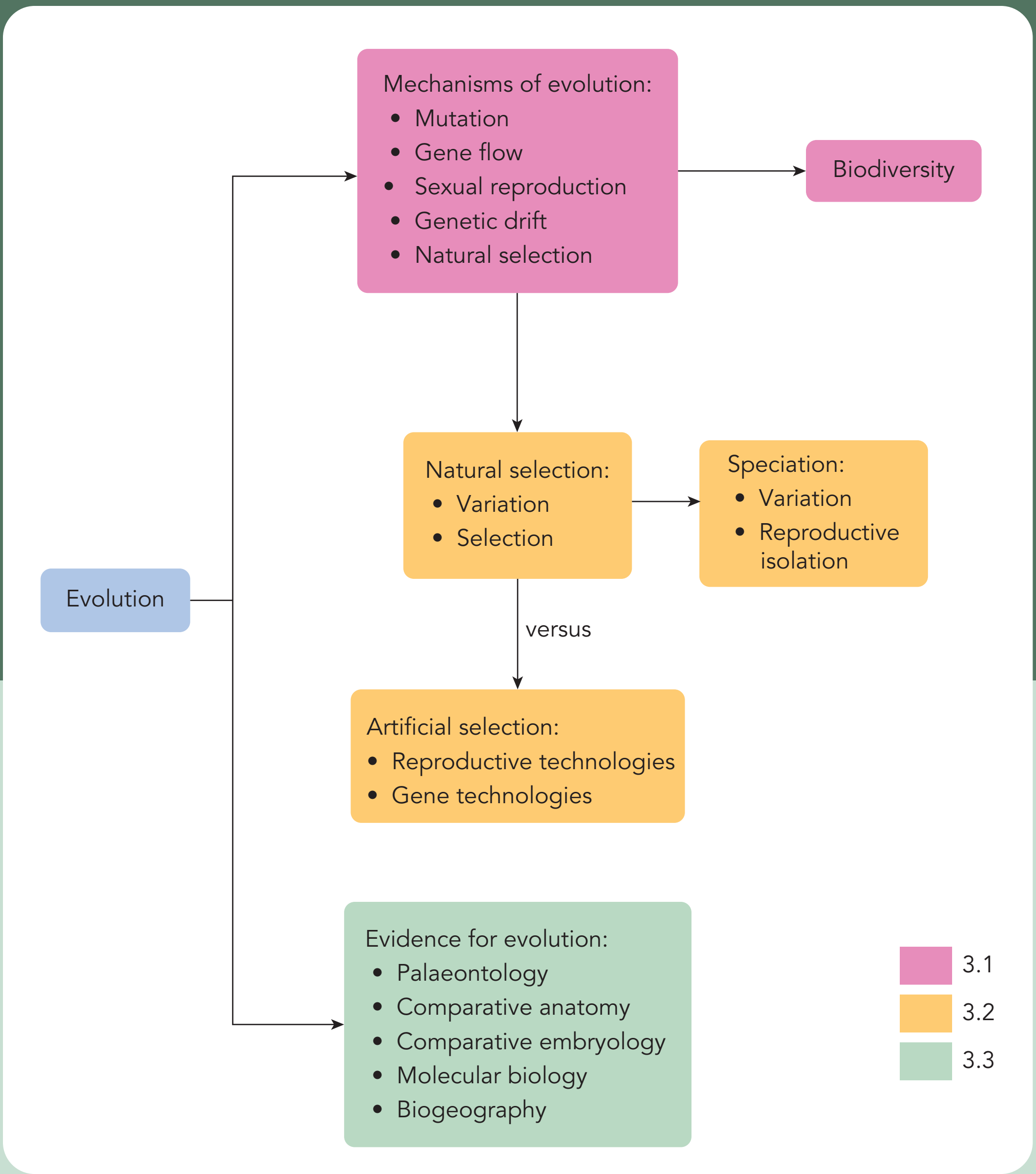
# Concept map

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## Curriculum

| | |
|---|---|
| Use the theory of evolution by natural selection to explain past and present diversity and analyse the scientific evidence supporting the theory AC9S10U02 | |
| examining biodiversity as a function of evolution | 3.1 |
| investigating some of the structural and physiological adaptations of First Nations Australians to the Australian environment | 3.1 |
| outlining processes involved in natural selection including variation, isolation and selection | 3.1, 3.2 |
| relating genetic characteristics to survival and reproductive rates | 3.1, 3.2 |
| investigating changes caused by natural selection in a particular population as a result of a specified selection pressure such as artificial selection in breeding for desired characteristics | 3.2 |
| analysing evidence for the theory of evolution by natural selection including the fossil record, chemical and anatomical similarities, and geographical distribution of species | 3.3 |



## Glossary terms

Absolute dating
Adaptation
Allele frequency
Analogous structures
Artificial selection
Biodiversity
Biogeography
Biostratigraphy
Biota
Bottleneck effect
Direct (evidence)
DNA hybridisation
Ecosystem diversity
Endangered
Endemism
Evolution
Evolutionary tree
Extinct
Fertile
Fossil
Fossil record
Fossilisation
Founder effect
Gene flow
Genetic diversity
Genetic drift
Genetic variation
Half-life
Homologous structure
Index fossil
Indirect (evidence)
Megafauna
Natural selection
Population (ecological)
Radioisotope
Relative dating
Reproductive isolation
Selection pressure
Selective advantage
Selective breeding
Speciation
Species
Species diversity
Stratigraphy
Trace fossil
Variation
Viable

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# 3.1 Evolution

**Learning goals**

1. To describe how evolution can take place through five key drivers.
2. To explore how biodiversity has changed over time.

DOC
WORKSHEET
Mechanisms for evolution

**Evolution** is a complex process that encompasses genetic changes occurring over extended periods within **populations**. These changes, in conjunction with environmental influences, give rise to phenotypic variation among individuals. The primary source of **genetic variation** is mutation, which introduces new genetic material into a population. Additionally, meiosis and the random fertilisation of gametes during sexual reproduction contribute to the reshuffling and mixing of existing genetic material.

Within a population, individuals possessing phenotypic traits that enhance their ability to survive and reproduce in a particular environment have a higher likelihood of passing on their advantageous alleles to their offspring. Over time, these advantageous alleles become more prevalent in the population, causing a shift in **allele frequency**.

The effect of these genetic changes, driven by natural selection, genetic drift, migration, and other evolutionary forces, leads to the changes in populations and the potential emergence of new species.

## Mechanisms of evolution

Evolution can take place through five key drivers:

- Mutation
- Gene flow
- Genetic drift
- Natural selection
- Sexual reproduction – including meiosis and random fertilisation (as discussed in Chapter 2).

**evolution**
change in the genetic composition of a population during successive generations, which may result in the development of new species

**population (ecological)**
a group of a particular species living and interbreeding in the same geographical area

**genetic variation**
the differences in DNA sequences between individuals within a population

**allele frequency**
the relative proportion of a specific allele within a population

**variation**
the range of differences or diversity in traits, characteristics or genetic make-up among individuals

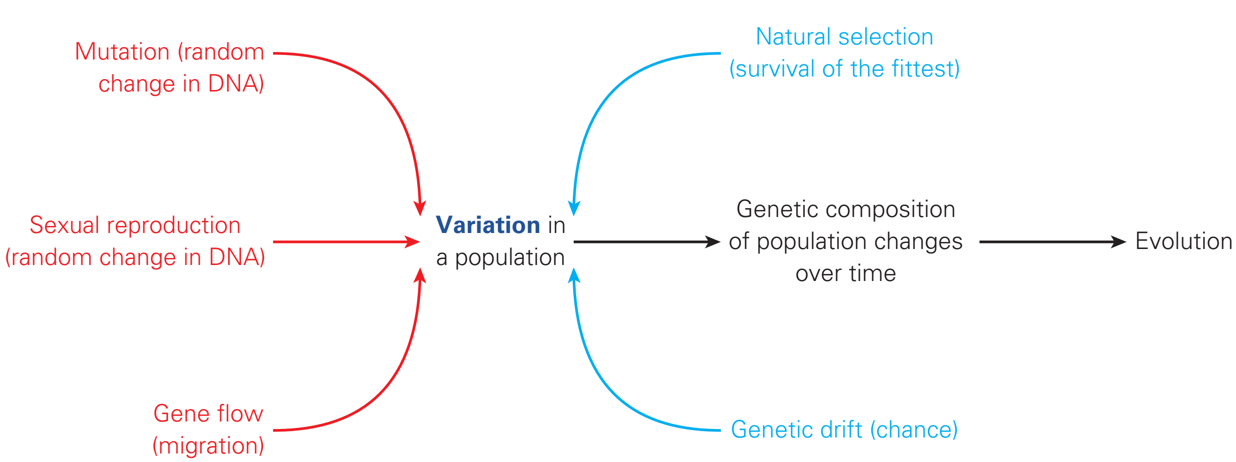


**Figure 3.1** Changing genetic information changes the variation within a population. This leads to an overall change in the genetic composition of a population, which means evolution is occurring.

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## Mutation

For evolution to occur, there must be a change in the genetic make-up of at least one individual. Recall from Chapter 2 that a mutation is a spontaneous or induced change in the genetic sequence of an organism's DNA. If present in gamete cells, mutations can be passed down to future generations (Figure 3.2).

Mutation is a random process, and changes can occur anywhere in the DNA. Mutations may have various effects on the phenotype of organisms, ranging from no change to large changes. These large changes include genetic diseases that are associated with a loss of function. Since genetic disease reduces an individual's chance of survival, these are often not passed on to future generations. However, in specific circumstances, mutations that are usually detrimental or harmful can be beneficial.

Mutations are the ultimate source of genetic variation as they introduce new alleles. If the mutation is advantageous and occurs in the gametes, it may lead to a shift in the genetic composition in the population. This links to another driver of evolution called natural selection, which will be covered later. Along with natural selection, mutations are one of the main drivers of evolution and without them, evolution cannot occur.

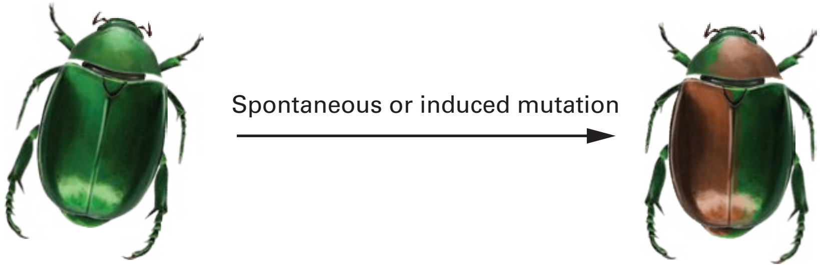


**Figure 3.2** A spontaneous or induced mutation in a gamete can cause a change in the DNA code passed onto the next generation, contributing to evolution.

| Genetic disease | Some of the outcomes |
|---|---|
| Albinism | No or little colour in skin, hair and eyes<br>Reduced sun protection |
| Cystic fibrosis | Thicker mucus lining organs<br>Respiratory and other health problems<br>Fatigue |
| Duchenne muscular dystrophy | Progressive muscle weakness |
| Haemophilia | Blood cannot clot properly<br>Abnormal bleeding |
| Sickle cell anaemia | Sickle-shaped red blood cells can interrupt blood flow<br>Pain and fatigue<br>Resistance to malaria, which is beneficial in areas where malaria is common |

**Table 3.1** Some examples of genetic diseases caused by mutations

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## Explore! 3.1

### First Nations Australians' adaptations

On initial contact with First Nations Australians, European colonisers noted that they were equipped with many advantageous traits, such as exceptional eyesight, reflexes, jumping ability, throwing accuracy, spatial awareness, running speed and stamina.

Investigate the following:

- What muscle fibre adaptations make First Nations Australians such exceptional sportspeople?
- Why were First Nations Australians highly sought-after in the whaling and pearling industries of the 1800s?
- Describe the mechanisms by which these structural and physiological adaptations developed in First Nations Australians.

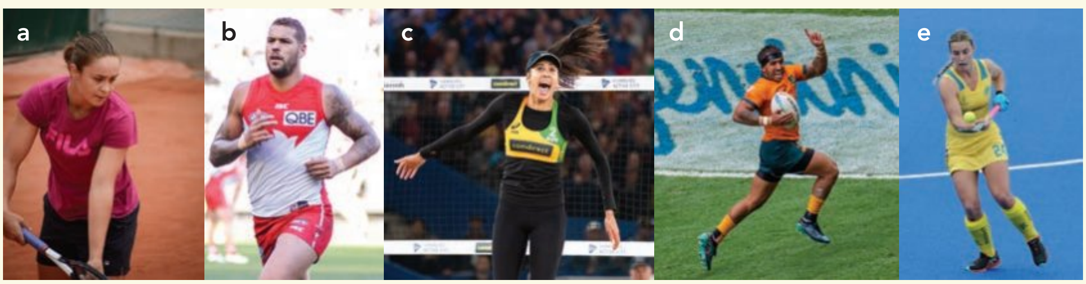


**Figure 3.3** Some famous First Nations Australian sportspeople: a) Ash Barty, b) Lance Franklin, c) Taliqua Clancy, d) Maurice Longbottom and e) Mariah Williams


**Figure 3.4** Marble Bar, in the Pilbara region of Western Australia, is Australia's hottest town. Temperatures more than 45°C are common in December and January. Researchers have found that approximately half of the First Nations Australian population of Western Australia have a mutation that makes them produce a different amount of thyroxine, a hormone that regulates metabolism including body temperature. This gives an advantage in areas that can regularly exceed 45°C.

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## Gene flow

Another way genetic variation can be introduced into a population is through **gene flow**, which is enabled by migration. Migration is the movement of individuals from one population to another, while gene flow specifically refers to the movement of alleles from one population to another. Gene flow can only occur between separate populations of the same species because they must be able to interbreed and reproduce (Figure 3.5).

Gene flow can occur through different kinds of events, such as seed dispersal, animals moving to different areas or movement forced by natural disasters such as fires or floods.

**gene flow**
the movement of genetic information from one population to another through migration

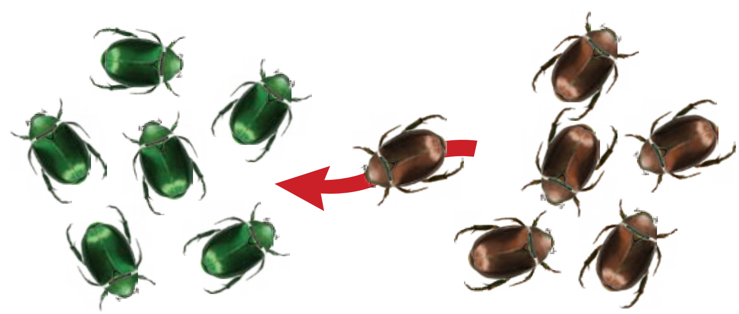

**Figure 3.5** Unlike alleles created by mutations, the alleles brought in by gene flow already exist within the species but are absent from some populations.

### Making thinking visible 3.1

**Claim, support, question: Koalas and gene flow**

While the koala is one species, there are five distinctly different genetic populations across Australia's east coast. The loss of genetic diversity from small, fragmented koala populations increases their risk of extinction due to both inbreeding and an inability to adapt when the environment changes. Maintaining genetic diversity in koalas is critical to their survival. This can be achieved by maintaining large, interconnected natural populations or through wildlife translocation, which is an artificial form of gene flow.

Wildlife translocation is being used with increasing frequency to conserve a variety of species, but it is also controversial, even among conservationists. Potential problems include the spread of diseases, increased stress and mortality of relocated animals and negative impacts on the organisms at release sites.

Using your prior knowledge and the information provided, make a **claim** about wildlife translocations.

Provide evidence to **support** your claim.

Pose a **question** related to your claim or supporting evidence. What remains unexplained or requires further investigation?


**Figure 3.6** The survival of koalas depends on maintaining gene flow between increasingly isolated populations.

The *Claim, support, question* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

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## Genetic drift

**Genetic drift** is random changes in allele frequencies in a population over time. Genetic drift is always happening in a population, as chance outcomes of meiosis, crossing over and fertilisation affect the genetic composition of each new generation. The effects of genetic drift are greater in smaller populations. Two extreme examples of genetic drift are the **founder effect** and the **bottleneck effect**.

The founder effect occurs when a small number of individuals leave a population and establish their own colony. Simply by chance it is likely that allele frequencies in the small founder population will be different from those in the larger population they came from.

A population 'bottleneck' occurs when the size of at least one generation of the population is severely reduced, perhaps by a chance event such as an environmental disaster or because of human activities such as habitat destruction or overhunting. This results in the deaths of many organisms, leaving behind a small, random population of survivors (Figure 3.8).

The bottleneck effect and the founder effect both result in populations with an allele frequency that differs in a random way from their source or original population. In both cases, because the remaining population is much smaller than the original population, genetic drift is amplified and there is also less genetic diversity. These factors may result in the new population becoming genetically distinct from the original population over time.

**genetic drift**
the random change in allele frequencies in a population from generation to generation

**founder effect**
the decrease in genetic diversity that occurs when a population is descended from a small population that separated from a larger one

**bottleneck effect**
the decrease in genetic diversity resulting from a rapid reduction in the size of a population, due to events such as natural disasters or human activities such as overhunting

**Figure 3.7** Norfolk Island, which is located between New Zealand and New Caledonia, was used as a penal colony and then abandoned in 1855. Most present-day islanders are the descendants of a founder population made up of a small number of the descendants of the HMS Bounty mutineers and Tahitian women who relocated from Pitcairn Island in 1856. The founder effect has significantly affected height and the prevalence of cardiovascular diseases of the islanders.

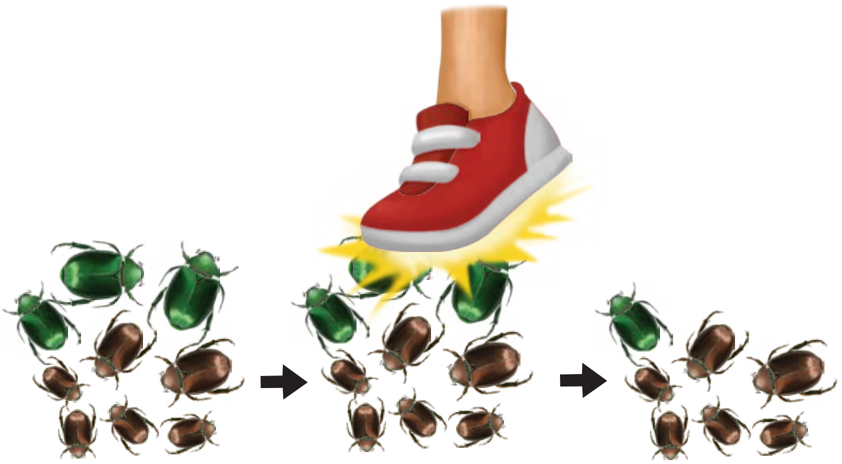

**Figure 3.8** Someone standing on some beetles by accident is a random or chance event. If the population size is greatly reduced to the extent that the genetic composition of the beetles' population has changed, this is an example of how the bottleneck effect contributes to evolution.

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**Did you know? 3.1**

**The black robin bottleneck**

Before European colonisation, black robins (*Petroica traversi*) were common on Rēkohu/Chatham Islands, New Zealand. However, their population crashed once rats invaded the archipelago, and by 1976, only seven birds survived. The birds were moved to a predator-free island, but scientists were not confident that the population, which had only one breeding pair (called Old Blue and Old Yellow), would recover due to the severe genetic bottleneck. However, as of 2022, there are approximately 290 surviving birds, and surprisingly, although the bird is certainly one of the most inbred in the world, genome analysis has shown that the frequency of harmful genetic alleles in the population did not increase as a result of the bottleneck.

**Figure 3.9** The black robin (*Petroica traversi*)

VIDEO Natural selection

## Natural selection

Individuals in a population show a wide range of phenotypes. Some of these phenotypes may provide **selective advantages**, meaning those individuals are more likely to survive and reproduce, passing on those advantageous alleles to their offspring. This is **natural selection**. Often, the term 'survival of the fittest' is used to describe this: the organisms that are best suited to their environment – that is, have the best **adaptations** – are more likely to survive and pass on their genetic information. For example, look at Figure 3.10. These beetles live in the leaf litter on the forest floor and have natural variation in their colour that is heritable: they can be green or brown. The birds eat more green beetles, because they are easier to spot. The green beetles are at a selective disadvantage (they have a lower fitness value), so fewer green beetles will survive to reproduce and fewer alleles that code for green colouring will be passed on to the next generation. The brown beetles are better adapted to their environment and have the better colour for survival (that is, the brown beetle is at a selective advantage; it has a higher fitness value). Alleles that code for brown colouring are more likely to be passed on to the next generation.

**selective advantage**
the characteristic of an organism that enables it to survive and reproduce better than other organisms in a population

**natural selection**
a process in which organisms whose phenotype is best adapted to their environment are more likely to survive and reproduce

**adaptation**
a characteristic that contributes to an individual's ability to survive in its environment

**Figure 3.10** Alleles within a population are less likely to be passed on to the next generation if they are disadvantageous. Brightly coloured beetles are more likely to be spotted by predators, which puts these organisms at a disadvantage.

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## Practical skills 3.1

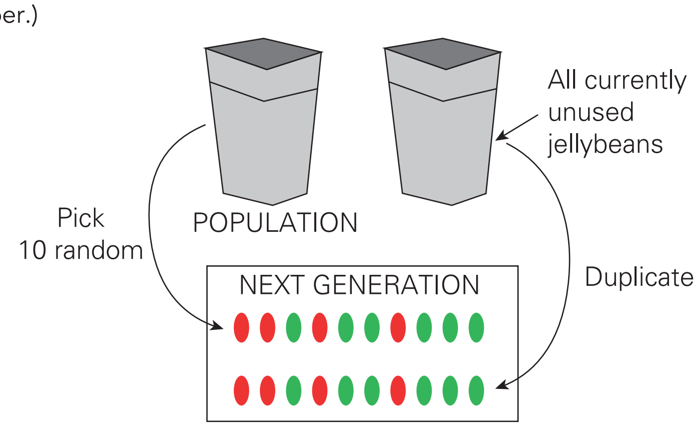
### Modelling genetic drift, natural selection and gene flow

**Be careful**
Do not consume food items.

**Aim**
To simulate genetic drift, natural selection and gene flow in a population of jellybeans and analyse the consequences of each.

**Materials**
- jellybeans: 20 red, 20 green and 20 blue (or anything similar e.g. coloured paper)
- 2 cups, one labelled 'Population'
- 1 piece of paper labelled 'Next generation'

**Method for genetic drift**
1. Copy the results table into your science journal.
2. Place 10 red jellybeans and 10 green jellybeans in your 'Population' cup. These represent the alleles of the population. Place all other jellybeans in the other cup for unused jellybeans. Record the current population in your results table.
3. With your eyes closed, pick 10 random jellybeans from the 'Population' cup and place them on the 'Next generation' piece of paper. These are the alleles that will be passed on.
4. Duplicate the 10 jellybeans (e.g. if you picked out 4 red and 6 green, pick out another 4 red and 6 green from the other cup and place them on the paper.)
5. Record this in the next row of your results table.
6. Throw the remaining beans from your 'Population' cup into the cup for unused jellybeans, and place the new generation alleles on the piece of paper into the 'Population' cup.
7. Repeat steps **3–6** until you have 10 rows of data or until one colour is eliminated.




**Method for natural selection**
1. Copy the results table into your science journal.
2. Start with 10 red jellybeans and 10 green jellybeans and place them in your 'Population' cup. Record this in your results table.
3. Imagine that green has a selective disadvantage (the opposite of a selective advantage). Pick out 3 green jellybeans from the population and move them into the cup for unused jellybeans.
4. With your eyes closed, pick 10 random jellybeans from the 'Population' cup and place them on the piece of paper.
5. Duplicate the 10 jellybeans on the piece of paper. Record this in the next row of your results table.
6. Throw the remaining beans from your 'Population' cup into cup for unused jellybeans, and place the new generation alleles on the piece of paper into the 'Population' cup.
7. Repeat steps **3–6** until you have 10 rows of data or until one colour is eliminated.

*continued …*

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*continued …*

**Results for genetic drift and natural selection**

| Generation | Number of alleles | |
|---|---|---|
| | Red | Green |
| 1 | 10 | 10 |
| | | |

**Method for gene flow**

1 Copy the results table into your science journal.
2 Start with 10 red jellybeans and 10 green jellybeans and place them in your 'Population' cup. Record this in your results table.
3 Add 5 blue jellybeans into the 'Population' cup.
4 With your eyes closed, pick 10 random jellybeans from the 'Population' cup and place them on the piece of paper.
5 Duplicate the 10 jellybeans. Record this in the next row of your results table.
6 Throw the remaining beans from your 'Population' cup into the cup for unused jellybeans, and place the new generation alleles on the piece of paper into the 'Population' cup.
7 Repeat steps **4–6** until you have 10 rows of data or until two colours are eliminated.

**Results for gene flow**

| Generation | Number of alleles | | |
|---|---|---|---|
| | Red | Green | Blue |
| 1 (before migration) | 10 | 10 | 0 |
| | | | |

**Discussion**

1 Plot your results on a graph. There should be one each for the genetic drift, natural selection and gene flow simulations.
2 Describe what happened in each case. How do the results compare to what you would expect for each process?
3 Did your results show any colour becoming extinct in your population?
4 Compare your results for genetic drift with those of another classmate or group. Account for any contradicting trends in the results.
5 Propose what step **6** could represent in the genetic drift simulation.
6 Propose what step **3** could represent in the natural selection simulation.
7 Propose what step **3** represents in the gene flow simulation.
8 Imagine that the introduced blue allele also had a selective advantage in the gene flow simulation. How would you simulate this scenario?
9 Imagine that there was a mutation in one of the jellybeans that turned it orange. How could this affect future generations?
10 What assumptions have we made about the red, green and blue alleles in this simulation?
11 Can reliable conclusions and predictions be drawn from the results? Justify your answer.
12 List some limitations of this simulation compared to what happens in real life. Justify your response.
13 What are some ways the simulations can be improved?

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Figure 3.11 Cane toads in rural areas have larger parotid (toxin) glands than those in urban areas. This may be because bush toads are at a higher risk of predation, so it is a selective advantage to have glands that can produce more bufotoxin.

**Quick check 3.1**

1. Define the terms 'evolution', 'population', 'variation' and 'adaptation'.
2. Identify the five drivers of evolution.

**Try this 3.1**

**Drivers of evolution**

Summarise the five drivers of evolution you have learned by copying and completing the following table.

| Mechanism | Definition | Contribution to evolution? |
|---|---|---|
| Mutation | | |
| Gene flow | | |
| Genetic drift | | |
| Natural selection | | |
| Sexual reproduction | | |

## Biodiversity as a function of evolution

**Biodiversity** (biological diversity) refers to the variety of life on Earth. It includes **species diversity** (the number of different species within an ecosystem), **genetic diversity** (the number of different alleles of genes in a population) and **ecosystem diversity** (the variation in ecosystems in a given area). Over time, populations within a species can become so different that they become a different species, increasing biodiversity. Therefore, it is evolutionary processes that have resulted in the biodiversity we see today.

Australia's unique biodiversity is best explained by isolation. Australia was once part of a supercontinent called Gondwana that even earlier was the southern part of a giant land mass called Pangaea. Gondwana was made up of the continents and countries that we know today as South America, Africa, Australia, India and Antarctica. Gondwana is thought to have begun breaking up approximately 140 million years ago. As a result, our plants and animals have been isolated over a long period of time from the plants and animals of other continents and land masses.

As the continents moved across the surface of Earth, so too did their assemblages of plants and animals. This not only created geographical barriers (like oceans, mountain ranges and large rivers), but over time it also brought new combinations of species together.

**biodiversity** the variety of life on Earth, including the diversity of species, the genetic differences within a species, and the ecosystems where species are found

**ecosystem diversity** the variation in ecosystems in a given area

**species diversity** the number and abundance of different species in a given area

**genetic diversity** the number of different alleles of genes in a population

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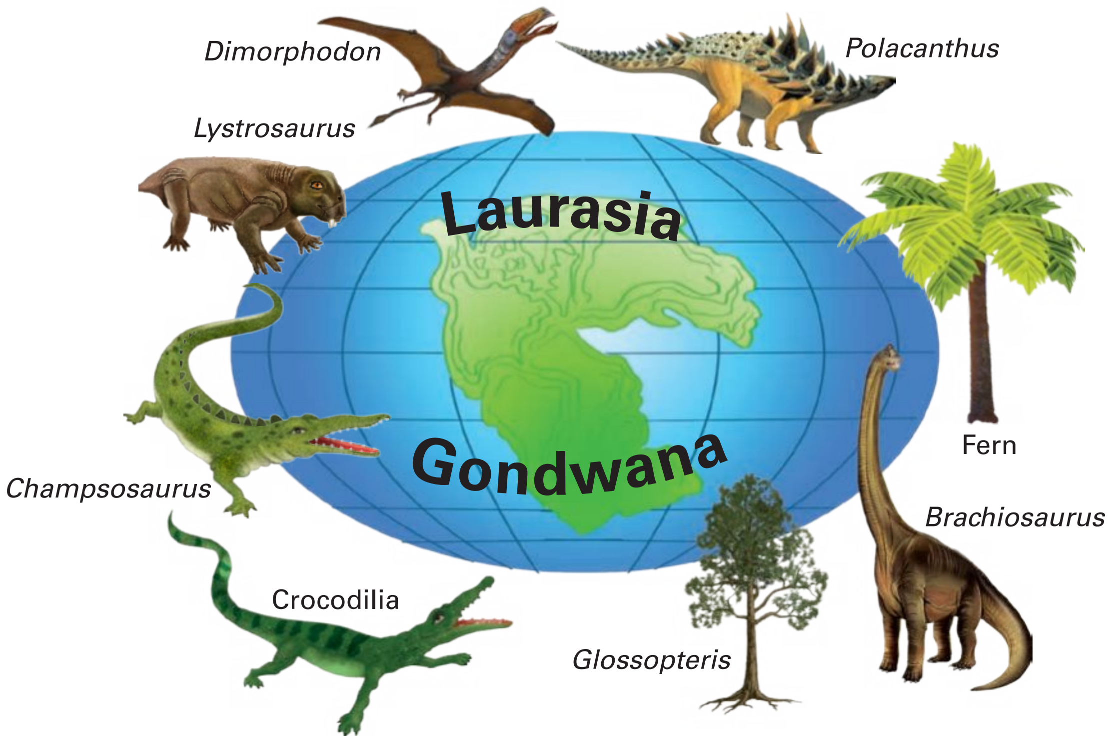


**Figure 3.12** This map shows the supercontinent Pangaea before it separated into a northern Laurasia and a southern Gondwana.

> **Quick check 3.2**
>
> 1. State what is meant by the term 'biodiversity'.
> 2. Recall what supercontinent Australia was once part of.
> 3. Explain how the movement of continents led to increased species diversity.

## Biodiversity through time

Our understanding of the origin of life on Earth is based upon the scientific evidence of the fossil record and genetic comparisons to modern life forms. Earth is approximately 4.5 billion years old, and the most primitive cells first developed some 3.5 billion years ago. Although life appeared early in Earth's history, evolution beyond the simple cell stage did not occur until much later – approximately 600 million years ago. Since then, the biodiversity that exists on Earth has fluctuated depending on changes in the environment. Figure 3.13 shows a timeline of the major stages in the development of life on Earth.

Biodiversity has been affected by five mass extinction periods. In mass extinctions, a huge number of Earth's species die off over thousands or even millions of years. One of the best-known causes of a mass extinction is an asteroid impact that may have killed off the dinosaurs. An asteroid is suspected to be involved in just one case of mass extinction, but volcanic activity has been implicated in at least four. Here are some hypothesised causes for the biggest mass extinctions on Earth:

- Volcanic activity
- Climate change
- Changes in deep ocean oxygen levels
- Changes in sea level.

A combination of the above causes may have contributed to mass extinctions, which caused major and rapid changes in the

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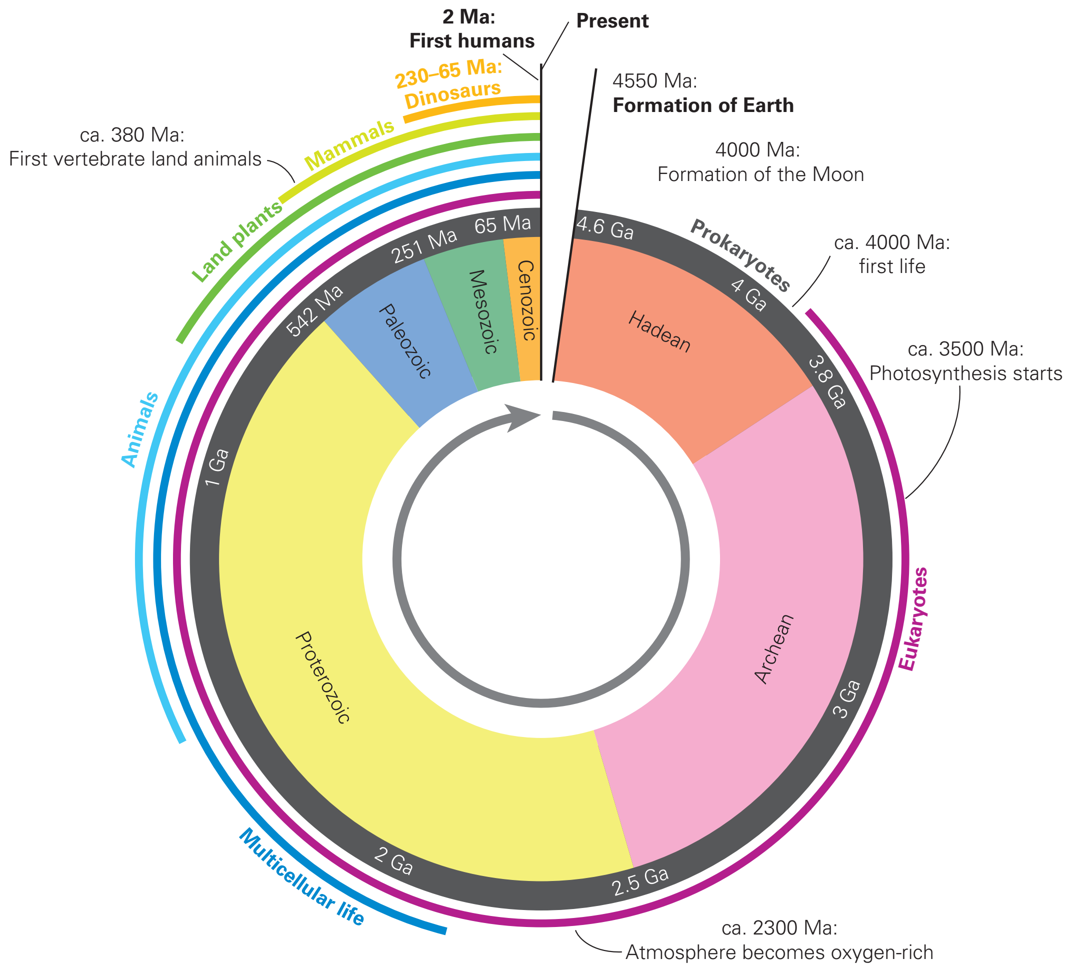


**Figure 3.13** A timeline of Earth's history (ages are abbreviated from Latin: Ga (giga-annum) represents a billion years, Ma (mega-annum) is a million years)

Earth's **biota**. If there is sufficient genetic variation in a species when an environmental change occurs, such as when there is a volcanic eruption, some organisms within a population will be better suited to that new environment than others. The survival of the better-adapted individuals will result in a change in the genetic composition of the species' population, resulting in their evolution over time.

**biota**
all the living organisms found within a particular region or ecosystem

**Figure 3.14** Eastern Australia is littered with the remnants of hundreds of volcanoes. The region was affected by repeated volcanic super eruptions between 256 and 252 million years ago. Evidence of this can be seen in light-coloured layers of volcanic ash in sedimentary rock (left). There is also evidence that large areas of forest disappeared and many species of animals became extinct after the supervolcanoes erupted, contributing to the global Permian–Triassic mass extinction. Smaller volcanic eruptions 24 to 27 million years formed the Glass House Mountains (right).

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## The biodiversity of Australia

Australia's biodiversity is rich and unique; estimates suggest that between 7% and 10% of all species on Earth are found here. This unique biodiversity developed in isolation over millions of years, producing a high level of **endemism**. This means a large number of species found in Australia are unique to the region and are not naturally found anywhere else in the world. This high level of endemism is attributed to Australia's geographical isolation and long evolutionary history, which allowed the development of species adapted to the specific Australian environment. Australia's biodiversity is also influenced by its unique environmental conditions, which include high fire frequency, nutrient-poor soils, climatic variability and a relatively flat landscape.

**endemism**
a state of being confined to a small defined geographic location

Human settlement, both by First Nations Australians and then by Europeans, has affected Australia's biodiversity. It is likely that the initial First Nations people arrived in Australia via south-east Asia when ocean levels were lower and there were more land bridge connections between landmasses. Many researchers believe that humans first arrived in Australia 60 000 years ago. Since then, the landscape has been modified by burning, habitat clearing and fragmentation, overhunting and the spread of invasive species, much of the change happening since European settlement.

**megafauna**
large animals with a body mass of over 45 kilograms

When First Nations Australians first arrived, **megafauna** would have been common. These were large land animals that evolved millions of years after the dinosaurs became extinct. In Australia, they included *Diprotodon optatum*, the largest marsupial ever to have lived, with a shoulder height of 1.8 metres and weighing close to 3 tonnes; *Palorchestes azael*, a marsupial about the size of a horse; *Thylacoleo carnifex*, a 1.5-metre-long marsupial lion; and *Wonambi naracoortensis*, a 50 kilogram, 5-metre-long snake.

Climate change and the arrival and spread of modern humans in Australia are believed to have led to the extinction of many megafaunal species. The fossil record suggests that the Australian megafauna went extinct after the arrival of First Nations Australians, due to overhunting or gradual destruction of megafaunal habitats by traditional techniques such as fire-stick burning. However, rock art and fossil evidence also suggest that megafauna coexisted with humans for many thousands of years.

Some experts have suggested that the climate getting drier and more arid caused the extinction of megafauna. Analysis of fossil teeth has found that climate change had a significant impact on megafaunal diets. This is due to sustained changes in water and vegetation availability, as well as increased fire frequency.

## Maintaining biodiversity

Maintaining biodiversity is extremely important. A reduction in biodiversity can have huge impacts on ecosystems and result in loss of species that are beneficial to other species,

**Figure 3.15** Illustrations of *Palorchestes azael* (left) and *Diprotodon optatum* (right), two extinct species classified as Australian megafauna

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Figure 3.16 Rock art depicting a hunter and a giant kangaroo in Anbangbang Shelter at Burrunggui, Kakadu National Park

including humans. Maintaining diversity means keeping a full range of species in ecosystems in order to conserve the variety of organisms on Earth. Species are considered **endangered** if they meet the criteria set by the International Union for Conservation of Nature (IUCN). These include species whose numbers have experienced a reduction of 70% in a decade and species with fewer than 250 mature individuals living in a single population.

**endangered**
a species that is in danger of becoming extinct

Endangered species are at risk of becoming **extinct**, especially if there is not enough genetic variation in the population. However, species can be at risk even if their population is large. Changes in the environment that may cause extinction include new diseases, new predators, competition with a better-adapted species and loss of habitat.

**extinct**
a species that has no living members

## Making thinking visible 3.2

**Chalk talk: The coral ark**

In 2023, the Great Barrier Reef Legacy, located in Port Douglas, established the world's first Living Coral Biobank. The project aims to conserve the genetic diversity of hard coral species by collecting, cataloguing and storing living fragments, tissues and genetic samples from coral species.

Read the following quote from Dr Dean Miller, managing director of Great Barrier Reef Legacy.

> **"We will collect all known corals and keep them alive in land-based facilities for their ultimate conservation."**
>
> ***Dr Dean Miller***

Figure 3.17 Despite covering less than 0.1% of the world's ocean floors, coral reefs provide a home for millions of different species.

1 Take a moment to reflect on the quote and write down any thoughts that come to mind.
2 Discuss your ideas as a group, sharing your individual perspectives on the quote.
3 Think about how your classmates' responses connect with your own thoughts, and write down any questions that arise as you listen to their feedback.

The *Chalk talk* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

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There are ways that humans can help to maintain biodiversity. In situ protection occurs within their natural habitat, such as in conservation reserves. Ex situ conservation occurs outside natural habitat, such as in zoos or seed banks. Many zoos have captive breeding programs in which they breed captive animals to help the survival of endangered species. Such programs aim to reintroduce the species back into the wild, which would aid in keeping population numbers up and limiting inbreeding.

**Figure 3.18** There are only about 3000 Nangur spiny skinks (*Nangura spinosa*) left in the wild. Critically endangered, they can only be found at two locations in south-east Queensland. A successful captive breeding program that began in 2021 at a facility in Brisbane has produced many young. The next step in the program is to determine if the captive-bred individuals can survive in the wild.

## Explore! 3.2

### Conservation of Australian species

Australia has the fourth-highest level of species extinctions in the world and is in the top three for critically endangered animals. Since 2016, 202 animal and plant species have been listed as threatened, including the regent honeyeater, northern quoll and the black-flanked rock wallaby. Conduct some research to answer the following questions.

**Figure 3.19** A regent honeyeater (*Anthochaera phrygia*)

1. Choose an endangered Australian species and research conservation efforts put into place for the species. These may include education programs, captive breeding, legal protection of habitats and ecosystems created artificially.
2. Many of today's species have survived by adapting where other species, less well adapted, died out. Do you think we should try to protect endangered species to preserve biodiversity? Why?

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## Quick check 3.3

1 Define the terms 'biodiversity', 'endangered' and 'extinct'.
2 Explain the link between biodiversity and evolution.
3 Name one change in the environment that may lead to the extinction of a species.
4 Discuss how humans have affected biodiversity and therefore evolution.

## Making thinking visible 3.3

**Connect, extend, challenge: Cat curfew**

Australia has the highest mammal extinction rate in the world: 34 mammal species have disappeared since European settlement. Introduced predators, particularly feral cats and the European red fox, have caused most of these extinctions. Extinctions have been particularly high in arid and semi-arid regions. One report found that every year each individual feral cat in Australia kills 390 mammals, 225 reptiles and 130 birds. Combined with those killed by domestic cats, over two billion native animals are killed by cats each year in Australia.

In many Australian local council areas, cat owners must now keep their pets on their own land. In some areas, there is a curfew so cats are not allowed outside after dark; in other areas, cats are not allowed outside at all.

After reading about mammal extinctions in Australia, reflect on the following:

1 How do the concepts and details connect to your existing knowledge?
2 Which new insights did you gain from the text that expanded your understanding or encouraged you to consider new perspectives?
3 What questions arise for you after processing this information?

**Figure 3.20** The Christmas Island pipistrelle (*Pipistrellus murrayi*, left) and the Bramble Cay melomys (*Melomys rubicola,* right) were the first Australian mammals to go extinct in the past 50 years.

The *Connect, extend, challenge* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

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QUIZ

## Section 3.1 questions

### Retrieval

1 **Define** the terms 'evolution' and 'population'.
2 **Name** one extinct Australian species.
3 **Name** one species deemed critically endangered within Australia.
4 **Define** the term 'variation' and give four different examples of variation within a species not provided in the text.
5 **Recall** where variation in a population comes from.
6 **Identify** an example of variation within a species that:
   a increases an individual's chances of survival
   b decreases the species' chance of survival
   c does not affect the species' chance of survival.

### Comprehension

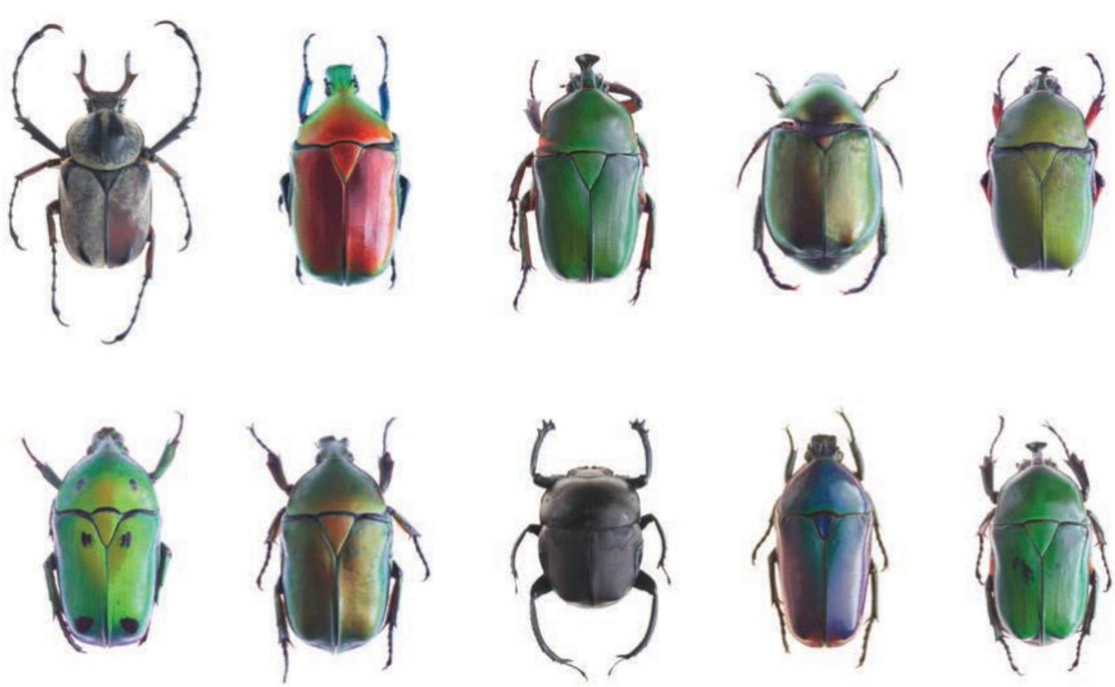
7 **Explain** how mutations contribute to variation within a species and, consequently, evolution.
8 **Explain** how gene flow can contribute to a change in the allele frequency of a population.
9 **Summarise** how a change of only one nucleotide in DNA can result in a different phenotype and eventually cause evolution.
10 **Explain** how extinctions can stimulate new biodiversity among species.

### Analysis

11 **Distinguish** between species diversity and genetic diversity.
12 **Distinguish** between extinct species and endangered species.

### Knowledge utilisation

13 **Discuss** why genetic biodiversity is important for the survival of a species.
14 In Earth's past, some species have been wiped out after an environmental change. **Decide** if this suggests the species had low or high genetic biodiversity and give reasons why this would occur.



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# 3.2 Natural and artificial selection

**Learning goals**

1. To be able to recall the steps in the process of natural selection.
2. To be able to outline the factors that lead to speciation.
3. To be able to describe some examples of artificial selection.

WORKSHEET
Natural selection

In Section 3.1, you read that there are five drivers of evolution: mutation, gene flow, genetic drift, natural selection and sexual reproduction. In this section, natural selection will be considered in more detail.

In 1831, at the age of 22, the naturalist Charles Darwin set out on a five-year voyage around the world to study and collect animal, plant and rock specimens. He visited the remote Galapagos Islands off the coast of Ecuador and recorded the plant and animal species of the islands.

Initially, Darwin took little interest in his collection of finches from the islands, but this changed when the eminent ornithologist John Gould classified them as 12 new species. Gould had noticed that they showed great variation in their beaks. It was his observations that helped Darwin develop his theory of evolution.

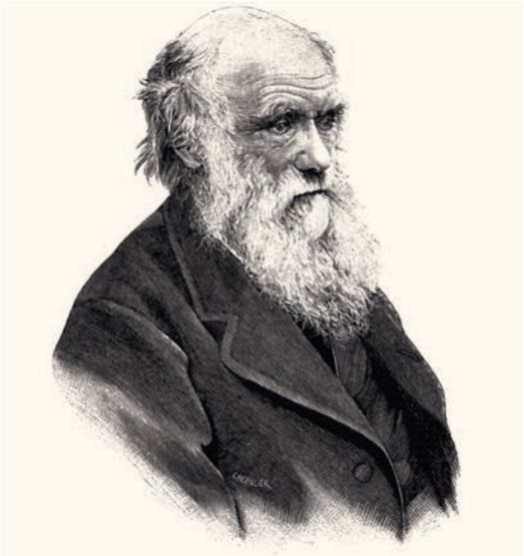

**Figure 3.21** Charles Darwin

**Figure 3.22** John Gould published the first comprehensive survey of birds in Australia. He was accompanied by his wife, Elizabeth Gould, who was a talented ornithologist and illustrator in her own right. This image was taken from his book *The Birds of Australia*, which was published from 1840 to 1848 in seven volumes.

Darwin speculated that although the different islands had similar animals and plants, many species seemed to have specialised features that were particularly suited to their local environments. For example, the different finch species had beaks suited to eating the food source that was available in the habitat they occupied on their island. Darwin explained how species change over time, using the theory we know today as 'natural selection'.

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WIDGET
Natural selection

## The process of natural selection

Natural selection occurs when an environmental factor acts on the phenotype. That is, some individuals in the population are different from others and those differences provide an advantage or disadvantage for survival and reproduction. The following steps outline the process of evolution through natural selection.

1. Genetic variation naturally exists in the population due to processes such as sexual reproduction, genetic drift, mutations and gene flow.
2. This genetic variation means that some individuals within the population have traits better suited to their environment.
3. Individuals with favourable traits are more likely to survive and reproduce than others of their species, and thus pass on those traits to the next generation. Those favourable traits are said to be 'selected for' by environmental (or selection) pressures.
4. Over time, individuals with the favourable traits become more numerous in the population.

An example is the case of the light and dark peppered moths (*Biston betularia*) in Britain. There are two varieties within the one species – one is light coloured, the other is dark coloured – and the colour is genetically determined. Look at the moths in Figure 3.23 – the light-coloured variety of the peppered moth initially had the favourable trait (selective advantage) as it blended well with the lighter lichen-covered bark of the trees. This meant that a hungry bird (the selecting agent) would be more likely to see the dark-coloured moth and eat them more often. Consequently, dark-coloured moths were rare. Light-coloured moths were better adapted to survive and reproduce, so they were able to pass on their genetic information to the next generation.

However, during the Industrial Revolution, pollution darkened the bark of trees. This gave the dark-coloured moths a selective advantage, as they were now better camouflaged against the trees and not as easily spotted by predators. Now the roles were reversed: light-coloured moths were at a disadvantage and their numbers fell. The darker moth was the 'fittest' or best adapted in this new environment and so was able to survive, reproduce and pass on its genetic information to the next generation. The proportion of dark moths rose. Interestingly, cleaner air in recent decades has seen the light-coloured moths favoured once again. This example also illustrates why genetic variation enables species to survive and adapt to new circumstances.

**Figure 3.23** There are two variations of peppered moth: light and dark coloured. Can you see both moths in each image? The picture on the left shows the moths against a light tree bark. The picture on the right shows the moths against a dark tree bark.

**Explore! 3.3**

**Doomed race theory**

Use your preferred search engine to research how policies and attitudes towards First Nations Australians in the 19th and early 20th centuries were influenced by scientific misconceptions about heredity and evolution. What were the misconceptions? How does it contrast to what we know now?

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**Quick check 3.4**

1 Recall where Charles Darwin collected his finch specimens.
2 Create a flow chart of the four steps involved in the process of evolution by natural selection. Then annotate your flow chart to show how each step relates to the peppered moth example.

## Selection pressures

Those organisms best suited to the pressures of their environment are more likely than others to survive, reproduce and pass on their genetic information to the next generation. We call these pressures **selection pressures** because they determine which variations provide individuals with better survival chances. Selection pressures refer to the factors that exert an influence on the fitness and reproductive success of individuals within a population. These pressures can be natural, such as predation, competition for resources, or climate conditions, or they can be anthropogenic, including human activities like habitat destruction or pollution. Selection pressures act as the driving forces behind natural selection, shaping the survival and reproductive outcomes of individuals based on their traits and adaptations.

Selective agents are specific factors or agents that directly cause the selection pressure. Selective agents are often associated with specific traits or features of the environment that directly impact an organism's survival or reproductive success. For example, a selective agent could be a particular predator species that preys on individuals with certain characteristics, leading to the selection for traits that enhance evasion or defence against that predator.

VIDEO Selection pressures

**selection pressure** a factor that affects the relative fitness or reproductive success of individuals within a population, leading to natural selection and potential changes in allele frequencies over time

Selection pressures can increase or decrease the occurrence of a trait in a population. Selection pressures are not static and may change with time or with changes in the environment.

**Figure 3.24** Variations of adult males of the frog species *Pristimantis leopardus* may experience different levels of reproductive success due to the selective pressures exerted by predation, competition for mates, and environmental conditions, thereby driving natural selection.

| Density-dependent factors | Density-independent factors |
|---|---|
| Predators | Natural disasters |
| Resource availability (e.g. water, shelter, nutrients) | Abiotic factors (e.g. $CO_2$ concentration, temperature) |
| Disease | |
| Waste accumulation | |

**Table 3.2** Selection pressures can be either density independent or density dependent. Density-independent pressures are typically abiotic factors (such as natural disasters or climate events that affect populations regardless of their size). Density-dependent pressures are often biotic factors (such as predation or competition for resources), which vary in impact depending on the population's size or density.

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## Try this 3.2

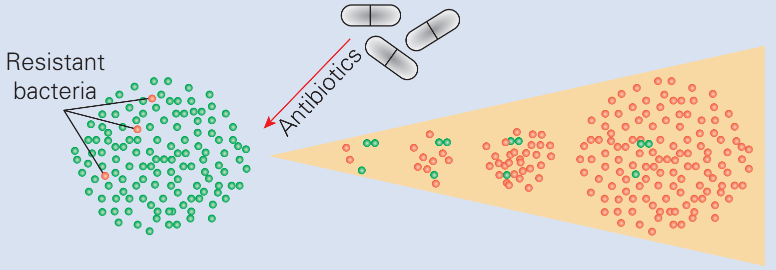
**Drug-resistant bacteria and traditional medicines**

Antibiotics are medicines used to prevent and treat bacterial infections. However, some bacteria have mutations that make them resistant to the effects of the drugs. The World Health Organization has identified antibiotic resistance as one of the greatest threats to human health today, potentially causing up to 10 million deaths per year by 2050 if not overcome.

Some researchers are studying traditional bush medicines that have been used by First Nations Australians for generations as alternatives to pharmaceutical antibiotics. Plants such as tea tree (*Melaleuca alternifolia*) and emu bush (*Eremophila* species) have been found to be as effective as some established antibiotics and may provide a solution for the current resistance crisis.

**Figure 3.25** *Eremophila longifolia* is one of many species of plants commonly known as 'emu bush'.

Consider the following diagram carefully and then answer the questions that follow.




1 What variation between bacteria can you see in the original population?
2 Which variation is selected for (the fittest)? Which was selected against?
3 Which variation will contribute less to the next generation?
4 Which variation will survive in greater numbers to reproduce and pass on its genetic information to the next generation?
5 Identify the selecting agent.

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## Explore! 3.4

### Bush medicines

The diagram in Try this 3.2 demonstrates how bacteria can become resistant to certain drugs. The combination of evolutionary pressures and high use of antibiotics in contemporary society has seen the emergence of strains of diseases that are resistant to many drugs.

Since the first European settlers came to Australia, they have looked to First Nations Australians' knowledge of bush medicines. These medicines have developed over millennia through observation and experimentation, and that knowledge has been passed down from generation to generation. Now, there is increasing research directed at identifying compounds in traditional medicines for use in pharmaceuticals.

Unfortunately, there has been a historical tendency for non-Indigenous scientists to treat First Nations Australians merely as sources of information rather than collaborators in the production of new medicine. Today, however, there is a greater appreciation for the valuable input First Nations Australian communities provide. One example is a dual patent that was granted to Griffith University and the Jarlmadangah Burru Aboriginal Corporation for an invention that relates to new analgesic (pain-relieving) compounds. John Watson, an elder from the Jarlmadangah Burru community, had his finger bitten off while on a crocodile hunting trip. He chewed the bark of the marjala plant and applied it to his wound, then travelled to a hospital. The pain had been stopped so effectively that it led to a collaboration with Griffith University to explore the commercial benefits of the plant.

Conduct some research into at least one of the plants used in the First Nations' pharmacopoeia and shown in Figure 3.26 to find out:

- what ailment it treats
- which part of the plant is used as a remedy or medicine
- how it is processed
- what new medicines (if any) scientists are trying to develop using the plant.

**Figure 3.26** Left to right, top to bottom: tea tree (*Melaleuca alternifolia*), corkwood tree (*Duboisia myoporoides*), kangaroo apple (*Solanum laciniatum*), Moreton Bay chestnut (*Castanospermum australe*), pale flax-lily (*Dianella longifolia*) and crimson turkey-bush (*Eremophila latrobei*)

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## Investigation 3.1

### Modelling natural selection

**Aim**

To model a beetle population to simulate natural selection and some of its consequences.

**Prior understanding**

Let us make the following assumptions about a beetle population:

- The original population of 30 beetles consists of 10 red, 10 yellow and 10 green.
- Each year the beetles mate once at random, and each pair produces one offspring (30 beetles produce 15 offspring, increasing the total population to 45 beetles).
- The colour of the offspring is determined by these rules:

| Parent colour | | Offspring colour |
|---|---|---|
| Parent 1 | Parent 2 | |
| Red | Red | All red |
| Yellow | Yellow | All yellow |
| Red | Yellow | All green |
| Green | Yellow | ½ green : ½ yellow |
| Green | Red | ½ green : ½ red |
| Green | Green | ¼ red : ½ green : ¼ yellow |

- After the beetles have produced their offspring, a predator kills ⅓ of the total population (15 beetles) each year. Therefore, the population of beetles returns to 30 at the beginning of each breeding season.
- On average, the colour ratio of beetles lost to predation is: 3 red : 2 green : 1 yellow (this ratio is reflected in the coloured sides of the dice).
- Other than the deaths caused by the predator mentioned, there will be no further deaths or migration.

**Materials**

- small circular, coloured stickers (three red, two green, one yellow) that are added to the sides of a die
- 60 coloured cards of each type (20 red, 20 green and 20 yellow)

**Method**

1. Copy the results table into your science journal.
2. To create your original population of 30 beetles, take 10 red, 10 yellow and 10 green cards.
3. Shuffle these 30 cards to model the process of random mating and deal them out into 15 pairs.
4. Using the rules from the table, determine the colour of the offspring for each of the 15 pairs.
5. Take a beetle card that represents the colour produced for each of the 15 offspring and add them to the population, creating an overall population size of 45.
6. Due to predation, 15 beetles will die and be removed each year. This will be modelled by rolling the coloured die on 15 different occasions and removing the corresponding beetle colour from the population each time. If the die lands on a particular colour of beetle that has disappeared altogether from population, roll it again.
7. After one year of mating and predation, complete column for year 1 in the results table, showing the total number of red, green and yellow beetles that remain in the population of 30.

*continued …*

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*continued …*

8 Repeat the process of mating and predation by repeating steps **3–7** for as many trials as possible (up to a maximum of 10 trials, modelling 10 years).

**Results**

Record the total number of red, yellow and green beetles at the end of each year in the results table.

| Colour of beetle | Number of beetles after year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Red | | | | | | | | | | |
| Green | | | | | | | | | | |
| Yellow | | | | | | | | | | |
| Total | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |

**Analysis**

1 Within the population of beetles you created, identify the beetle's phenotypic trait that was observed, and its variations.
2 Explain the crucial role that variation plays in natural selection.
3 Based on your observations, did any beetle colour give a greater chance of survival than other colours in the population? Explain your answer using the data from your results table.
4 Describe how the process of natural selection relates to genetics.
5 Was there any evidence of natural selection taking place in your population of beetles? Refer to your results in your answer.
6 Did your results show any coloured beetle becoming extinct in your population over the generations?
7 a Think of another possible ratio of a beetle predation according to colour that differs from the 3 red : 2 green : 1 yellow used in this experiment.
  b Using the predation ratio of beetles you provided in part **a**, write a hypothesis for this experiment.
8 Another group of students obtained a beetle population of 10 red : 10 green : 10 yellow after completing the same experiment and modelling the same mating and predation rules for 10 trials. What possible explanation could be given for these results?

**Evaluation**

**Reliability**

1 Compare the results between different student groups.
2 Can reliable conclusions and predictions be drawn from the results? Justify your response.

**Limitations**

3 Can you identify possible limitations of this method when applied to a real-life scenario? Justify your response.

**Improvements**

4 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

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**Quick check 3.5**

1 Variation is essential for the process of natural selection to occur. Explain what 'variation' means, including where it comes from in a population.

2 Define the term 'selection pressure' and describe how it contributes to natural selection.

## Speciation

Sometimes, natural selection can lead to a new species forming, which is called **speciation**. For this to occur, there needs to be one extra step in the process of natural selection: isolation.

**speciation**
the process by which populations evolve to become distinct species

**species**
a group of organisms consisting of similar individuals who can interbreed with one another

**fertile**
able to reproduce

**viable**
able to survive

A **species** is often described as a group of organisms that are phenotypically and genetically similar and are capable of interbreeding with each other to produce **fertile** and **viable** offspring. However, there are at least 26 recognised ways to define a species!

For example, the offspring of a male and female horse will be a horse that is able to mate and produce offspring with another horse. However, the offspring of a female horse and a male donkey is a mule. A mule is infertile, which means it is unable to produce offspring. This is evidence that horses and donkeys are two different species: they cannot produce fertile offspring.

Hybrids are usually sterile because they either have an extra chromosome that prevents the usual meiosis process, or the chromosomes are incompatible, which means that viable gametes are not produced. However, this is not always the case. A few female hybrids have successfully bred with individuals in the original parent population.

### Geographical isolation

An essential feature in speciation is isolation of populations from one another to prevent gene flow. Isolation is not required for natural selection but is necessary for speciation. Isolation may be caused by a geographical or physical barrier (for example, a large river, a desert or mountain range) or even a natural disaster like a fire, flood or volcanic eruption. The consequence is the original population is divided into two populations, not necessarily the same size.


**Figure 3.27** Examples of interspecific hybrids: a) mule, b) 'wolphin', c) liger, d) zonkey

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## Selection

The isolated populations may now be exposed to different selection pressures; for example, one environment may be cooler than the other. Those organisms best suited to their environment will survive, reproduce and pass on their genetic information to the next generation. On the cold side of the mountain, individuals with thicker fur will be selected for, while on the sunny side of the mountain, those with a thinner coat will be selected for.

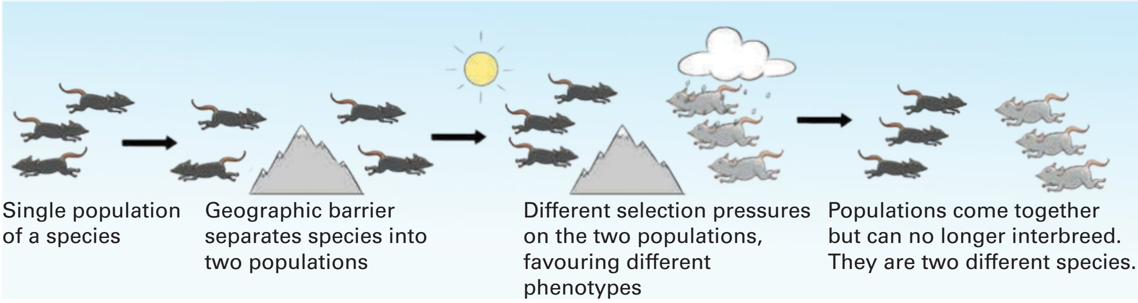


**Figure 3.28** Natural selection can cause speciation.

## Reproductive isolation

Over time, the different selection pressures on the two populations will change the genetic composition of the two populations in different ways. Eventually, enough differences may accumulate between the two populations that individuals cannot interbreed with one another to produce fertile and viable offspring. The two populations are now **reproductively isolated** and are two separate species.

**reproductive isolation** when members of two related populations can no longer interbreed

### Science as a human endeavour 3.1

**Rock wallabies**

Did you know there are 16 species of rock wallaby? Six of these species are found in north-east Queensland and have different numbers of chromosomes. They are different species, meaning that they cannot reproduce to create fertile and viable offspring. However, scientists recently found that gene flow somehow occurs between them, meaning that despite being six different species with different numbers of chromosomes, they *can* interbreed. Scientists now know that their evolution is a lot more complex than previously thought, and the way that new species form may need to be further investigated.

**Figure 3.29** A yellow-footed rock wallaby

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## Quick check 3.6

1. Define the term 'species'.
2. Speciation can occur as a consequence of natural selection with one additional step. Recall what must also occur and its role in speciation.
3. Describe how you could determine if two populations were the same species.

## Try this 3.3

**Speciation story time**

With a classmate, take turns telling stories of speciation. You may like to use the images below as inspiration. To tell a story of speciation, use all the scientific terms you have learned that relate to natural selection and speciation. Begin by talking about the possible variation that naturally exists in your organism's population, then a possible geographical barrier that could divide and isolate the population, finishing up with the process of selection and how this leads to the creation of a new species.

**Figure 3.30** These Australian animals are perfectly suited to their environment and so can survive, reproduce and pass on their genetic information to the next generation.

VIDEO Artificial selection

## Artificial selection

**Artificial selection** is selection that does not happen naturally but is directed by humans. In other words, humans choose the characteristics they want passed on to the next generation and breed organisms with those traits. Thus, humans, not the environment, select who reproduces. For example, a farmer wants her cows to produce lots of milk, so she selectively breeds the best milk-producing cows and prevents the poorer producers from mating. Artificial selection is also called **selective breeding**, and humans have been using these techniques for thousands of years. Can you think of any other examples?

**artificial selection** intentional breeding of organisms with particular characteristics to produce offspring with more desirable traits

**selective breeding** another term for artificial selection

Artificial selection is certainly beneficial for humans, but this manipulation typically reduces biodiversity and alters the course of evolution. The outcome is often a population that is genetically very similar and has low variation. For example, there is a worldwide decline in agricultural crop diversity. A 2021 WWF report found that 75% of the food that humans eat comes from just 12 plant sources and 5 animal sources. Of the plants, just three crops make up 60% of the plant-derived calories in the human diet.

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**Figure 3.31** Since 1900, 76% of genetic diversity in agricultural crops has been lost, but there is renewed interest in heirloom or heritage crops. Heritage apples are those that were grown before World War II. Some still remain, but many have been lost after commercial orchards that grow mass-produced apples such as pink lady, Granny Smith and gala became more popular. New varieties of apples are constantly being developed to bring novelty to the apple industry. One example is the yello, a cross between a golden delicious apple and a heritage apple from Japan called senshu.

These crops are artificially selected for their production values, but what are the chances of the population surviving if it is exposed to a change in environment or a new disease? Reduced variation in the population may mean the crop is more susceptible to threats like these.

## Human reproductive technologies

To assist human reproduction today, we use many reproductive technologies that involve artificially selecting the genetic information that is passed to the next generation. In this way, humans are affecting their own genetic diversity and consequently affecting our own evolution.

For example, in vitro fertilisation (IVF) involves selecting viable sperm and combining them with eggs in a test tube.

**Figure 3.32** Artificial selection in action: each of these organisms was selectively bred for particular characteristics.

### Did you know? 3.2

**Broccoli and kale are the same**

Did you know that broccoli, kale, cabbage, brussels sprouts, cauliflower and gai lan are just some of the variations of the plant species *Brassica oleracea*? Each variation is called a 'cultivar', which is a plant variety produced by selective breeding.

**Figure 3.33** Some of the many varieties of *Brassica oleracea*

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**Explore! 3.5**

**Dog breeds**

All domestic dogs belong to one species, *Canis familiaris*, so how can they appear so different? Go online to research the following topics.

1. Choose one dog breed and identify its unique characteristics.
2. Critique some of the ethical considerations involved in breeding a dog for a particular characteristic that may be detrimental for their health. For example, the cocker spaniel's long floppy ears make it particularly susceptible to ear infections. The pug's wrinkled face is susceptible to infections resulting from dead skin cells and moisture being trapped in the folds of skin.

**Figure 3.34** Despite their differences, domestic dogs are all the same species!

After fertilisation, the healthiest embryo is selected for development and the remainder are frozen.

Medical technology lets us genetically test embryos prior to their implantation and also genetically screen babies. Decisions made on the basis of information gained by using these technologies can change the genetic composition of the human population in the next generation. Evolution takes an extremely long time, so the results of our actions will not be seen for thousands of years.

## Gene technologies

Desirable traits can also be acquired using gene technology, rather than relying on selective breeding. Gene technology lets us transfer genes from one individual or species to another. Gene therapy allows faulty genes found in an organism to be replaced by the normally functioning gene. Genetically modified organisms (GMOs) are produced when an organism has its DNA altered or modified using genetic engineering.

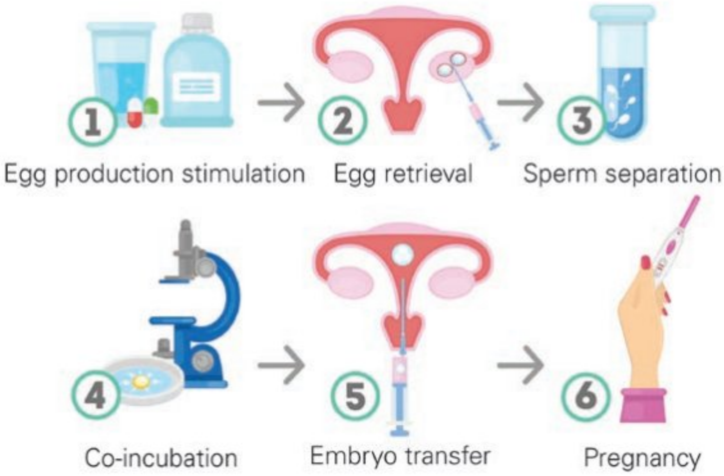


**Figure 3.35** The process of IVF artificially selects the eggs, sperm and embryos that have the best chance of survival.

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Consider how gene therapy could change the biodiversity of the human population. Would there be more or less variation? And what would this mean for the process of evolution? What about GMOs? Genetically engineered cotton crops (*Bacillus thuringiensis* cotton; Bt cotton for short), were created to produce an insecticide to combat bollworm. GM cotton was first grown in Australia in 1996, and now, over 99.5% of cotton grown in the country is genetically modified. What effects could GMOs have on biodiversity and evolution?

**Figure 3.36** Worldwide, bollworm causes millions of dollars worth of damage a year to crops such as cotton and vegetables.

## Explore! 3.6

**What will humans look like in 10 000 years?**

Some scientists have argued that civilisation has ended natural selection in humans. To a large degree, the selection pressures of the past (such as predation) no longer affect us in the same way. Humans modify their surroundings to survive in a wide range of environmental conditions, and vaccines and antibiotics help us to address disease.

However, there have been evolutionary changes since the earliest civilisations. As diets changed to include grains and dairy, genes that coded for enzymes to digest starch and lactose were selected for. People now live in densely populated regions which could allow the rapid spread of disease, but also have mutations that code for disease resistance.

Today, evolution has become less about survival and more about reproduction. Some scientists have suggested that this greater focus on reproductive success might increase selection for attractiveness. And humans might also become more uniform in appearance as travel leads to mixing of populations and easy access to worldwide media may create a set standard of beauty.

Scientists have suggested that the following changes may take place in humans over the next 10 000 years. Complete some research and discuss why future humans may have:

- longer lifespans
- taller stature
- lighter, less-dense skeletons
- reduced muscle, especially in the upper body
- smaller jaws
- fewer wisdom teeth
- smaller brains
- less aggressive behaviour.

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### Quick check 3.7

1 Define the term 'artificial selection' and provide an example.
2 Contrast natural selection and artificial selection.
3 Discuss whether artificial selection increases or decreases variation and therefore biodiversity.
4 Explain how reproductive technologies can affect human biodiversity.

## Section 3.2 questions

**Retrieval**

1 **Recall** the key processes involved in natural selection.
2 **Identify** geographical barriers that could divide a bird population, an eel population and a mammal population.
3 **State** the different sources of variation in an individual and in a population.
4 **Identify** three examples of abiotic selection pressures and three examples of biotic selection pressures.
5 **Name** some different ways that technology can affect the biodiversity of the human population.

**Comprehension**

6 **Describe** what is meant by the term 'selective advantage'.
7 **Summarise** the three processes in speciation.
8 **Explain** why variation is necessary for natural selection to occur.
9 **Explain** why isolation is necessary for speciation to occur.

**Analysis**

10 Tomato breeders have created the sweetest and juiciest tomato ever. **Reflect** on how they would have done this, given that they started with a not-so-sweet and not-so-juicy crop of tomatoes.
11 **Distinguish** between artificial and natural selection, providing examples for each.

**Knowledge utilisation**

12 The Galapagos finches share similar features but are recognised as distinct species. **Propose** a test that could be used to identify if two similar kinds of finch are different species or subspecies of the one species.
13 **Determine** how speciation, biodiversity and evolution are linked.
14 **Decide** if humans are evolving by natural selection.
15 **Predict** what will happen if a particular species has low genetic variation and there are changes in the environment in which they live.

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# 3.3 Evidence for evolution

**Learning goals**

1. To be able to describe the evidence for evolution.
2. To be able to describe how a fossil forms.
3. To be able to describe that radiometric dating of fossils relies on nuclear decay processes.

WORKSHEET
Evidence for evolution

Evolutionary theory is supported by a multitude of evidence and findings from observations and experiments, including the sources in Table 3.3.

| Field of science | Evidence |
|---|---|
| Palaeontology | The study of fossils, including their identification and interpretation, enabling the identification and interpretation of ancient organisms, which contributes to our understanding of past life forms and evolutionary history |
| Comparative anatomy | The study of the structure of specific organs and limbs of different organisms, providing insights into their functional adaptations and evolutionary relationships |
| Embryology | The study of the development of the embryo in different organisms, providing information about shared developmental processes and evolutionary patterns |
| Molecular phylogeny | The ability to sequence DNA to indicate the degree of relatedness between organisms, aiding in the construction of evolutionary trees and understanding evolutionary relationships |
| Biochemistry | Similarities and differences in the biochemical make-up of organisms that can help distinguish differences and similarities |
| Biogeography | The study of the geographic distribution of organisms which can help ascertain the origins, dispersal and adaptation of species in different regions |

**Table 3.3** Sources of scientific evidence for the theory of evolution

VIDEO
Paleontology

## Palaeontology

The term **fossil** refers to any parts of, or impressions made by, a plant or animal that is preserved following death. Normally, an organism decomposes after it dies, and after a time, no trace of it remains. On rare occasions, evidence of the organism is preserved in the form of a fossil. Fossils may be the hard parts of an organism, like its bones and teeth (called **direct** evidence), or evidence of an organism's presence, like footprints, burrows and faeces (called **indirect** evidence or **trace fossils**.). The process of forming a fossil is called **fossilisation**. However, because fossilisation is rare, and organisms with hard parts are more likely to form fossils, there are gaps in our **fossil record**. Also, we cannot dig everywhere looking for fossils, so many go undiscovered.

**fossil**
the shape or impression of a bone, a shell or a once living organism that has been preserved for a very long period of time

**direct (evidence)**
evidence that supports an assertion without intervening inferences

**indirect (evidence)**
evidence that requires inferences to be made

**trace fossil**
a trace of an animal, such as footprint or imprint, that has become fossilised

**fossilisation**
the process of forming a fossil

**fossil record**
the record of past life and evolution inferred from fossils

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## Fossilisation

Fossils are formed in many ways, but they are most likely to be found in sedimentary rock. When an organism dies, soft tissues normally decompose, leaving only the hard parts behind. The organism gets buried under sediment, volcanic ash or lava. Over a period of time, minerals can fill up empty spaces or replace material, eventually changing to rock.

**Figure 3.37** Many opalised fossils have been found on the opal fields of Coober Pedy, South Australia. This phenomenon occurs when opal, instead of the usual minerals found in groundwater, replaces the skeletal material. The photos show a drawing of an extinct, squid-like belemnite (left), a belemnite fossil found in shale (middle) and an opalised belemnite found in Coober Pedy (right).

Other ways in which fossils can be formed are presented in Table 3.4.

| Method of fossil formation | Description |
|---|---|
| Impression | The organism's remains are washed away, but an empty space is left in the shape of the organism. If it remains empty, it is a mould. If it fills with minerals, then it is a cast.  **Figure 3.38** An impression fossil of a pterosaur |
| Amber | Organisms become trapped in tree resin that then hardens.  **Figure 3.39** A 100-million-year-old spider attacking its prey |

**Table 3.4** Methods of fossilisation

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| Method of fossil formation | Description |
|---|---|
| Trace fossils | Trace fossils, such as footprints, burrows or faeces, give some insight into an organism's behaviour, how they lived and how they interacted with the environment.<br><br>**Figure 3.40** Queensland is home to one of the world's most famous trace fossil sites. Lark Quarry Conservation Park near Winton is the only known site of a dinosaur stampede, providing the most concentrated set of dinosaur footprints in the world. Over 3000 footprints can be seen in an area approximately the size of a tennis court. Trace fossils can provide important information relating to the size and walking or running posture of an extinct species. |
| Soft tissue | It is extremely rare for soft tissues to survive the pressure, heat and chemical changes needed for fossilisation to occur. But nowadays, scientists are increasingly reporting finding fossilised skin and even brain material preserved along with bones.<br><br>**Figure 3.41** In 2018, researchers found what they believe are fossilised lungs preserved inside a 120-million-year-old bird. Scientists have previously found four fossils of this ancient bird, *Archaeorhynchus spathula*, but never with plumage or suspected lungs. |

**Table 3.4** *(Continued)*

Fossilisation requires the following conditions:

- Burial is rapid. Organisms must be buried quickly in oxygen-poor sediments. Usually this happens when organisms die in seas, lakes, floods or mud slides. Organisms can also be preserved in ice or amber or buried under ash from volcanic eruptions (lava will usually incinerate any remains).
- Decomposition is prevented. Bacteria, which normally cause the decay of organisms, must be reduced or absent. For example, many bacteria that cause decomposition will die in the absence of oxygen or water, or in conditions of high acidity or extreme cold. Soft tissue and

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organs break down chemically, so they do not usually get fossilised even in the absence of bacteria.
- Remains lie undisturbed. Predators and scavengers do not dig up the remains.

**Figure 3.42** The town of Richmond in outback Queensland was once 40 metres underwater, covered by an ancient inland sea. Between 145 and 66 million years ago, the region would have been rich with fish and marine reptiles. Fossil hunters are finding a new species of ancient marine life as often as once a month when digging in fossil pits.

**Figure 3.43** Fossilised skull of Owen's ninja turtle (*Ninjemys oweni*), an extinct large stem-turtle from the Pleistocene period, in Queensland. Despite weighing over 200 kilograms and having a horned head, it was a herbivore.

## Quick check 3.8

1 State two sources of evidence for evolution.
2 Recall some of the information you can find out from fossils that helps explain evolution.
3 Explain why it is rare to find fossils.
4 Summarise the conditions required for fossilisation.
5 Describe what is meant by a 'trace' fossil.

## Did you know? 3.3

**Living fossils**

Charles Darwin coined the phrase 'living fossils' and, despite not being a scientific term, it has remained in use. It describes modern species of plants and animals that are almost identical to species that lived in ancient geological ages. This means they have survived mass extinctions, ice ages and comets hitting Earth! Examples include the Wollemi pine, the Queensland lungfish, mountain shrimp and the Australian ghost shark.

**Figure 3.44** The Queensland lungfish (*Neoceratodus forsteri*) is considered a 'living fossil' as it was prevalent in the Devonian period, some 400 million years ago!

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## Dating fossils: Relative dating

Until last century, **relative dating** was the only method available for dating fossils. As the term suggests, relative dating techniques only work out how the age of a fossil compares to the ages of other fossils. For example, it can tell you that fossil X is older than fossil Y, but it cannot tell you the actual numerical age of the fossil. Relative dating is used to order the layers of rocks and geological events into a time sequence. The study of the order of the layers of rock (strata) is called **stratigraphy**.

**relative dating**
determining the order of past events without the specific age

**stratigraphy**
the branch of geology studying the rock layers

### Try this 3.4

**Stratigraphy**

Where the sediments in which fossils are found have not been disturbed by later events, they nearly always show an age sequence, with the oldest fossils deepest under the ground and the youngest at the top. Often these fossil sequences let us see the change in a species over time. This highlights how the fossil record is valuable for collecting evidence of evolution. For example, fossils have provided evidence for the evolution of modern horses from the ancient four-toed mammal, and the discovery of *Archaeopteryx* gave us evidence for the link between reptiles and birds. The fossil record also tells us more about organisms that are now extinct and what Earth was like when particular species existed.

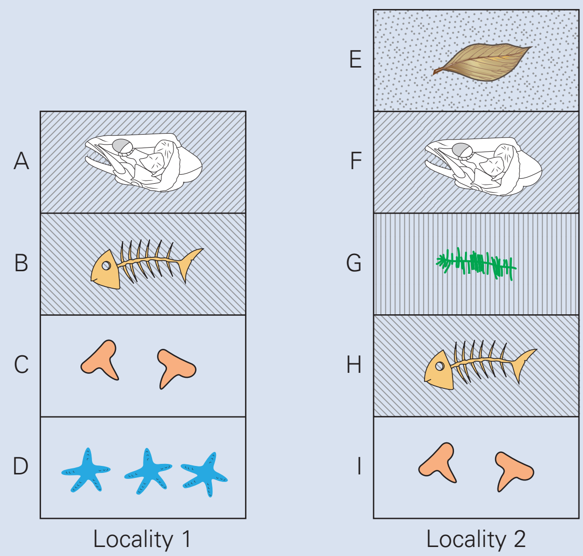


**Figure 3.45** Relative dating: the different strata and their relative positions at locations 1 and 2 help us date the fossils in each layer relative to other fossils.

The diagrams in Figure 3.45 represent the strata (rock layers) found at two different locations (1 and 2). Each layer has a letter associated with it, and you can see the different fossils found in each layer. Knowing that the youngest layers are on the top and the oldest down below, work out the relative age of all the layers in both locations from oldest to youngest. Then list the clues you used to work this out.

For example, layer G is younger than layer B, but older than layer A.

Fossils are important for working out the relative ages of sedimentary rocks too. Similar fossils in different rocks, even if a great distance apart, suggest the rocks are the same age. This matching process is called correlation, and it has been important in constructing geological timescales. Throughout the history of life, different organisms have appeared, flourished and become extinct. Some of these organisms became fossilised in sedimentary rocks. The geological study of their patterns of appearance and disappearance over time is called **biostratigraphy**.

**biostratigraphy**
a branch of stratigraphy focused on dating rock layers using the fossils found in them

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**index fossil**
a fossil used as the basis for dating the strata it occupied

To help identify matching strata, and to compare strata in different locations, indicator or **index fossils** can be used. An index fossil is a fossil of known age found in a particular type of sedimentary rock layer. It can be used to indicate the age of any deposit in which it is found, at any locality. For example, trilobites are good index fossils as they were very common at the time they existed (between 488 and 225 million years ago), easy to recognise, well preserved because of their hard exoskeleton and they evolved rapidly, which means there were different species present at different times.

## Did you know? 3.4

**Two legs better than four?**
The fossil record shows that kangaroo ancestors were quadrupedal (walking on four legs) and had teeth adapted to eating woody vegetation. These adaptations were advantageous in forested habitats, but as the environment started to dry out, giving way to open grassland, the selection pressures of the environment were very different. Over millions of years, what we now know as kangaroos became bipedal and their teeth evolved to be able to graze on grass.

**Figure 3.46** At low speeds, bipedal hopping is energy inefficient for a kangaroo. It only becomes useful at high speeds. Since their environment changed millions of years ago, hopping has provided a useful adaptation to evade predators in wide open grasslands.

**absolute dating**
determining the actual age of a material

**radioisotope**
a radioactive isotope of a chemical element with an unstable nucleus that emits excess energy (radiation)

**half-life**
the length of time needed for the radioactivity of a radioactive substance to be reduced by half

## Dating fossils: Absolute dating

**Absolute dating** gives a precise age (within certain error margins) for a fossil or, more commonly, for the rock or soil in which a fossil is found. Absolute dating uses radiometric techniques, which means looking at the level of radioactivity detected in rocks containing certain naturally occurring radioactive isotopes (**radioisotopes**). These isotopes occur in living things and have a known rate of radioactive decay. By measuring the amount of radioactive isotope left in a sample, we can work out how long the organism has been dead. The time in which half of the sample of the radioactive isotope (parent) has decayed to a more stable form (daughter) is known as its **half-life** and is unique to each isotope. Knowing this helps us determine the best isotope to use to work out the absolute age of a fossil. The longer the half-life of the isotope used, the older the fossil or rock that can be dated.

| Radioactive isotopes (parent to daughter) | Half-life (years) | Estimated age range of fossils they can date |
|---|---|---|
| Carbon-14 to nitrogen-14 | 5730 | Up to 55 000 years ago |
| Uranium-235 to lead-207 | 710 000 000 | 1 million to 1 billion years ago |
| Potassium-40 to argon-40 | 1300 000 000 | 500 000 years and older |

**Table 3.5** Each radioactive isotope has a different half-life. The longer the half-life, the older the fossil or rock that can be dated.

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**Figure 3.47** Fossil of a trilobite, *Albertella helena*

## Did you know? 3.5

*Zygomaturus trilobus* was a large wombat-like marsupial approximately the size of a bull. Dating using uranium–thorium shows that a fossil specimen of *Zygomaturus* died 33 000 years ago. We know that First Nations Australians arrived in the same area at least 50 000 years ago, so the uranium–thorium dating shows that people and megafauna coexisted for at least 17 000 years. The coexistence of First Nations Australians and Australian megafauna is further supported by paintings in Arnhem Land rock shelters of species such as *Genyornis newtoni* and *Palorchestes parvus*.

**Figure 3.48** This rock painting of the megafauna herbivore in the genus *Palorchestes* displays two prominent tufts of chest hair and is accompanied by a smaller (perhaps younger) version of the same animal.

## Try this 3.5

### Modelling half-lives

**Be careful**

Do not consume food items.

### Materials

- 100 M&Ms or counters with one side marked
- graph paper
- plastic container with lid
- plastic tray
- gloves

*continued …*

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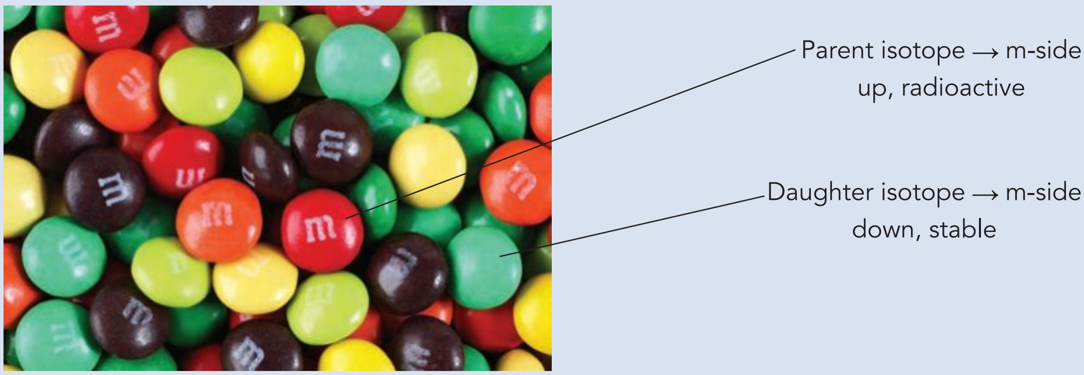
*continued …*

**Instructions**

1 Copy the results table into your science journal.
2 Predict the number of M&Ms that will 'decay' into daughter isotopes each time trial. Place all 100 M&Ms parent isotopes on your plastic tray with the 'm' side up.
3 Record your original number of parent isotopes in your results table for time 0.




4 Place all the isotopes in the plastic container and shake for 10 seconds.
5 Pour your isotopes back onto the plastic tray.
6 With your gloves on, remove all the stable daughter isotopes (m side down) from the tray and set them aside.
7 Count the remaining M&Ms (parent isotopes), which will be a percentage of the original number since that was 100, and record this in your results table for time 1.
8 Repeat steps **4–7** another eight times, ensuring that you only place parent isotopes back in the container each time.
9 Collate the class results on the board and calculate means for each time.
10 Calculate the percentage of undecayed parent isotopes for each time period.
11 Draw a graph of the time ($x$-axis) versus percentage undecayed parent isotopes ($y$-axis) using the class results.

| Time | Number of removed daughter isotopes | Number of remaining parent isotopes | Percentage undecayed parent isotopes $\frac{\text{Number of remaining parent isotopes}}{\text{Starting number of parent isotopes}} \times 100$ | Class mean percentage undecayed parent isotopes |
|---|---|---|---|---|
| 0 | | | | |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |

12 Calculate the half-life of your isotope by using your graph to identify the time in which half of the parent isotopes had decayed into daughter isotopes.

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## Quick check 3.9

1. Describe relative dating.
2. Define the terms 'stratigraphy' and 'index fossil'.
3. Describe absolute dating.
4. Name one isotope that could be used to accurately measure the absolute age of a fossil.

## Science as a human endeavour 3.2

### The latest fossil finds

In 2022, an international team of palaeontologists identified the world's oldest meal in a 550-million-year-old fossil. Analysing the fossilised remains of a slug-like Ediacarian called *Kimberella* showed that it had a mouth and a gut and ate algae and bacteria from the ocean floor. The organism was advanced for the time period, as most other species did not have a gut that went through their entire body.

**Figure 3.49** New fossils are providing key insights into the evolution of life on Earth.

## Comparative anatomy

Genetic variation can produce a huge diversity of forms among closely related organisms. But some animals display physical likeness despite not being closely related at all. Think about a bird and a bat, a dolphin and a shark, a sugar glider and a flying squirrel. The members of each pair, despite not being closely related, share some obvious structural characteristics. For example, sugar gliders and flying squirrels look alike, sharing similar characteristics such as size, big eyes and a white belly. Their most striking similarity is that they both have thin, loose skin between their limbs which keeps them stable when stretched while they glide.

However, sugar gliders (native to Australia) and flying squirrels (native to Asia, central and North America, and Europe) also have many differences. Sugar gliders are marsupials, so they have a pouch to protect their young, whereas flying squirrels are placental mammals, having larger babies and no pouch.

By studying their genes and other traits, biologists discovered that sugar gliders and flying squirrels are not very closely related at all. So why do they share some common physical characteristics?

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Figure 3.50 A sugar glider (left) and a flying squirrel (right) have many common characteristics, but they are not closely related.

**analogous structures** structures that have a similar function but evolved separately

**homologous structure** a similar physical feature in organisms that have evolved from the same common ancestor

The characteristic 'wings', which are flaps of skin, are known as **analogous structures**. These are structures that have a similar function but have evolved independently. The two organisms have evolved from different ancestors but in similar environments, so the same selection pressures have caused the same feature to be selected for. The fin shape of sharks (a fish), penguins (a bird) and dolphins (a mammal) is another example of an analogous structure (Figure 3.51). The shape of their fin (or the wing of the penguin) is adapted for swimming through water. The three types of animals faced similar selection pressures in their aquatic environment, and evolved into a similar shape, but they do not share a recent common ancestor.

**Homologous structures** are structures that organisms inherit from a common ancestor. 'Homo' comes from the Greek word *homos* meaning 'same'; hence, they inherited the same general body plan from the same ancestor. We say these structures have a common evolutionary origin. Homologous structures have similar underlying anatomy but have evolved in different ways over time due to different selection pressures. An example of a homologous structure is the pentadactyl

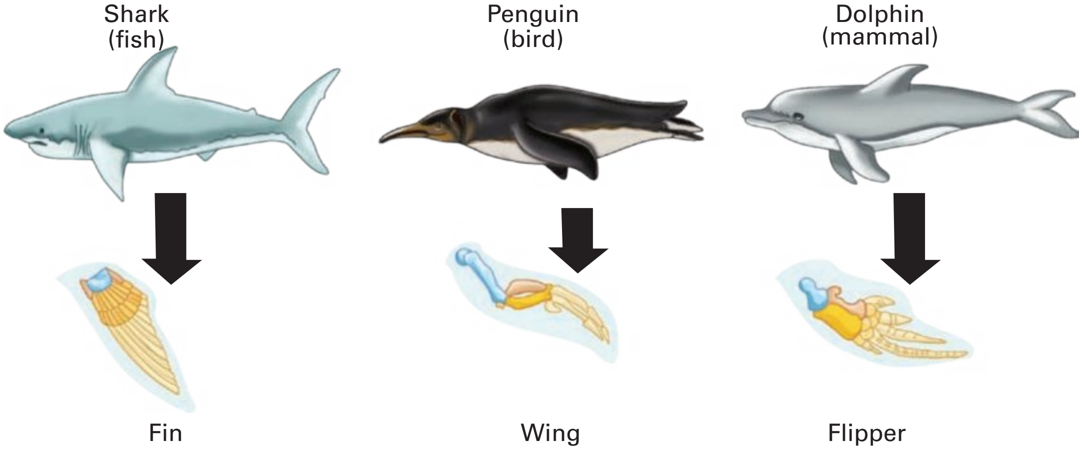


Figure 3.51 The shark, penguin and dolphin have analogous structures, that is, structures with the same function. These arose because they live in similar environments and face similar selection pressures.

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limb, the five-digit limb typical of tetrapod (four-limbed) vertebrates (that is, amphibians, reptiles, birds and mammals). The limbs of different species show basic similarities in the bones present and how they are arranged, even though the limbs may serve different functions (Figure 3.52).

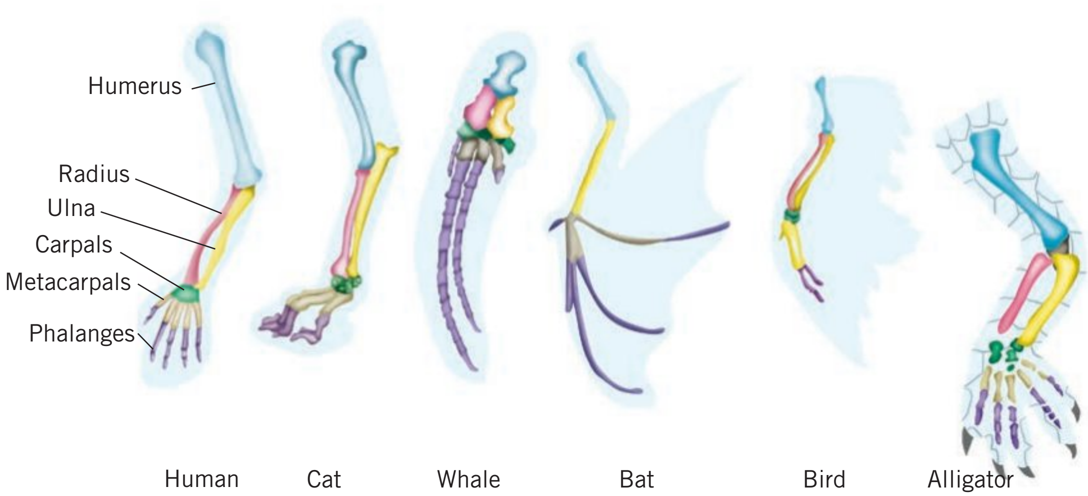


**Figure 3.52** The limbs of different tetrapod vertebrates have a common structure and are called homologous, despite having different functions, such as grasping, swimming or flying.

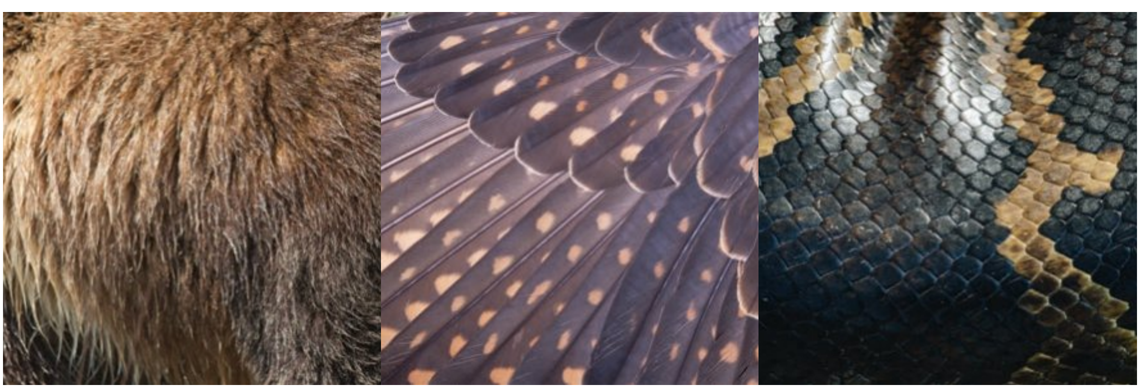

**Figure 3.53** The hair of mammals (left), feathers of birds (middle) and scales of reptiles (right) are structures that share a common ancestry in reptilian scales; they have been inherited and modified over time. The fibres in each are composed of keratin complexes.

The different limbs are the same bones arranged for different uses. If homologous structures are found in different organisms, that suggests they had a relatively recent common ancestor, which helps to explain their evolutionary path.

**Quick check 3.10**

1 Describe analogous structures, providing an appropriate example.
2 Describe homologous structures, providing an appropriate example.

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## Practical skills 3.2

### Dissection of a chicken wing

**Be careful**
Take care when using scissors and probes.
Clean the benches and wash your hands before leaving the laboratory.

**Aim**

To compare the structure of a chicken wing to the structure of a human arm.

**Materials**

- fresh chicken wing
- dissecting board
- dissecting scissors
- probe
- disposable gloves
- human skeleton model

**Method**

**Part 1: Examining the chicken wing**

1 Hold the chicken wing at the shoulder and the tip and then stretch out the wing. Identify where the joints are and in which direction they bend.
2 Use your fingers to feel the bones and muscle under the skin.
3 Using dissecting scissors, carefully remove the skin from the chicken wing, taking care not to cut the muscles, ligaments and tendons.
4 Identify the muscles of the wing and see if you can work out how each one is attached to the bones of the wing.
5 Look for the tendon, which is white and tough and attaches the muscle to the bone.
6 Try squeezing the muscle in the wings and observe what happens to the bones. You may notice there are two muscles which can flex or extend the wing.
7 Look at the surface of each bone where it forms a joint. It should appear white, shiny and slippery – this is called cartilage. Can you find the cartilage at the joint between the humerus and the radius and ulna?

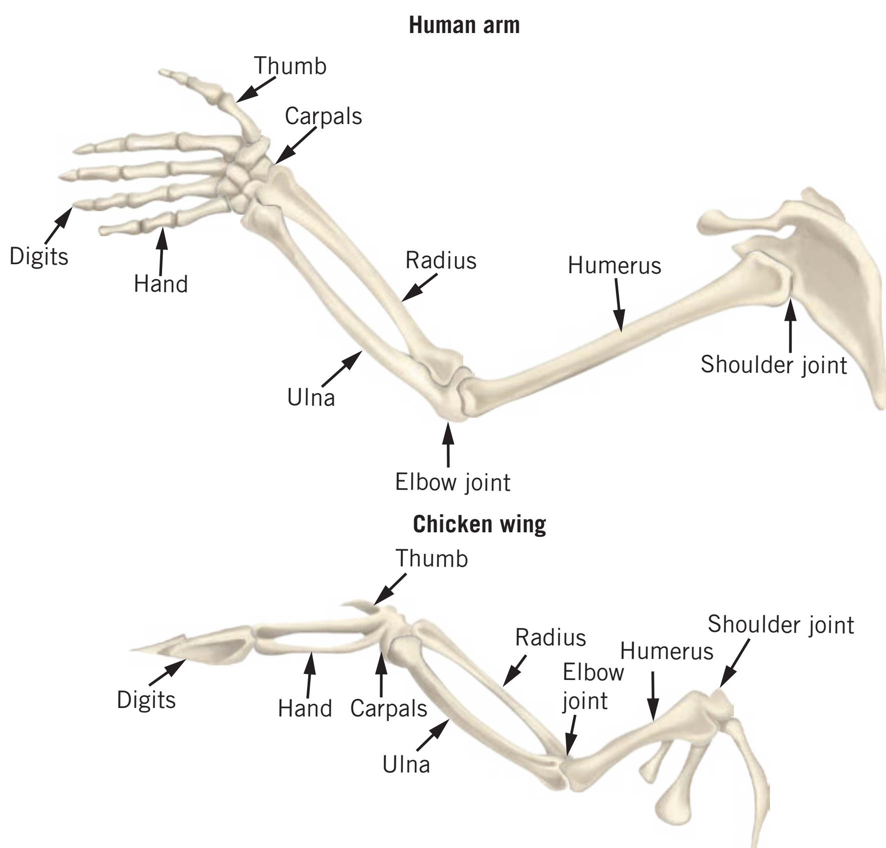


Figure 3.54 The bones of a human arm and a chicken wing

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**Part 2: Examining your arm**

1 Identify the humerus, ulna and radius in your arm. What other features of the chicken wing and your arm are similar?
2 Bend your arm at the elbow and hold it tight. Notice that your bicep muscle shortens. Now, extend your arm and feel your bicep lengthen.
3 Now, look at your hand and identify where the muscles are that move your fingers. You may need to press on your wrist or forearm to figure this out.
4 With a partner, raise and lower a textbook by bending your arm at the elbow. Which muscles were acting as you raise and lower?

**Results**

Take a photo of the finished dissection of the chicken wing.

**Analysis**

1 Compare the structure of a chicken wing with a human arm.
2 Define the term 'analogous structures' and explain what they can tell us about the evolution of a species.
3 Define the term 'homologous structures' and explain what they can tell us about the evolution of a species.
4 Would the chicken bones and human bones be considered homologous or analogous structures? Discuss.

Scientists can construct **evolutionary trees** using fossil evidence and radiometric dating to estimate when different groups of species diverged from a common ancestor. Evolutionary trees can be constructed when scientists have studied the anatomy of different species to determine which ones have homologous structures. Only homologous traits are evidence of a shared ancestry. An example of an evolutionary tree is shown in Figure 3.55.

**evolutionary tree**
a diagram used to represent evolutionary relationships between organisms

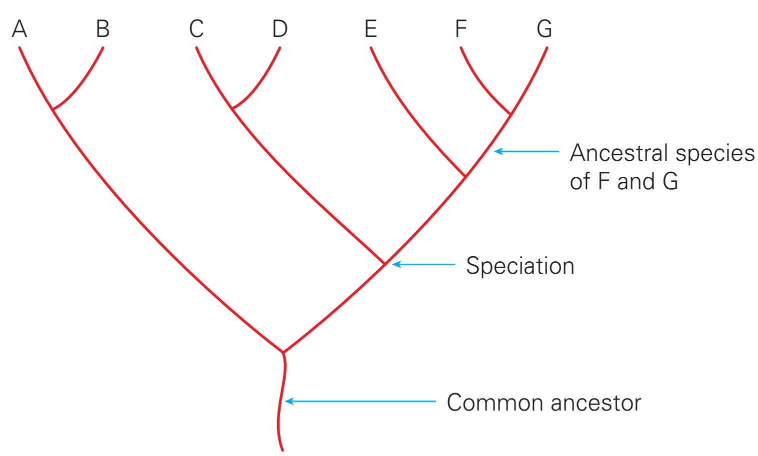


**Figure 3.55** An example evolutionary tree

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For example, humans, chimpanzees and gorillas all have thumbs that are very similar anatomically and are considered to be homologous (Figure 3.56). The giant panda also has a thumb, but it has been found to be analogous to these primate thumbs – it serves the same function but is structurally formed by different bones, so it evolved separately. This suggests that humans, chimpanzees and gorillas are much more closely related to one another than any of them is related to giant pandas.

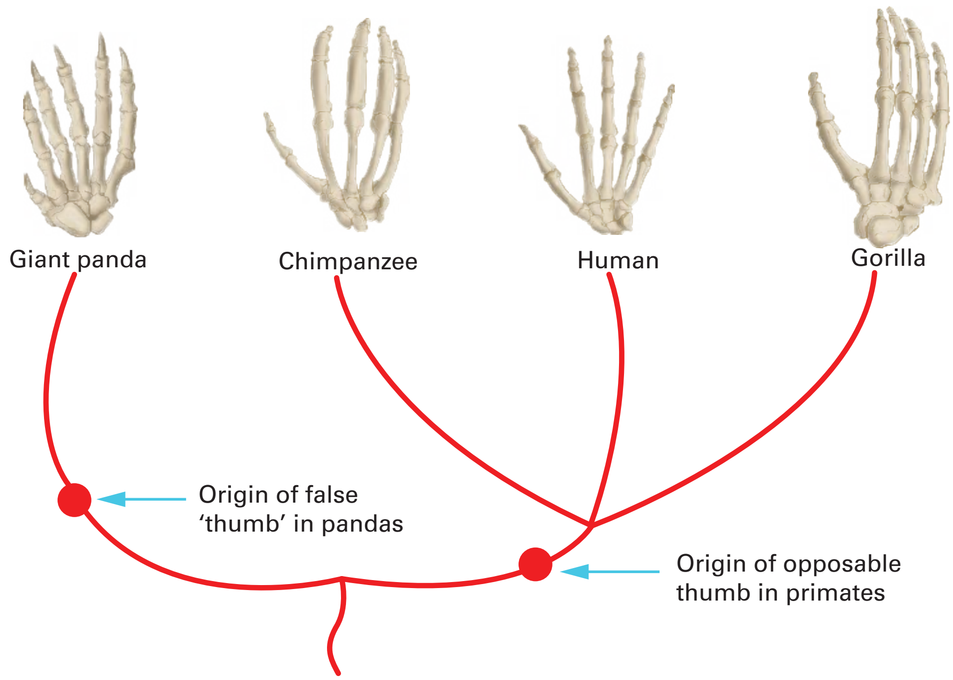


**Figure 3.56** An evolutionary tree showing how their homologous opposable thumbs mean that humans, chimpanzees and gorillas have a recent common ancestor

## Comparative embryology

The embryos of vertebrate animals look very similar in the early stages, which suggests that they inherited some of the genetic information that contributes to embryo development from a common ancestor. For example, a very early stage human embryo has gill slits, a tail and a simple heart, similar to that of a fish. At later stages, the human embryo develops body proportions similar to the embryos of reptiles and then apes.

Comparative embryology also finds evidence for evolution in the circulatory system of fish and mammals. Adult fish and mammals have quite different circulatory systems. However, during embryonic development you can clearly see that the circulatory systems are based on the same pattern. This suggests that the genetic information responsible for the development of the fish and mammalian circulatory systems has been inherited from a common ancestor.

### Quick check 3.11

1 Describe an evolutionary tree.
2 Explain how embryology provides evidence for evolution.

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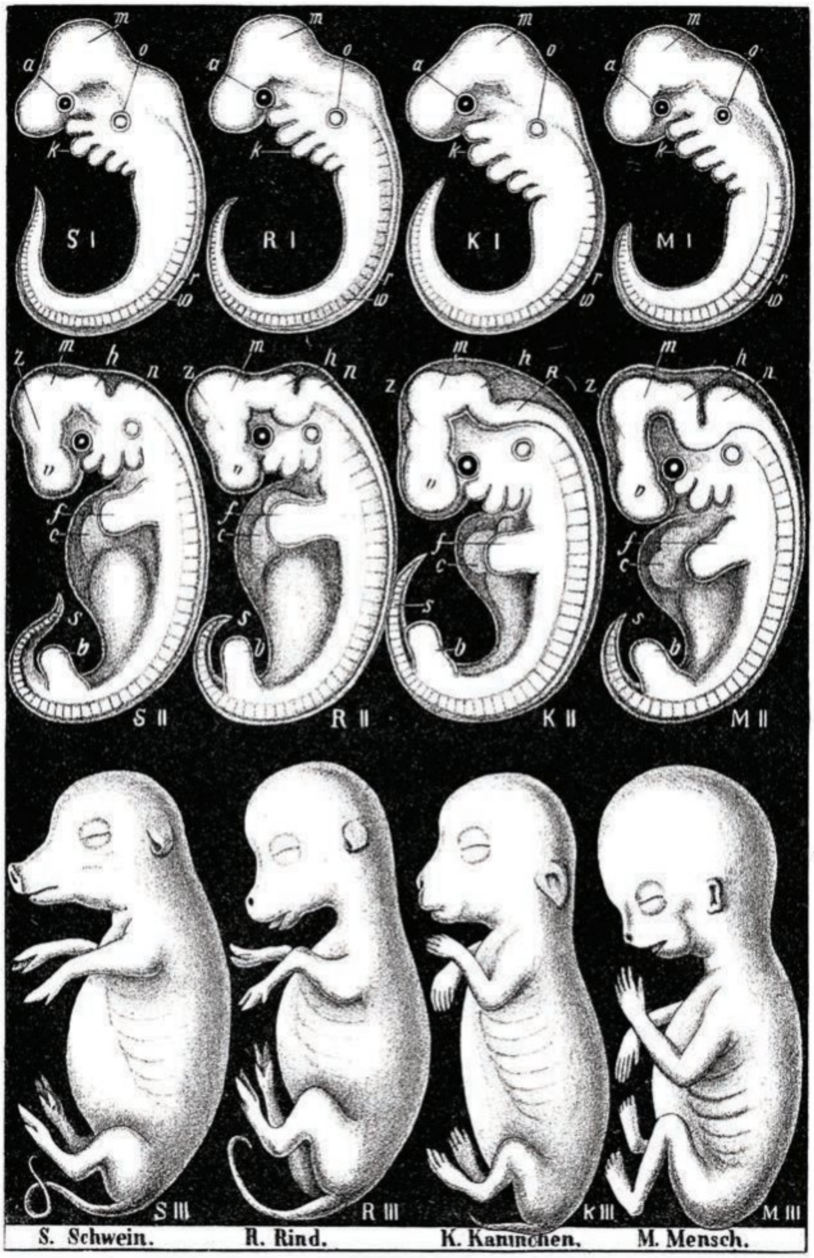


**Figure 3.57** Comparative embryology drawings of embryos at three stages from (left to right): a pig, cow, rabbit and human

## Molecular biology

Substances that are found in most or all living things are very useful in the investigation of evolutionary relationships. For example, all living things contain DNA, so it is commonly used to compare organisms. This is what the study of molecular biology is all about – investigating DNA, its code and the proteins it codes for. Molecular biology lets evolutionary scientists:

- trace ancestors of species
- estimate how long ago one species diverged into two
- discover how closely related two species are.

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## DNA analysis

**DNA hybridisation** is a technique to compare the DNA sequences of two species to find out how closely related they are. First, as shown in Figure 3.58, the DNA from each organism is extracted and heated so it forms two single strands. When the single strands from the two organisms are mixed together and allowed to cool, complementary nitrogenous bases will bind together (hybridise). The degree to which the single strands form a stable double-stranded DNA molecule is an indication of the relatedness of the species. For example, if there is a lot of hybridisation, there must be a lot of complementary bases, which means the organisms are similar and, therefore, have a recent common ancestor.

**DNA hybridisation**
a technique that measures genetic similarity between two organisms

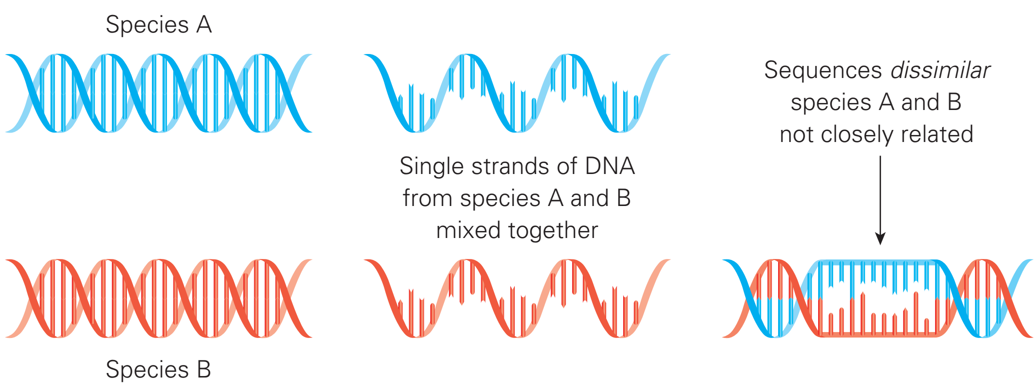


**Figure 3.58** The process of DNA hybridisation allows scientists to determine the relatedness of two organisms by comparing their DNA.

## Protein analysis

As we know, proteins are made up of building blocks called amino acids. Scientists can analyse the differences in the amino acid sequences, knowing that this relates to how similar proteins are in the different organisms. The number of different amino acid sequences in the proteins of different species is an indicator of the number of mutations and hence the degree of separation of species. In other words, a large difference in amino acid sequences between two organisms means they had a distant common ancestor, while a small difference in amino acid sequences mean they had a recent common ancestor. The cytochrome c protein is often studied as it is involved in cellular respiration and is found in most eukaryotic organisms. Table 3.6 shows the differences in the amino acid sequence for cytochrome c between humans and other organisms. Notice how the monkey has the lowest number of differences, suggesting they are more closely related to humans.

Note that it is also possible to predict amino acid sequences from the DNA code, and the latter also tells you about the relationship between organisms.

| Organism | Number of differences in the amino acid sequence for cytochrome c compared to humans |
|---|---|
| Horse | 12 |
| Chicken | 13 |
| Dog | 11 |
| Moth | 31 |
| Tuna | 21 |
| Monkey | 1 |

**Table 3.6** The differences in the amino acid sequence for cytochrome c between humans and other organisms

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## Did you know? 3.6

### Molecular clocks

The molecular clock concept says that mutations accumulate in biomolecules at a roughly constant rate because they occur by chance. We can use this mutation rate to deduce the time when life forms diverged. The biomolecular data that is normally used for calculations are DNA nucleotide sequences, including those found in mitochondrial DNA (mtDNA).

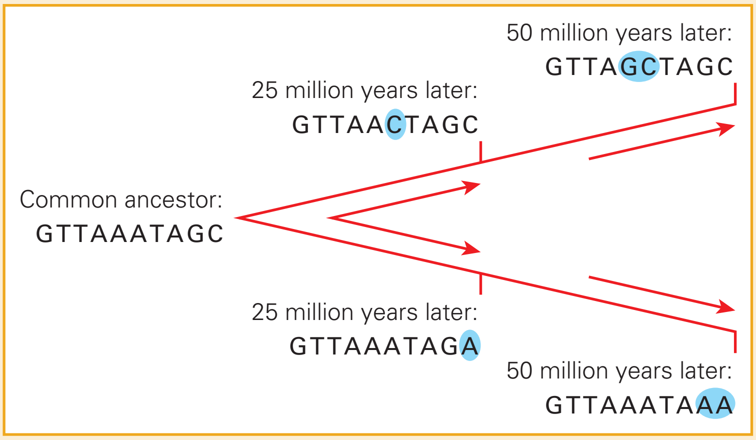


**Figure 3.59** In the same way that a clock tells the time, a molecular clock allows scientists to determine how long ago two species diverged.

## Quick check 3.12

1 Describe DNA hybridisation and how it provides evidence for evolution.
2 Describe how the number of differences in the amino acid sequence for cytochrome c can be used to establish the relationship in evolutionary terms between organisms.

## Biogeography

**Biogeography** is the study of the distribution of organisms, both today and in the past. Biogeography provides us with additional evidence for evolution, such as when ancient fossils in one area resemble modern organisms in that same area and have a similar pattern of distribution (for example, fossil and modern platypuses are both found in Australia). The similarity of fossil and modern organisms suggests that the modern organisms have descended from ancestors living in same areas.

Remember that the continents were once joined in one big supercontinent, and ancestral organisms were distributed across more than one continent. When the continents split up and drifted apart, the separated populations evolved into different organisms due to reproductive isolation. However, in some cases, the selection pressures in each new area were so similar, that speciation created very similar looking organisms. For example, the emu of Australia, the ostrich of Africa, the cassowary of Papua New Guinea and northern Australia and the rhea of South America are all large, flightless birds. Despite being found on different continents with oceans between them, one possible explanation for their similarity is that they descended from a common ancestor that occurred on the ancient Gondwana supercontinent.

**biogeography** the study of the geographical distribution of plants and animals

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Figure 3.60 (Left to right) While the emu and cassowary can be found in Australia, rheas live in South America and ostriches in sub-Saharan Africa.

**Quick check 3.13**

1. Define the term 'biogeography'.
2. Explain how biogeography provides evidence for evolution.

VIDEO Human evolution

## Evolution of humans: Bringing it all together

In order to understand human origins, we need to first look at what humans are. Humans are in the animal kingdom, phylum Chordata, class Mammalia, order Primates, family Hominidae, genus *Homo* and species *Homo sapiens* (see Figure 3.61).

The primates living today gradually evolved over 65 million years from ancestral primates that were small tree-dwelling mammals. We did not evolve from apes and monkeys, but we share a common ancestor with them. About six million years ago, the line that led to humans is thought to have diverged from the chimpanzee line due to different habitats and different selection pressures.

This divergence led to the evolution of the earliest members of the human family, the Australopithecines, which lived in Africa between about 4 and 2 million years ago. These early hominids were bipedal and had a small brain and teeth and jaws adapted to a diet that included tough plant materials. Over time, members of the human family continued to evolve and develop new adaptations, such as a larger brain and the ability to use more complex tools.

One of the most important periods of human evolution occurred around 2.5 million years ago with the emergence of the genus *Homo*. The first species in this genus, *Homo habilis*, was known for its ability to create stone tools; it had a slightly larger brain than the Australopithecines.

Over the next few million years, other species of *Homo* emerged, including *Homo erectus*, which was the first hominid to leave Africa and migrate into other parts of the world. *Homo neanderthalensis*, commonly known as the Neanderthals, was a species of hominids that lived in Europe and parts of Asia from about 400 000 to 40 000 years ago. They were named after the Neander Valley in Germany, where the first Neanderthal fossils were discovered in the mid-19th century.

Neanderthals were well adapted to life in cold environments, with a stocky build and short limbs that helped to conserve body heat. They are also known to have used fire and create shelters, indicating a level of social and technological sophistication. Neanderthals produced art, made jewellery and performed burial rituals, indicating a degree of symbolic thought.

The most recent and only surviving species of the *Homo* genus is *Homo sapiens*, which

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emerged in Africa around 300 000 years ago. *Homo sapiens* is characterised by its large brain, complex culture, and use of language. Genetic studies have shown that Neanderthals interbred with modern humans, as evidence of their DNA has been found in the genomes of non-African humans. However, they eventually became extinct around 40 000 years ago for reasons that are not entirely clear, although factors such as climate change, competition with modern humans, and disease have been suggested as possible contributing factors.

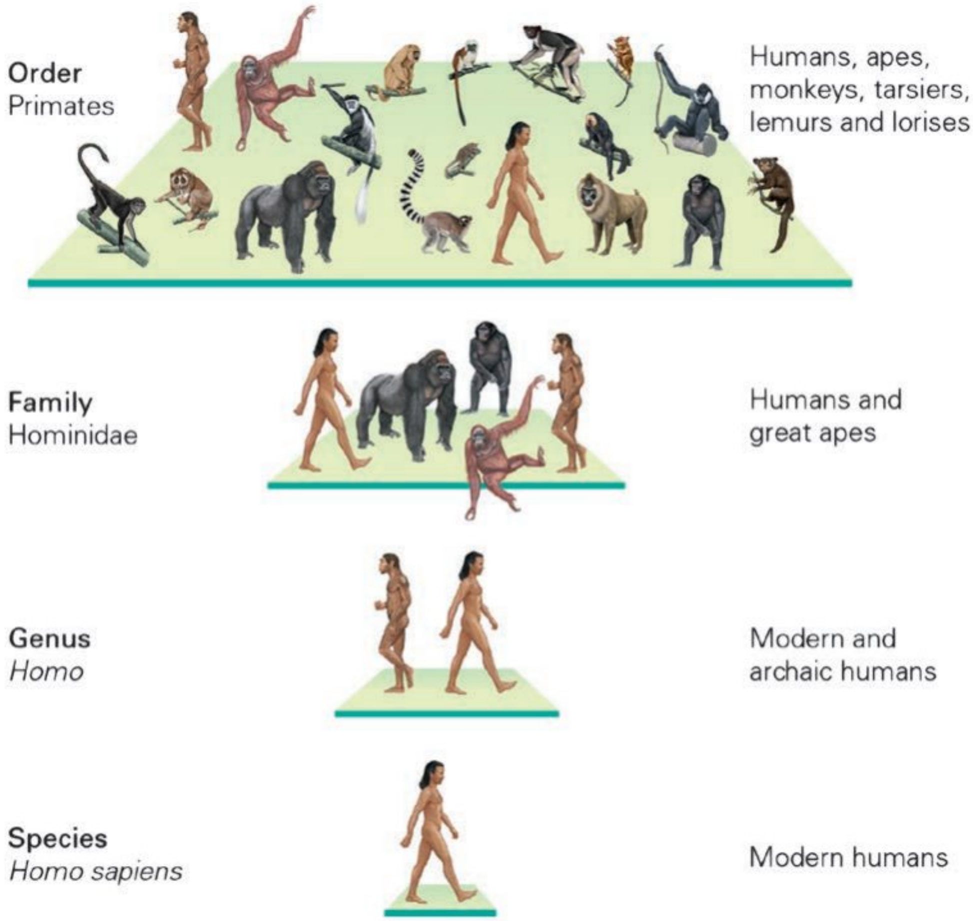


**Figure 3.61** Classification of *Homo sapiens* within the order Primates

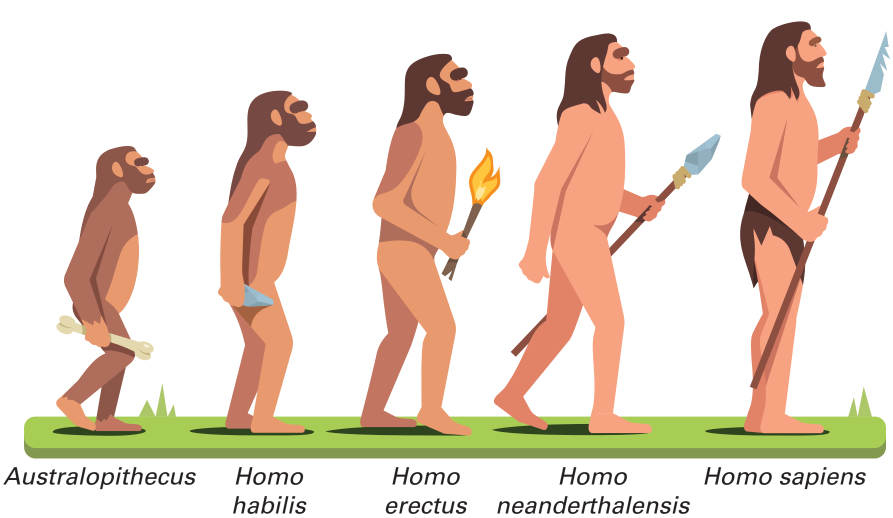


**Figure 3.62** The biologist and anthropologist Thomas Henry Huxley (1825–1895) was the first to suggest that humans and other species were related.

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## Explore! 3.7

### Evidence for human evolution

In this section you have learned about the different ways that we can gather evidence about evolution: palaeontology, comparative anatomy, embryology, molecular biology and biogeography. However, we have not investigated how they have informed us about human evolution.

**Figure 3.63** An archaeological excavation uncovers human remains.

1 Research the fossil evidence of human evolution. Summarise what fossils teach you about the evolution of humans and use pictures to illustrate what you find.
2 Research homologous and analogous structures related to human evolution. Summarise what comparative anatomy teaches you about the evolution of humans and use pictures to illustrate what you find.
3 Research the DNA evidence of human evolution. Summarise what DNA teaches you about the evolution of humans and use pictures to illustrate what you find.

QUIZ

## Section 3.3 questions

### Retrieval

1 **Name** five sources of evidence for evolution.
2 **Recall** what is meant by the term 'fossil'.
3 **Recall** what the term 'biogeography' refers to.

### Comprehension

4 **Describe** analogous structures, providing an example.
5 **Explain** how the scales of reptiles and the feathers of birds are considered homologous structures.
6 **Explain** how DNA hybridisation can show that two organisms share a common ancestor.
7 **Summarise** why fossils of soft-bodied organisms are relatively rare.

### Analysis

8 Figure 3.64 represents the layers of rock found within a cave. **Identify** the layer (1 to 5) where you would expect to find the oldest group of fossils, giving reasons for your answer.

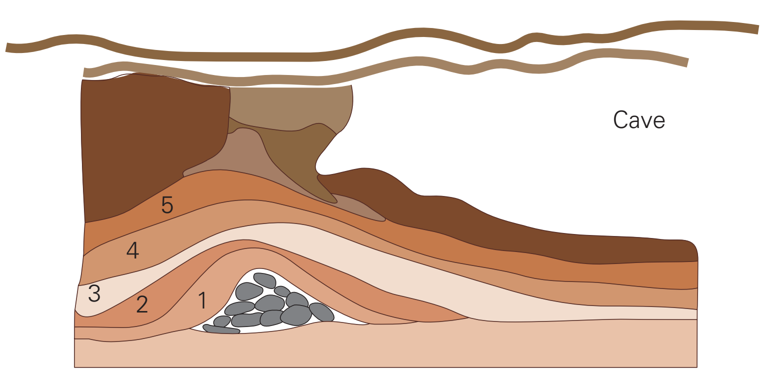


**Figure 3.64** Layers of rock within a cave

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**9** **Distinguish** between absolute and relative dating techniques.

**10** Figure 3.65 shows a timeline for the evolution of some dinosaurs. The average mass of each dinosaur is shown in brackets under its name. **Identify** the appropriate dinosaur for each statement.

- **a** The dinosaur that lived the longest time ago is the _______________.
- **b** The dinosaur/dinosaurs that evolved from *Agilisaurus* is/are the _____________.
- **c** The dinosaur from which *Camarasaurus* evolved is the _____________.
- **d** The dinosaur with the largest average mass is the _______________.

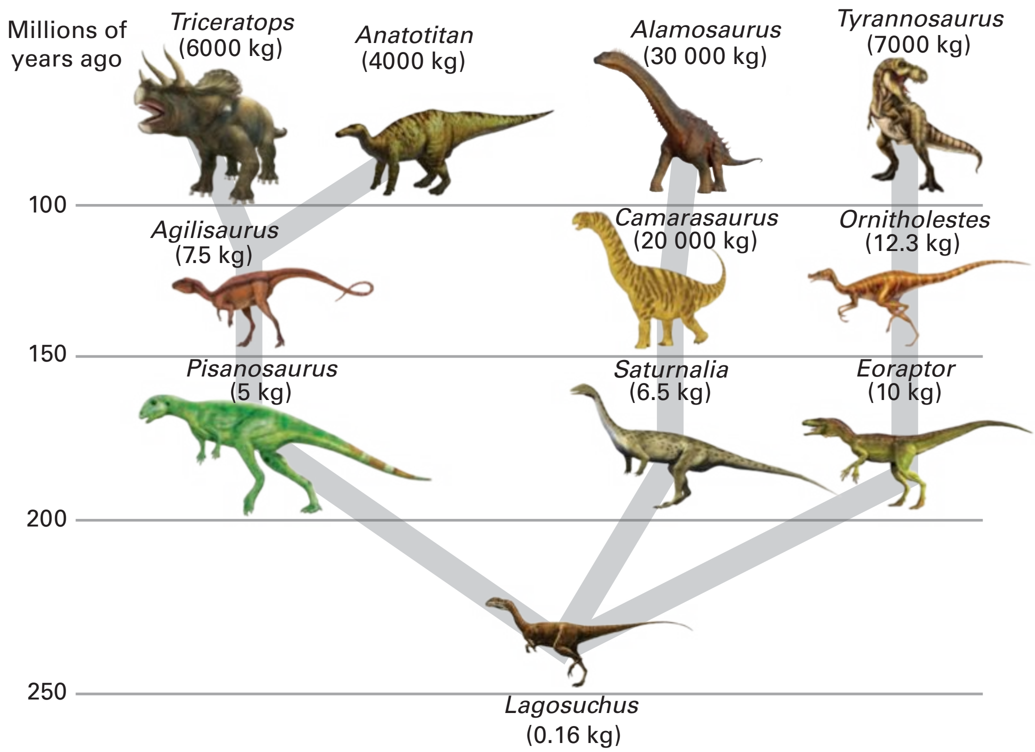


**Figure 3.65** Timeline for the evolution of some dinosaurs

**11** The chronogram in Figure 3.66 shows the evolutionary relationship between some freshwater fish.

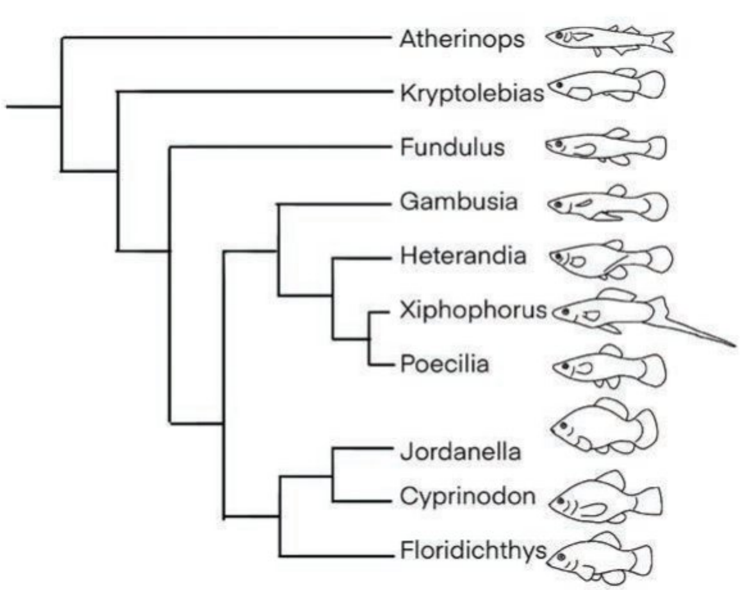


**Figure 3.66** Chronogram showing evolutionary relationship between some freshwater fish

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a **Infer** which genus is most distantly related to *Poecilia*.

b Between the genera *Cyprinodon* and *Fundulus*, **infer** which is more closely related to *Poecilia*.

**Knowledge utilisation**

12 The table below shows the number of nucleotide differences between a region of mitochondrial DNA in humans, chimpanzees and a Neanderthal.

| | Human 2 | Chimpanzee 1 | Chimpanzee 2 | Neanderthal |
|---|---|---|---|---|
| Human 1 | 15 | 77 | 76 | 20 |
| Human 2 | | 79 | 80 | 27 |
| Chimpanzee 1 | | | 23 | 72 |
| Chimpanzee 2 | | | | 71 |

a Based on the table, **deduce** which organism is most closely related to the Neanderthal.

b Based on the table, **deduce** which organism is the least closely related to the Neanderthal.

c **Decide** which method could be used to estimate the absolute age of a Neanderthal fossil.

d **Decide** which method could be used to estimate the relative age of a Neanderthal fossil.

Figure 3.67 A skull of *Homo neanderthalensis*

13 **Propose** how you would investigate whether birds are more closely related to mammals or reptiles. Include what evidence you would expect if the organisms were related or not related.

14 **Create** a concept map that shows the links between the different ways we can gain evidence for evolution. Include information on how each method sheds light on evolution.

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# Chapter review

## Chapter checklist

You can download this checklist from the Interactive Textbook to complete it.

| Success criteria | | Linked questions | Check |
|---|---|---|---|
| 3.1 | I can recall the definition of evolution. | 1 | |
| 3.1 | I can describe the five drivers of evolution (mutation, gene flow, genetic drift, natural selection, sexual reproduction). | 1, 11 | |
| 3.1 | I can describe the concept and importance of biodiversity. | 9 | |
| 3.1 | I can describe some reasons for species becoming endangered or extinct and propose ways to minimise this problem. | 18 | |
| 3.2 | I can recall the steps in the process of natural selection. | 6, 7, 14 | |
| 3.2 | I can explain how speciation occurs. | 10 | |
| 3.2 | I can distinguish between artificial and natural selection. | 12 | |
| 3.3 | I can recall the main evidence for evolution. | 3 | |
| 3.3 | I can describe how a fossil forms. | 5 | |
| 3.3 | I can describe that radiometric dating of fossils relies on nuclear decay processes. | 3 | |

## Review questions

SCORCHER

### Retrieval

1 **Define** the terms ‘evolution’, ‘gene flow’, ‘genetic drift and ‘natural selection’.

2 **Recall** the main causes of variation among organisms.

3 Scientists excavated an abandoned quarry and found a set of dinosaur footprints that could be up to 145 million years old. The trails of 90 uninterrupted prehistoric footprints are thought to have been made by a sauropod – a class of heavy dinosaurs with long necks and tails. **Recall** how the quantity of the isotope carbon-14 in a fossil can be used to accurately date a fossil.

### Comprehension

4 **Describe** what is meant by the concept of variation in the field of evolution.

5 **Describe** how a fossil found in sedimentary rock is formed.

6 **Explain** how the camouflage of organisms supports the idea of natural selection.

7 **Explain** why ‘survival of the fittest’ does not necessarily mean survival of the biggest and strongest.

8 **Explain** how amino acid sequences can provide evidence for evolution.

9 **Describe** the importance of biodiversity.

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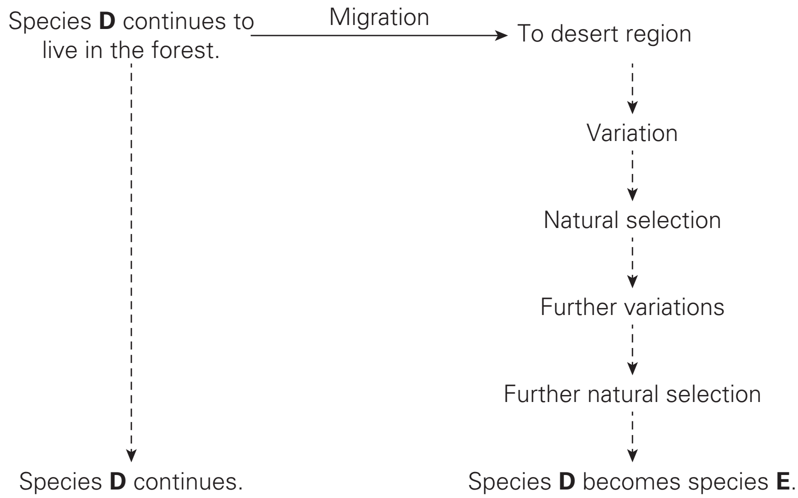
10 The following diagram represents the process of speciation.



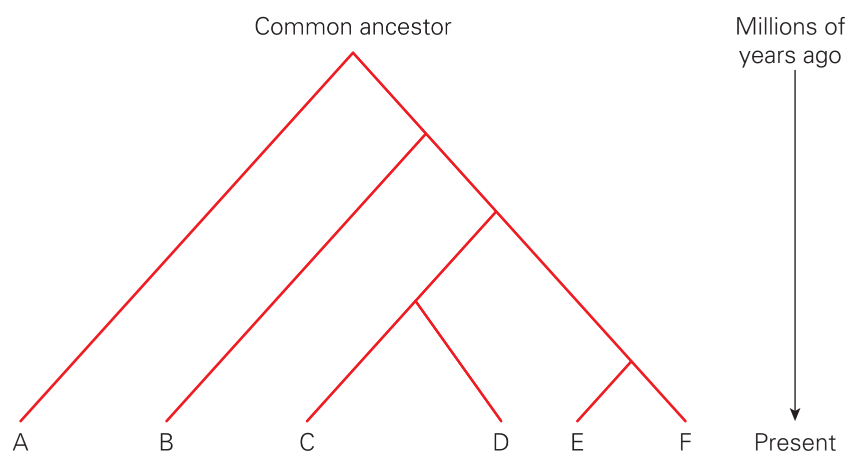

**Explain**, using the information from the diagram, the key drivers behind the creation of the new species E in the desert.

11 **Explain** how mutations contribute to the process of evolution.

**Analysis**

12 **Critique** the process of artificial selection.

13 The following diagram shows the evolutionary tree for six organisms from a common ancestor.




- **a** According to the diagram, **identify** the present-day organism that is least closely related to the others. Justify your response.
- **b** **Infer** which two organisms have the most recent common ancestor, giving reasons for your response.

**Knowledge utilisation**

14 Using diagrams, **discuss** how rabbits may have become resistant to the deadly myxoma virus, which was released in Australia to try to control rabbit populations.

15 **Discuss** how scientists use information gained from sedimentary rock to arrange fossils into an evolutionary sequence over time.

16 **Propose** a reason why members of the new species E shown in Question **13** cannot breed successfully with species D.

17 **Decide** why scientists want to find out about evolution.

18 **Discuss** why we should conserve species.

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## Data questions

### Apply

*Geospiza fortis* is a ground finch that feeds on seeds on Daphne Major, one of the Galapagos Islands. From 1975 to 1977, the island experienced a severe drought. The graphs in Figure 3.68 show features of the *G. fortis* population and the island's seed supply during these years.

1 **Calculate** the percentage decrease in population size between July 1975 and December 1977.

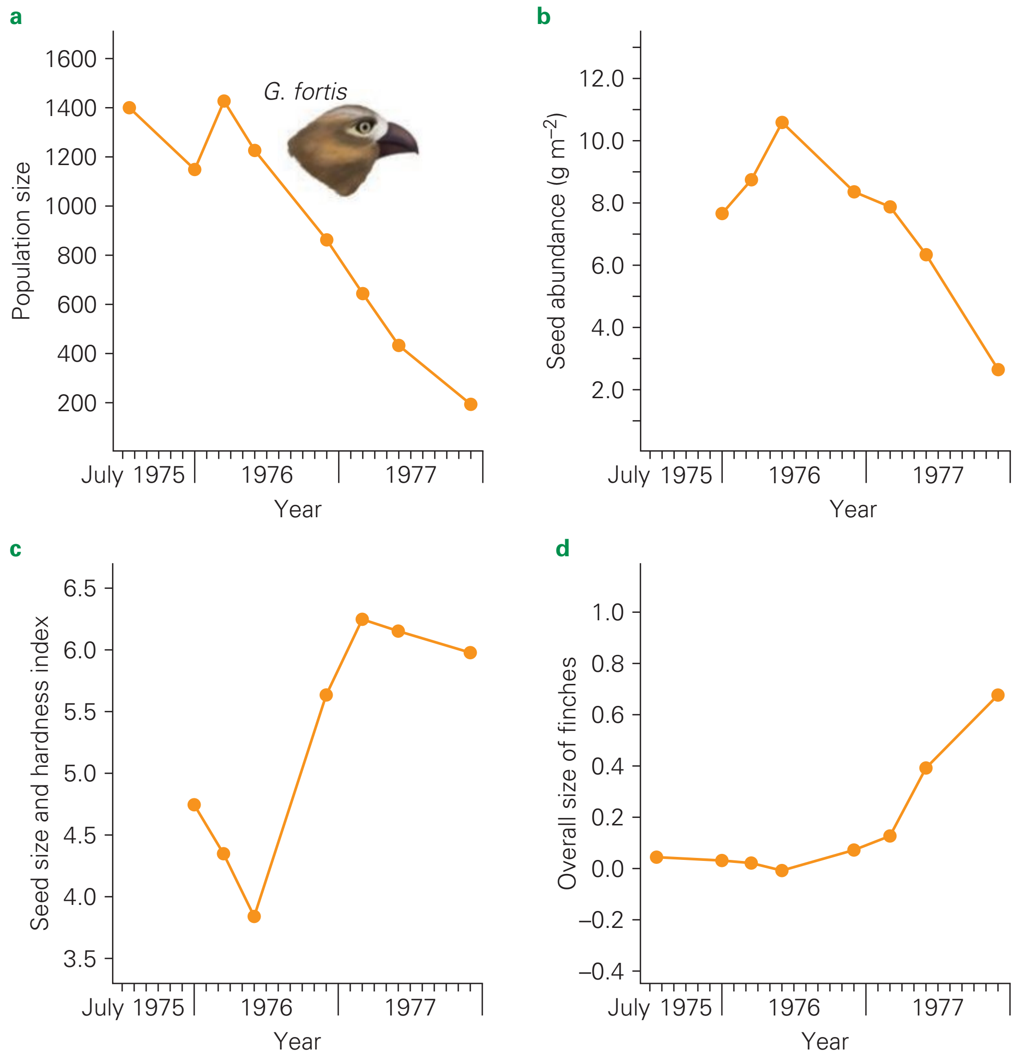


**Figure 3.68** Features of the *Geospiza fortis* population and the seed supply on Daphne Major

### Analyse

2 **Identify** any relationships you can find in the graphs.

### Interpret

3 **Infer** why the size of the finches increased as the drought continued.

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# STEM activity: Designing a wheelchair to aid dogs with genetic problems

## Background information

Individuals in a species become well adapted to their environment by the process of natural selection. In this process, individuals with characteristics that allow them to thrive in the environment are selected for, and they pass their suitable genes onto subsequent generations. However, individuals within a species being too similar genetically can be detrimental to a species' survival. If the environment changes, genetic variation within a species gives it a better chance of survival because there are individuals that can cope better with the changed environment. A lack of genetic variation can result in extinction from an environmental change.

Inbreeding occurs when genetically similar individuals from a species breed with each other. There are many examples of inbreeding in humans and other species that are bred selectively, like dogs. In these cases, the problem is not that a population could be wiped out by an environmental change, but that genetic conditions that would be very rare in wider populations continue to be passed onto subsequent generations.

A famous example of this occurred with haemophilia, a condition resulting from a mutation on the X chromosome. In people with this condition, blood does not clot properly, so injury can cause excessive bleeding. Haemophilia spread throughout European royal families in the 19th and 20th centuries because of arranged marriages among the related royal families.

Humans have bred dogs for thousands of years, originally to serve a specific purpose or job like herding and hunting. All modern dog breeds exist because of human selective breeding. Unfortunately, many pure-bred dogs suffer from genetic conditions because of inbreeding. For example, pure-bred dachshunds commonly suffer from knee problems because of their short legs and non-ideal angle for the knees. They also often have hip dysplasia and spinal problems because of their long bodies, and eye problems like cataracts.

**Figure 3.69** Left: Dachshunds are prone to numerous genetic diseases because their signature long bodies and tiny legs were developed by inbreeding. Right: Dachshunds are not the only dog breed that may need the aid of a wheelchair.

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While dog owners can take preventive measures to reduce the effects of these disorders, often reactive treatment is the method used to give affected dogs a good quality of life. Wheelchairs are a potential solution to help with mobility for dachshunds that have hip and knee problems.

**Design brief:** Design a wheelchair to aid dachshunds with genetic knee and hip problems.

## Activity instructions

In small groups, research the features of dog wheelchairs. You may like to put together a collection of different designs to help you decide which features you would like to include in your own design.

Draw your chosen design and label its features and the materials you intend to use. You will need to consider the method of attaching the wheelchair to the dog and whether the dog's legs will hang down or be supported on a platform. You will also need to think about the best way to make it comfortable for the dog. Some research into the specific genetic problems occurring in dachshunds may be necessary to make sure you are catering for the dogs' needs.

Your wheelchair will need to be sturdy, so remember to use appropriate shapes and bracing to achieve the right strength for your design.

## Suggested materials/presentation formats

- cardboard
- fabric/felt
- glue
- scissors
- wheels
- icy-pole craft sticks
- elastic bands
- straws
- sticky tape

## Research and feasibility

1 Research and list all the features that make a wheelchair comfortable and functional.

| Feature | Functionality |
|---|---|
| e.g. padded seat | Comfortable to use for long amounts of time |
| | |

2 Research current dog wheelchairs available and how they are used for dogs with hip and knee problems. List all the problems that exist with current models and solutions that could be included.

3 Research the dachshund breed and make note of the size of the dogs and their common hip and knee problems.

## Design and sustainability

4 Design a prototype of a wheelchair specifically for a dachshund. Annotate your diagram and include all design features and the functionality it provides.

5 Reflect on the sustainability of the materials used, and the life cycle of the wheelchair prototype regarding its durability.

## Create

6 Construct the prototype using available materials.

## Evaluate and modify

7 Describe any difficulties you came across when constructing your model. Explain how you overcame these difficulties.

8 Propose some improvements to the design of your wheelchair to improve comfort and functionality.

9 Depending on the size of your model, you may be able to test it by using your wrist or palm as the back of the dog and your index and middle fingers as the front legs to pull it along. Test it with different amount of downward pressure to represent different dog sizes and weights. Comment on how your wheelchair fared in your tests.

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# Chapter 4
# The universe

## Chapter introduction

Ranging from subatomic particles to the expanding universe, no other branch of science has the overall scope of astronomy. It has ancient origins and yet is still advancing. In this chapter, you will learn about our position in the universe, how the universe began and what it is made of. You will consider how stars evolve and the ways we use technology to observe and learn about space.

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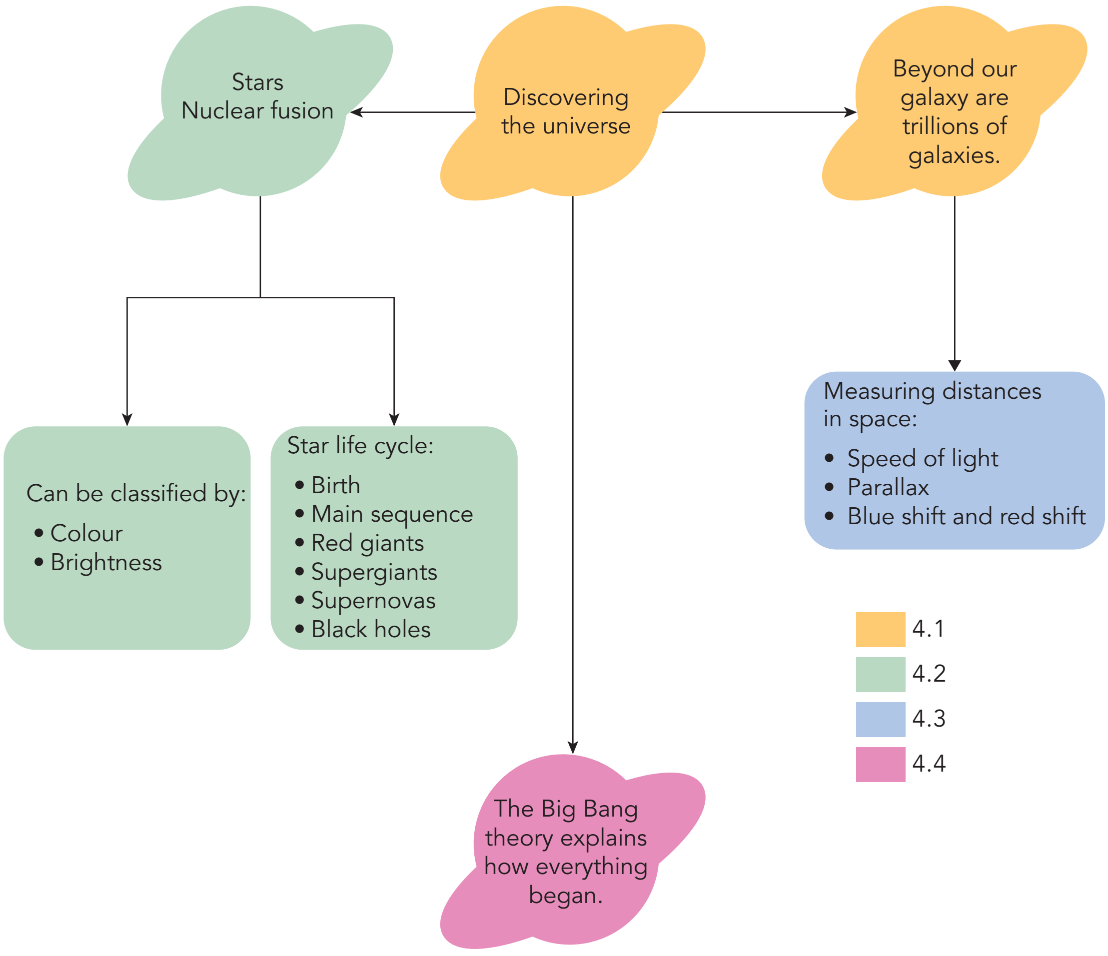
# Concept map

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## Curriculum

| | |
|---|---|
| Describe how the big bang theory models the origin and evolution of the universe and analyse the supporting evidence for the theory (AC9S10U03) | |
| researching First Nations Australians' knowledges of celestial bodies and explanations of the origin of the universe | 4.1 |
| exploring recent advances in astronomy, including the Australian Square Kilometre Array Pathfinder, and astrophysics, such as the discovery of gravitational waves, dark matter and dark energy; and identifying new knowledge which has emerged | 4.1 |
| identifying the different technologies used to collect astronomical data and the types of data collected | 4.1 |
| examining how stars' light spectra and brightness is used to identify compositional elements of stars, their movements and their distances from Earth | 4.2 |
| describing the major components of the universe using appropriate scientific terminology and units including astronomical units, scientific notation and light-years | 4.3 |
| constructing a timeline to show major changes in the universe which are thought to have occurred from the Big Bang until the formation of the major components such as stars and galaxies | 4.4 |
| explaining how each different type of evidence, such as cosmic microwave background radiation, red or blue shift of galaxies, Edwin Hubble's observations and proportion of matter in the universe, provides support for the acceptance of the big bang theory | 4.3, 4.4 |



## Glossary terms

Absorption spectrum
Arcsecond
Astronomical unit
Baseline
Big Bang
Black hole
Blue shift
B–V colour index
Constellation
Continuous spectrum
Cosmic microwave background
Dark energy
Dark matter
Doppler effect
Emission spectrum
Epoch of recombination
Exoplanet
Galaxy
Geocentric
Goldilocks zone
Heliocentric
H–R diagram
Hubble's law
Interferometry
Light year
Luminosity
Main sequence
Nuclear fusion
Observable universe
Optical telescope
Parallax
Parsec
Radio telescope
Recessional velocity
Red giant
Red shift
Retrograde motion
Singularity
Spectral class
Supernova
White dwarf

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# 4.1 Discovering the universe

WORKSHEET
Discovering the universe

WIDGET
Timeline of the universe

VIDEO
The Big Bang

**Learning goals**

1. To understand First Nations Australians' knowledges of celestial bodies and explanations of the origin of the universe.
2. To explore recent advances in astronomy.
3. To be able to identify the different technologies used to collect astronomical data and the types of data collected.

First Nations Australians were probably some of the first humans to name the celestial objects in the night sky and are sometimes called the 'world's first astronomers'. They have a rich and intricate astronomical knowledge that informs various aspects of their culture and society, including navigation, weather prediction, calendars, cultural identity and storytelling.

First Nations Australians' understanding of the origin of the universe differs between different communities. For example, in many First Nations cultures, the Sun is represented by a female goddess. However, in some areas she is known as Alinga, in others Wuriupranili. In south-east Australia she is Gnowee, who lost her son when the world was still dark. She lights a torch and climbs the sky each day looking for him. In northern Australia, she is known as Wala, who travels across the sky each day. In the west, Bila is a cannibal Sun goddess, roasting humans over a fire that provided light for the world. The different interpretations of the Sun goddess story reflect the importance of the Sun and its role in providing light and warmth to the world, as well as its link to fertility and life. Despite the variations in the stories, the Sun goddess is an important part of the cultural heritage of First Nations Australians.

Many **constellations** are associated with stories, and these differ between communities. First Nations Australian astronomy not only identifies stars and constellations by their brightness, but also from patterns originating from the dark clouds.

**constellation**
a group of stars as seen from Earth that appear to form a familiar shape

## Did you know? 4.1

**Stories based on fact**

Experts believe that many of the Dreaming stories relate to real events. For example, giant spirit animals in some of the stories could be the megafauna that the original inhabitants of Australia encountered thousands of years ago.

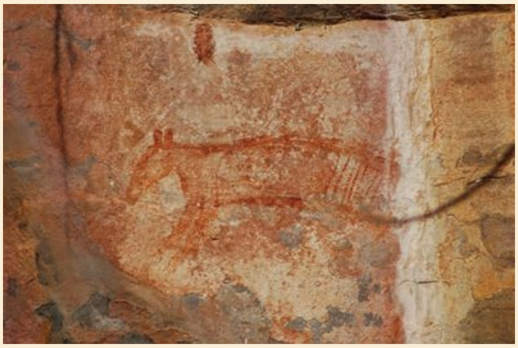

**Figure 4.1** First Nations Australian rock art depicting a thylacine (*Thylacinus cynocephalus*). Thylacines coexisted with humans alongside megafauna for many thousands of years, but were extinct on the mainland by the time of European colonisation.

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## Explore! 4.1

### Constellations

Some Dreaming stories describe the ancestral beings who created the cosmos, including the stars, Moon, Sun and other celestial bodies.

The Seven Sisters, also known as the Pleiades, is a star cluster in the constellation Taurus. The Seven Sisters are culturally important to First Nations Australians. Although the star Dreaming story varies between Indigenous groups, it generally describes seven sisters who are pursued by a man and transformed into stars to escape him. In some versions, the man is an ancestral being who wants to marry the sisters, while in others he is a hero who is trying to catch the sisters for their own good.

Research First Nations Australians' knowledges of celestial bodies and explanations of the origin of the universe.

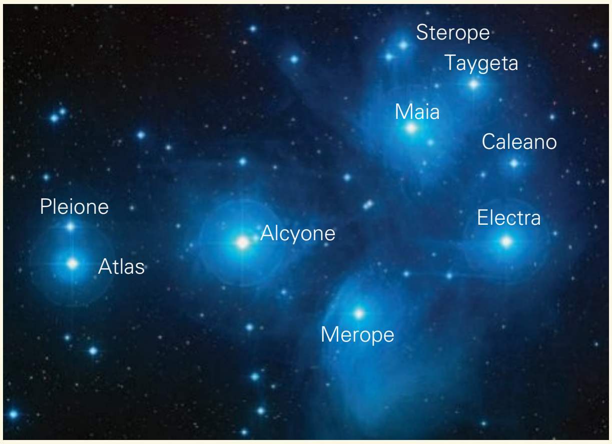


**Figure 4.2** The Pleiades is located approximately 400 light years from Earth in the Taurus constellation. In Greek mythology, Atlas and Pleione are the parents of the seven sisters.

**Figure 4.3** Painting of the Seven Sisters Dreaming story by First Nations Australian artist Mona Mitakiki

Constellations were important in early human migration and thereby shaped the modern world. Today, astronomers and astrophysicists use advanced technology to make their observations. However, astronomy is a field of science where you do not have to be a professional to take part. An Australian amateur astronomer, Thiam-Guan Tan, discovered a distant planet orbiting a star 40 light years away from Earth from his backyard. The planet is thought to be one of billions of other planets that are 'habitable', in other words, able to support life.

**geocentric** a model of the solar system with Earth at the centre

## Other early astronomers

The early astronomers relied on the naked eye to make observations about the positions of celestial objects and how they moved over time.

Claudius Ptolemy was an astronomer in the 2nd century who suggested that Earth was at the centre of the universe. He proposed a **geocentric** model in which all celestial objects orbited around Earth. It is easy to see why he suggested this model, given that the Sun, stars and Moon all appear to rise in the east, follow a circular pattern while they are up, and then set in the west.

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There was one main problem with Ptolemy's geocentric model. At different points in the year, the motion of the planets across the sky appear to go backwards for a few days. This is called **retrograde motion** and could not happen if the planets orbited Earth.

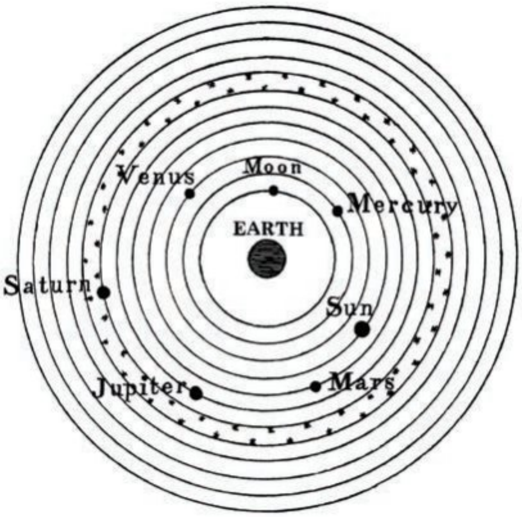


Figure 4.4 The geocentric model proposed that Earth was the centre of the universe, with the planets and stars orbiting around it.

In the early 1500s, Nicolaus Copernicus proposed a **heliocentric** model of the solar system, in which the planets revolved around the Sun. This could explain the retrograde motion of the planets.

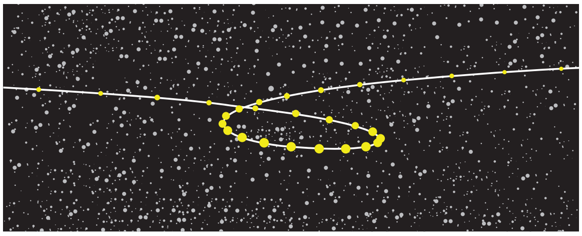

Figure 4.5 Retrograde motion of Mars across the sky as seen from Earth

With the invention of the telescope in the 1600s, Galileo Galilei was able to observe the four largest moons of Jupiter and could confirm that they were orbiting that planet.

**retrograde motion**
apparent backwards motion of a planet as seen from Earth

**heliocentric**
a model of the solar system with the Sun at the centre

Telescopes changed the world of astronomy in a huge way. They allowed us to see the outer planets of the solar system, the moons of other planets, stars which are invisible to the naked eye and galaxies beyond our own Milky Way.

## Quick check 4.1

1. What celestial object is at the centre of a geocentric model?
2. What celestial object is at the centre of a heliocentric model?
3. How can the circular path of the Sun and stars across our sky each day be explained?
4. Who are known as the 'world's first astronomers'?

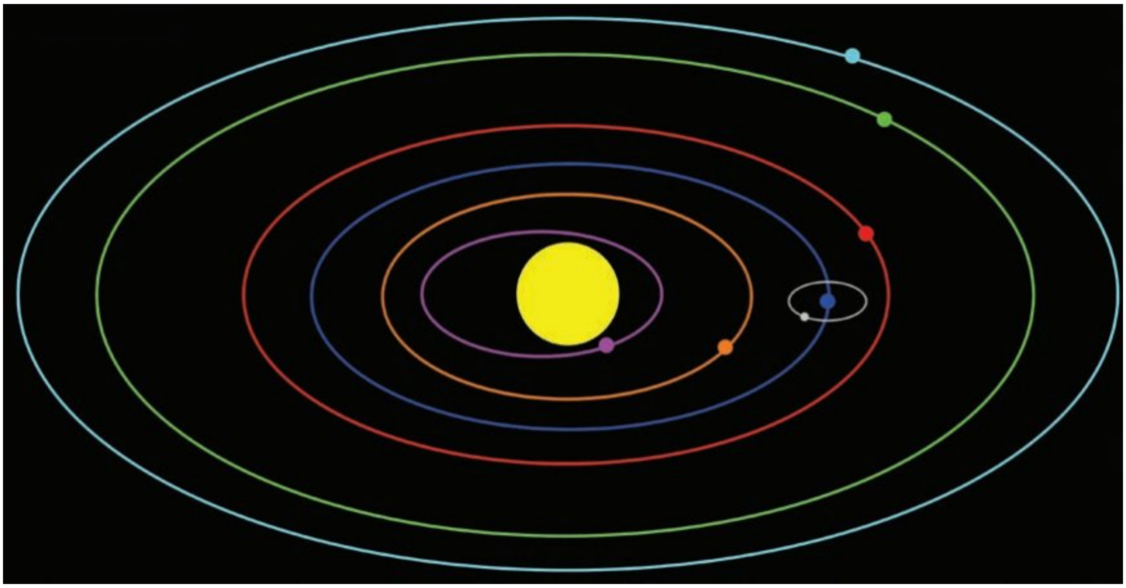

Figure 4.6 The heliocentric model proposes that planets revolve around the Sun, rather than around Earth.

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## Modern-day astronomy

Modern-day astronomers have amazing technology to work with and use a variety of technologies to collect astronomical data as shown in Table 4.1.

**interferometry** a technique that uses the interference of waves to measure distances

| Technology | Description |
| --- | --- |
| Telescopes | Observe radiation across the electromagnetic spectrum. Optical telescopes and radio telescopes are the most commonly used.<br><br>**Figure 4.7** The Parkes radio telescope in New South Wales was used to receive live television images of the Apollo 11 Moon landing in 1969. |
| Spectroscopy | Measures the amount and distribution of light at different wavelengths. It provides information about the chemical composition and temperature of celestial objects. |
| Photometry | Measures the brightness of celestial objects to study their physical properties, such as size and temperature, as well as their distance from Earth |
| **Interferometry** | Creates high-resolution images using multiple telescopes to work together as a single, larger telescope to observe the interference of light or radio waves<br><br>**Figure 4.8** The Northern Extended Millimeter Array (NOEMA) located in the French Alps. During observations, the multiple antennas work as a single telescope. |

**Table 4.1** Technologies used in astronomy

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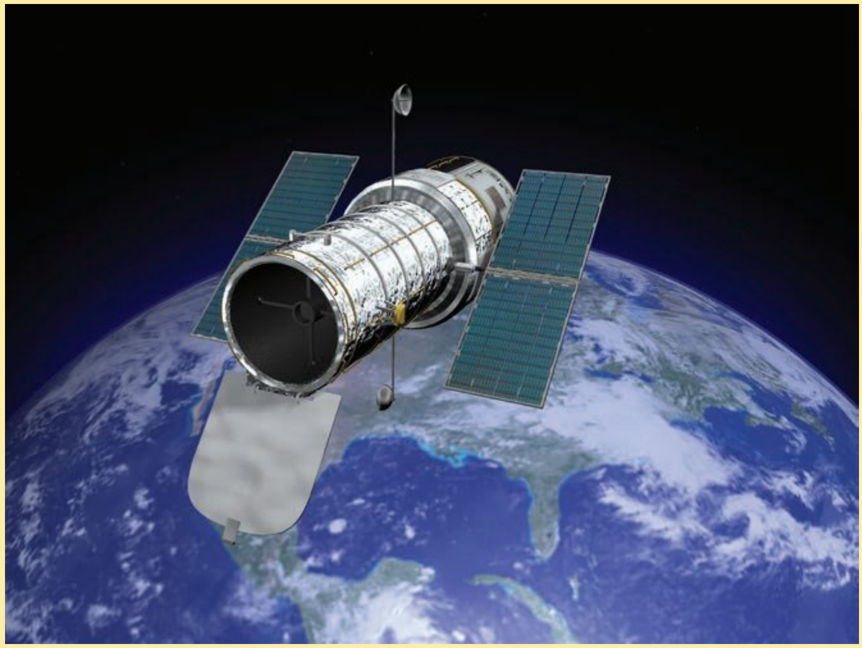
| Technology | Description |
| --- | --- |
| Space-based observatories | Allow astronomers to observe celestial objects without the interference of Earth's atmosphere<br><br>**Figure 4.9** The Hubble Space Telescope is a space-based observatory that can observe the light from distant galaxies without the dimming effects of Earth's atmosphere. |

**Table 4.1** *(Continued)*

Table 4.2 shows the data collected by these astronomical technologies.

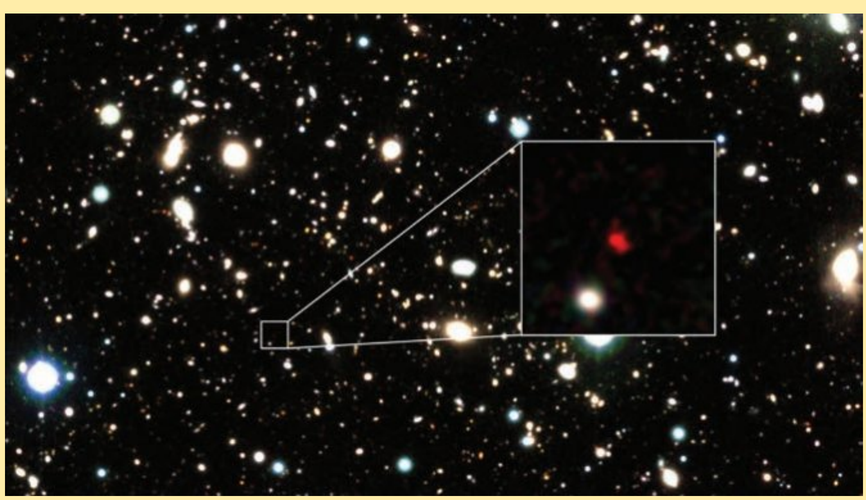
| Data | Description |
| --- | --- |
| Imaging data | Provides information about appearance and position of celestial objects<br><br>**Figure 4.10** A three-colour image of HD1 galaxy, which is the red spot in the centre of the zoom box. In April 2022, HD1 was the most distant galaxy ever identified (at a distance of 13.5 billion light years). The image was created using data from four telescopes around the world. |

**Table 4.2** Types of astronomical data

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<table>
<tr><th>Data</th><th>Description</th></tr>
<tr><td>Spectral data</td><td>Provides information about the chemical composition and physical properties of celestial objects, such as temperature and density

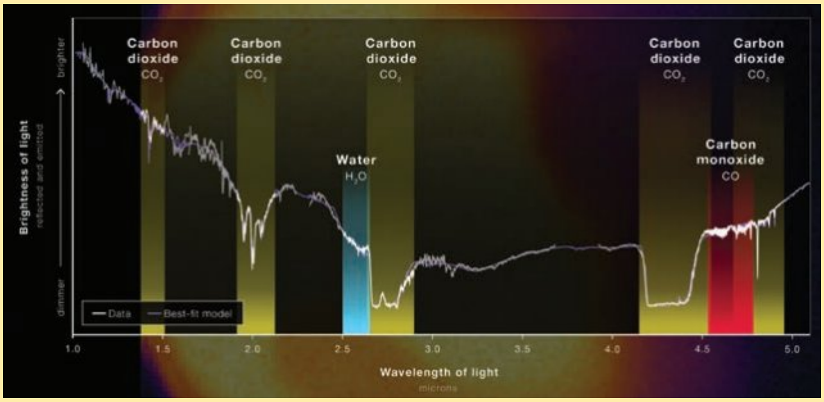


**Figure 4.11** This spectrum of Mars combines data measured by the James Webb Space Telescope NIRSpec instrument. NIRSpec stands for near-infrared spectrograph. Spectra like this are created when light is split apart, producing the signatures of water, carbon dioxide and carbon monoxide in Mars's atmosphere.</td></tr>
<tr><td>Photometric data</td><td>Provides information about the brightness of celestial objects

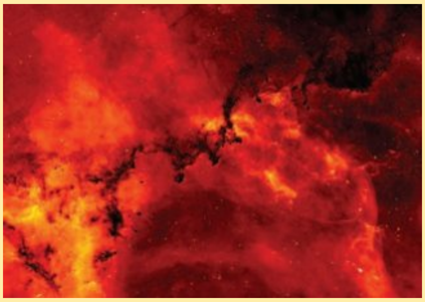

**Figure 4.12** A view of the Rosette Nebula obtained from the Isaac Newton Telescope (INT) Photometric H-Alpha Survey (IPHAS). The red colour comes from hydrogen.</td></tr>
<tr><td>Polarimetric data</td><td>Provides information about the polarisation of light from celestial objects, which can be used to study magnetic fields and the properties of dust and gas

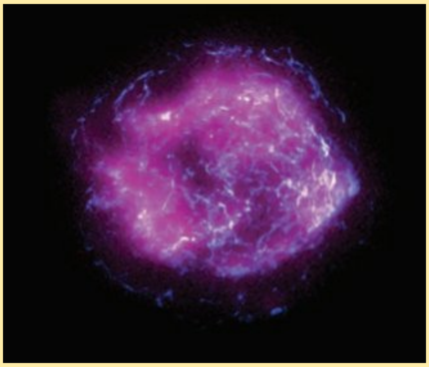

**Figure 4.13** In 2022, astronomers measured and mapped polarised X-rays from the remains of an exploded star called Cassiopeia A using NASA's Imaging X-ray Polarimetry Explorer (IXPE).</td></tr>
</table>

**Table 4.2** *(Continued)*

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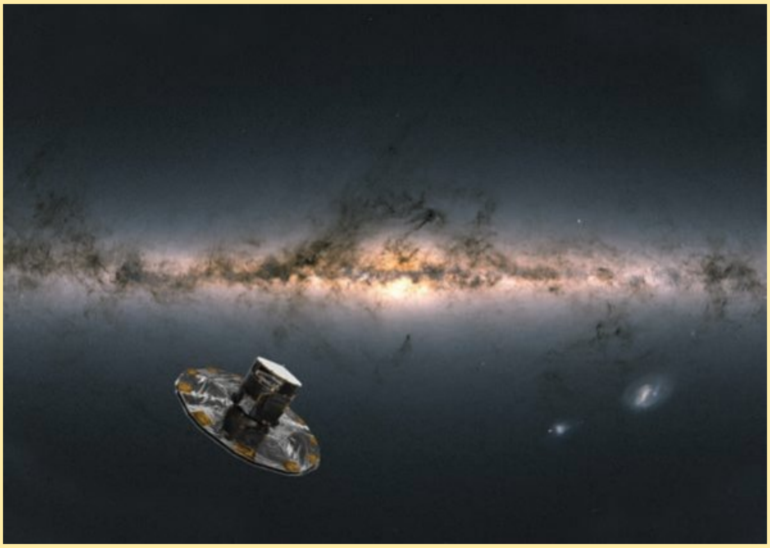
| Data | Description |
|---|---|
| Astrometric data | Provides information about the position and motion of celestial objects, to determine their distances, motions and orbits  **Figure 4.14** Gaia is a space observatory of the European Space Agency (ESA) that is designed to measure the positions, distances and motions of stars. |

**Table 4.2** *(Continued)*

## Telescopes

Modern telescopes have become larger and larger to allow us to see further into space. In 1995, the Hubble Space Telescope was pointed towards a region of space previously thought to be empty. The photo produced after two days showed multitudes of galaxies that had never been observed before. It further demonstrated the enormous size of the universe.

To minimise the effects of light pollution and the distorting effects of the atmosphere completely, the Hubble Space Telescope was launched into Earth's orbit and is controlled remotely from the ground. It has been instrumental in developing our understanding of the universe and the Big Bang.

The first telescopes were **optical telescopes**, which use lenses to collect light and focus it for the eye to see. The larger the diameter of the lens, the more light that can be collected and the further you can see. But, as telescopes got larger, the size of the glass lenses required reached the point where they became too heavy. Sir Isaac Newton first used polished mirrors instead of lenses to collect and focus light in 1668. The Very Large Telescope (VLT) array in Chile has mirrors 8.2 metres in diameter, and the Extremely Large Telescope (ELT) under construction in Chile will have a mirror 39.3 metres in diameter upon its completion in 2026. Optical telescopes are built in regions of low rainfall to avoid clouds and must be positioned far away from light pollution and at a high altitude to minimise the effects of the atmosphere.
The the best optical telescopes are located on high mountains in Chile and Hawaii.

**optical telescope**
a device that collects and focuses light from the visible spectrum to form an image

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**radio telescope** a device that receives radio waves emitted by stars and other celestial objects

VIDEO The square kilometre array

**Figure 4.15** A portion of the Hubble Ultra Deep Field image, taken over a period of months from 2003 to 2004 (top). More detailed than the original Deep Field image from 1995, the full image covers a tiny portion of the sky and yet shows approximately 10 000 galaxies, many of which contain billions of stars. The new James Webb Space Telescope captured much greater detail again in 2022 (bottom).

**Radio telescopes** gather information in the form of radio waves. Radio telescopes follow the same principle as optical telescopes in that they collect signals and reflect them inwards to focus them, but the reflective surfaces do not need to be polished mirrors. This means that radio telescopes can be made much larger than optical telescopes. Multiple radio telescopes can also be linked together to look even further into space.

The Australian Square Kilometre Array Pathfinder (ASKAP) in Western Australia is a precursor radio telescope that was built to test the technology that will be used in the construction of the full Square Kilometre Array (SKA) Observatory in Australia and South Africa. Composed of 36 dishes and completed in 2012, ASKAP's purpose was to demonstrate the feasibility of the SKA Observatory project.

The SKA radio telescope is expected to be completed in Western Australia in 2028. It will be made up of thousands of dishes whose total collection area will be bigger than one square kilometre (or one million square metres). An artist's impression of the SKA Observatory is shown in Figure 4.17.

**Figure 4.16** The Square Kilometre Array Pathfinder is made up of 36 identical 12-metre dishes.

**Figure 4.17** The Square Kilometre Array Observatory has the potential to look further into space than has ever been possible before.

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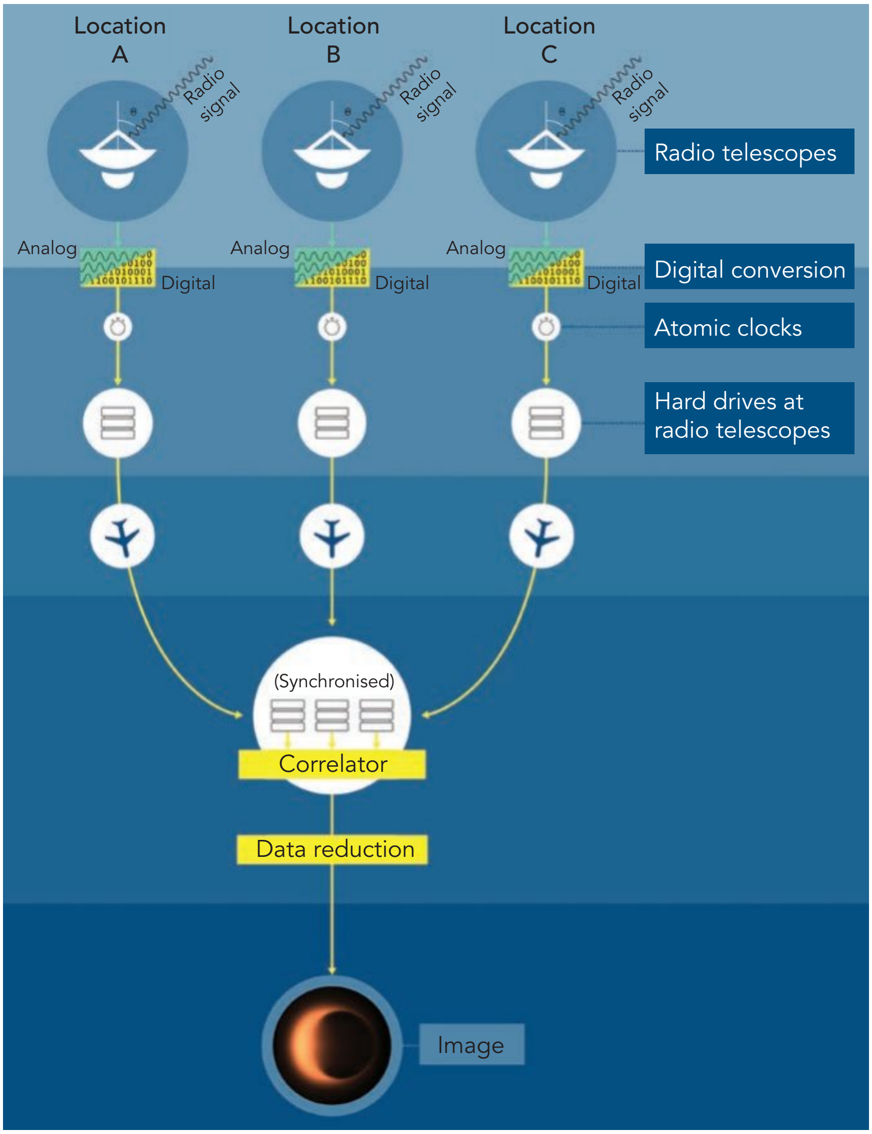


**Figure 4.18** VLBI allows multiple antennas to collect signals which are then converted to digital signals and stored in hard drives. These are then processed at a central location to create an astronomical image.

The Event Horizon Telescope (EHT) is an international collaboration of radio observatories. It captures images of black holes using very-long-baseline interferometry (VLBI) techniques. This allows the participating radio telescopes located around the world to work together as if they were a single telescope. This collective power allows the EHT to achieve a higher angular resolution, making it possible to observe black holes and their properties. The Earth's atmosphere only allows light and radio waves through; it blocks the other parts of the electromagnetic spectrum. The ability to place telescopes in space lets astronomers explore the universe by imaging other wavelengths, such as infrared, ultraviolet and gamma rays.

### Quick check 4.2

1 Name the two main types of telescopes and recall which part of the electromagnetic spectrum they detect.
2 Recall where the best telescopes are located.
3 Why is interferometry so useful?

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## Did you know? 4.2

**The James Webb Space Telescope**

The James Webb Space Telescope is the largest optical telescope humans have sent out into space. It can gather light that has been travelling for 13.5 billion years, almost since the beginning of the universe. It is essentially a time machine, allowing us to observe the first galaxies to form after the Big Bang and how they evolved. As it detects infrared light using a Near-Infrared Camera (NIRCam), it can also see through dust clouds and view objects too old, distant or faint for the Hubble Space Telescope.

**Figure 4.19** The James Webb Space Telescope has revealed details about the Tarantula Nebula. Young stars can be seen in pale blue at the centre of the image, while stars that are still developing are shown in red. NIRCam can detect these dust-enshrouded stars due to its resolution at near-infrared wavelengths.

QUIZ

## Section 4.1 questions

### Retrieval

1 **Recall** the reason that most observatories are located in remote areas and at high altitudes.

2 **Name** the data collection method where two or more telescopes are used together.

### Comprehension

3 **Explain** the advantages and disadvantages of having a telescope in space.

4 **Illustrate** a diagram to show the purpose of the large dish on the Parkes radio telescope.

### Analysis

5 **Contrast** the geocentric and heliocentric models and explain why the motion of the planets as observed on Earth supports the heliocentric model.

### Knowledge utilisation

6 **Discuss** the improvements in technology since early astronomers that have allowed us to look further and further into space.

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# 4.2 Stars

**Learning goals**

1. To be able to describe how stars' light spectra and brightness are used to identify compositional elements of stars, their movements and their distances from Earth.

WORKSHEET
Stars

VIDEO
Star life cycle

With the exception of hydrogen and a small amount of helium produced during the Big Bang, everything that comprises us and the Earth was formed within stars, either through ongoing fusion processes or during supernova explosions.

## Nuclear fusion

Many people will describe the Sun and other stars as big balls of burning gas. That is a rather oversimplified explanation of how they produce their energy. In reality, their energy comes from a process called **nuclear fusion**.

Nuclear fusion occurs when two atoms combine (or fuse) to create a new element. Because it is so hot inside the cores of stars, hydrogen nuclei have enough energy to overcome the electrostatic repulsion between their protons. They fuse together to form helium, and an enormous amount of energy is released in the process.

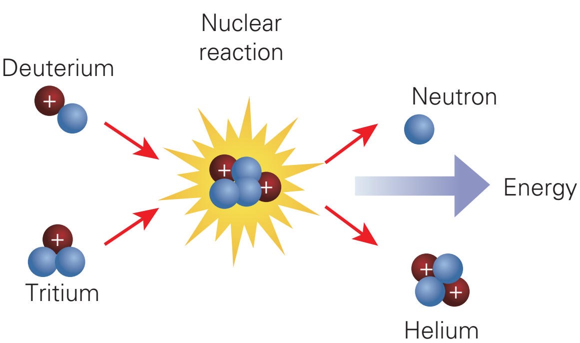


**Figure 4.20** One step in the fusion of hydrogen happens when the isotopes deuterium (one proton and one neutron) and tritium (one proton and two neutrons) fuse together. A neutron is released and a helium nucleus is formed (two protons and two neutrons).

## Star colour and temperature

When you look at stars in the night sky, you will notice that they vary in colour. The colour of a star is related to its temperature: blue stars are the hottest and red stars are the coolest. Stars are given a **spectral class** letter based on their temperature and colour (Table 4.3). They were originally classified alphabetically starting at A, but some letters were skipped and others reordered as more was discovered about star surface temperatures. Our Sun is a relatively small yellow star with a surface temperature of around 6000 kelvin (K), so is classified as a G-type star.

**nuclear fusion**
the process of joining two nuclei to produce energy

**spectral class**
a group into which stars are classified based on their spectra

| Colour | Star temperature (K) | Spectral class |
|---|---|---|
| Blue | >30 000 | O |
| Blue white | 10 000 to 30 000 | B |
| White | 7500 to 10 000 | A |
| Yellow white | 6000 to 7500 | F |
| Yellow | 5200 to 6000 | G |
| Orange | 3700 to 5200 | K |
| Red | 2400 to 3700 | M |

**Table 4.3** Temperatures and spectral classes of stars of different colours

## B–V colour index

Most stars look white, but a few, such as Betelgeuse, seem to have a very slight reddish tinge. So how do we know what the colours of stars are? Astronomers measure the brightness of stars through different coloured filters. They subtract the amount of light that comes through a green filter (called the visual filter)

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**B–V colour index**
the difference in brightness measured through blue and green filters, indicating the colour of a star

from the amount of light that comes through a blue filter. This is called the **B–V colour index**. The lower (or more negative) the number, the bluer the star, and the higher (or more positive) the number, the redder the star. Rigel, a large blue star, has a B–V colour index of –0.03, for example. Betelgeuse, a large red star, has a B–V colour index of 1.85.

### Quick check 4.3

1 What is the name of the process that occurs inside stars?
2 Recall what the colour of a star tells us.
3 What colour would a star be with a temperature of 5500 K?

### Explore! 4.2

**Spectral classes**
Aldebaran is the brightest star in the Taurus constellation. It is classified as an orange K-type star and has a surface temperature of around 4000 K. Research examples of stars that belong to each spectral class (O, B, A, F, G, K and M).

**continuous spectrum**
a continuous range of colours (wavelengths)

**absorption spectrum**
a spectrum showing dark lines representing specific wavelengths that have been absorbed by a substance

**emission spectrum**
a spectrum showing bright lines at wavelengths specific to emission from a substance

**luminosity**
the intrinsic brightness of a celestial object

## Light from stars

All stars emit a full range of wavelengths from the visible spectrum (colours). This means you would observe a complete rainbow if you were to split the star's light into different colours using a prism. The peak of a star's spectrum depends on its temperature. This peak wavelength is the one that the star emits most of and is the colour that we observe the star to be. You will notice that there are no green stars listed in the spectral class system. There actually are stars whose spectrum peaks are in

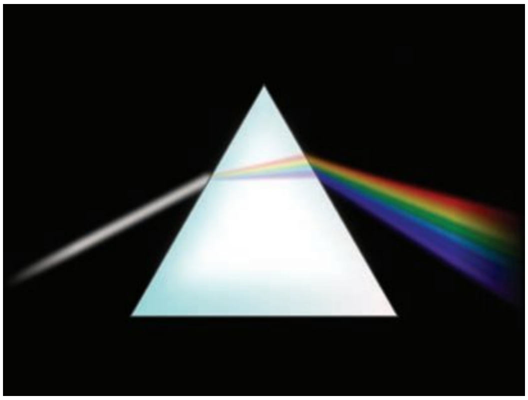

**Figure 4.21** White light consists of the full range of wavelengths (colours) from the visible spectrum.

the green part of the spectrum, but their total combination of colours emitted appears white to our eyes.

A **continuous spectrum** contains all the wavelengths and colours possible from the visible spectrum. When light passes through gas (like through an atmosphere), some of the wavelengths (colours) of light are absorbed and black lines will appear in the spectrum. This is called an **absorption spectrum**. We can compare that to light produced by the gas itself, which absorbs and emits light of a single wavelength. This produces an **emission spectrum**. Figure 4.22 shows the differences between these spectra.

## Luminosity

In general, stars that are located far away are expected to appear less bright than those that are closer. However, if you were able to observe all stars from the same distance, they would not all appear equally bright. The brightness of a star depends on its **luminosity**, and stars that produce more light are considered to be more luminous. Luminosity is measured on a scale on which our Sun has a luminosity of 1. A star with a luminosity of 100 would be 100 times brighter than the Sun when observed from the same distance.

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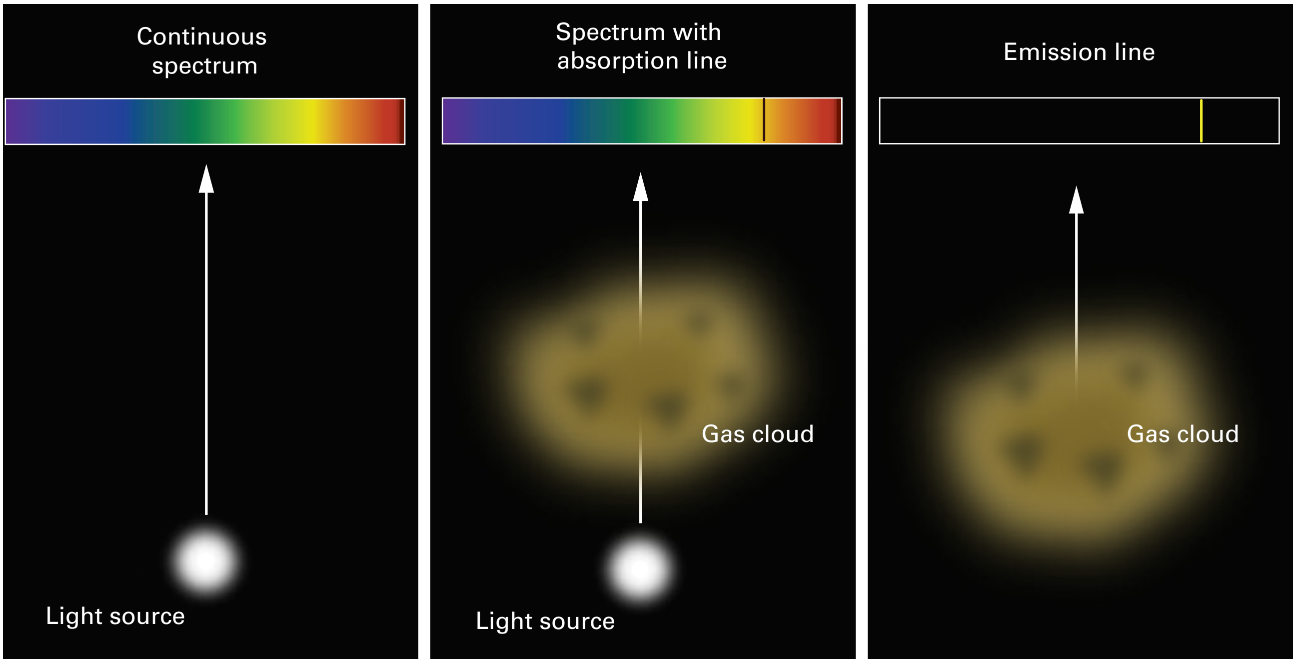


**Figure 4.22** A demonstration of how the three types of spectra are produced

## Practical skills 4.1

### Flame tests and observing emission spectra

**Be careful**
Wear appropriate personal protective equipment, including safety glasses. Wash your hands after the practical.

**Aim**

To investigate how emission spectra can be used to determine the metal in unknown substances.

**Materials**

- solutions of copper chloride, potassium chloride, sodium chloride, lithium chloride and strontium chloride
- unknown solutions labelled A, B and C (A, B and C should each contain one of the known solutions above)
- wooden splints
- Bunsen burner
- bench mat
- matches
- emission spectrometer

**Method**

**Part 1: Prepare the results table**

Copy the results table into your science journal.

**Part 2: Test the known solutions**

1 Set up the Bunsen burner with a bench mat and attach the Bunsen burner to the gas.
2 Turn on the Bunsen burner and adjust to a blue flame.

*continued …*

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*continued …*

3 Dip the wooden splint into the first known solution and place in the flame.
4 Observe the colour and record.
5 Dip the same splint into the same solution and have your partner observe the flame through the spectroscope.
6 Draw lines on the results table to match the spectral lines shown through the spectroscope. Take note of the very faint dark lines, the most notable being at wavelengths of 4.9 and 5.2 (in hundreds of nanometres).
7 Repeat steps **4–6** with the other known solutions.

**Part 3: Test the unknown solutions**

Repeat steps **4–6** and record the colour and emission spectra for the unknown solutions.

**Results**

Determine the metal present in the unknown solutions (labelled A, B and C) and record in the table by drawing lines that match the colours you see. The first row has been completed as an example.

| Solution | Flame test | Spectroscope | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Colour in flame | Colours (wavelength in hundreds of nanometres) | | | | | | |
| | | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 |
| **Known solution** | | | | | | | | |
| Copper chloride | Blue or bluish-green | | | | | | | |
| Lithium chloride | | | | | | | | |
| Strontium chloride | | | | | | | | |
| Sodium chloride | | | | | | | | |
| Potassium chloride | | | | | | | | |
| **Unknown solution** | | | | | | | | |
| A | | | | | | | | |
| B | | | | | | | | |
| C | | | | | | | | |

**Analysis**

1 Determine the identity of the three unknown solutions. Justify your statements with data.
2 At which wavelengths would you observe dark lines in the Sun's spectrum? Research which elements are found in the Sun's atmosphere that coincide with spectral lines at those wavelengths.
3 Suggest why spectra are referred to as 'fingerprints' of the stars. Explain how the data supports the statement.

## Star life cycle

Stars do not have a limitless fuel source. Most stars produce light by converting hydrogen to helium, but all stars will eventually run out of nuclear fuel and will evolve. The changes that stars go through in their lifetime is predictable and depends on their size.

### Birth of stars

Stars form inside clouds of dust and gas called molecular clouds. The dust and gas collapse under their own gravity and form a protostar. Over millions of years, a protostar stabilises and begins nuclear fusion.

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**Figure 4.23** In 2023, the James Webb Space Telescope released an image showing a young cluster of stars known as NGC 346. Located more than 200 000 light years from Earth, scientists believe it resembles the conditions of the early universe when stars were being rapidly formed.

## Main sequence stars

Stars spend most of their life in the **main sequence**. This is the phase in which they convert hydrogen into helium via nuclear fusion. Roughly 90% of known stars are in the main sequence. Our Sun is 4.6 billion years old and will spend another 5 billion years in the main sequence before it moves to its next stage.

## Red giants

As an average-sized star's hydrogen is converted into helium, the helium builds up in the core of the star. The region where hydrogen is still undergoing fusion becomes a shell around the core, and the star will gradually increase in size to become a **red giant**. For our Sun, this size increase will begin in roughly five billion years, and the red giant will envelop the first four planets in our solar system (including Earth). Nuclear fusion in the core of a red giant will then begin to fuse helium into heavier elements.

When a red giant runs out of fuel, its outer layers drift off in a planetary nebula (a cloud of gas and dust) and its core collapses into a **white dwarf**. The white dwarf will slowly cool over time and eventually be no longer visible. A star at this stage is given the name black dwarf, but it is only theoretical because a black dwarf is expected to take longer to form than the current age of the universe!

**main sequence**
the phase during which stars convert hydrogen into helium in their cores

**red giant**
a very large, bright, cool star that has run out of hydrogen in its core

**white dwarf**
a small, dense, dim star that has lost its outer layers and is at the end of its lifetime

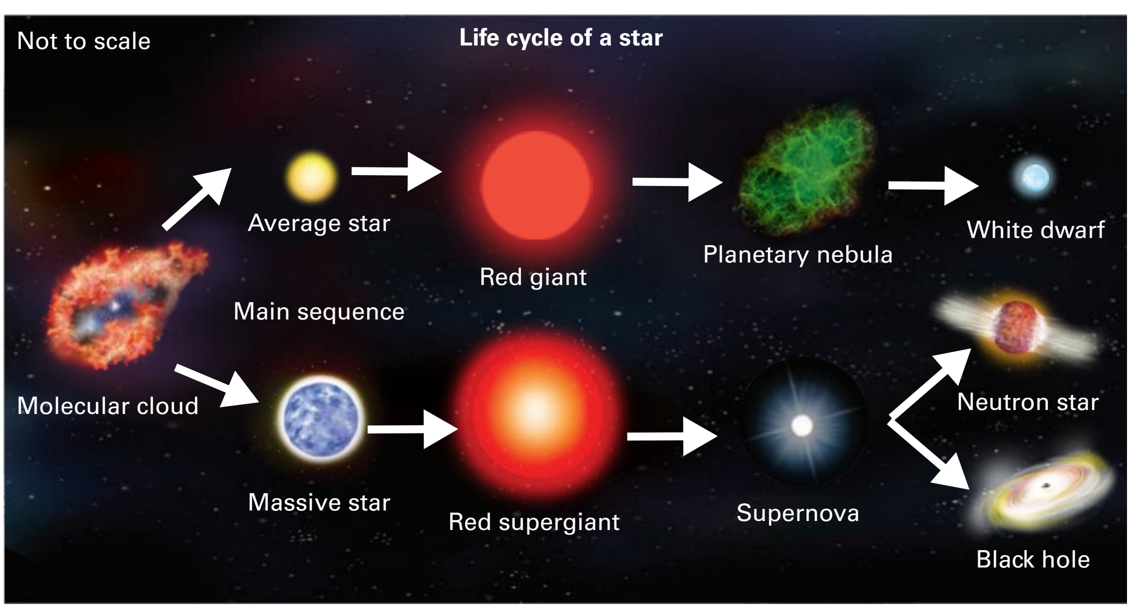


**Figure 4.24** How stars change over time depends on their size.

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## Supergiants

Stars that are more than 10 times the mass of our Sun take a different path. Massive stars have a much shorter lifespan than smaller stars like our Sun. They may be anywhere up to 50 times as massive as our Sun but can be more than a million times brighter. This means that they burn much hotter and faster than smaller stars. Massive O-type stars may only live for a few million years because they burn through their fuel so quickly, whereas the smaller K-type and M-type stars live for many billions of years.

**supernova** the explosion of a massive star

**black hole** the extremely dense remnant of a massive star; a region in space where gravity is so strong that nothing can escape, not even light

**galaxy** a gravitationally bound system containing billions of stars and planets

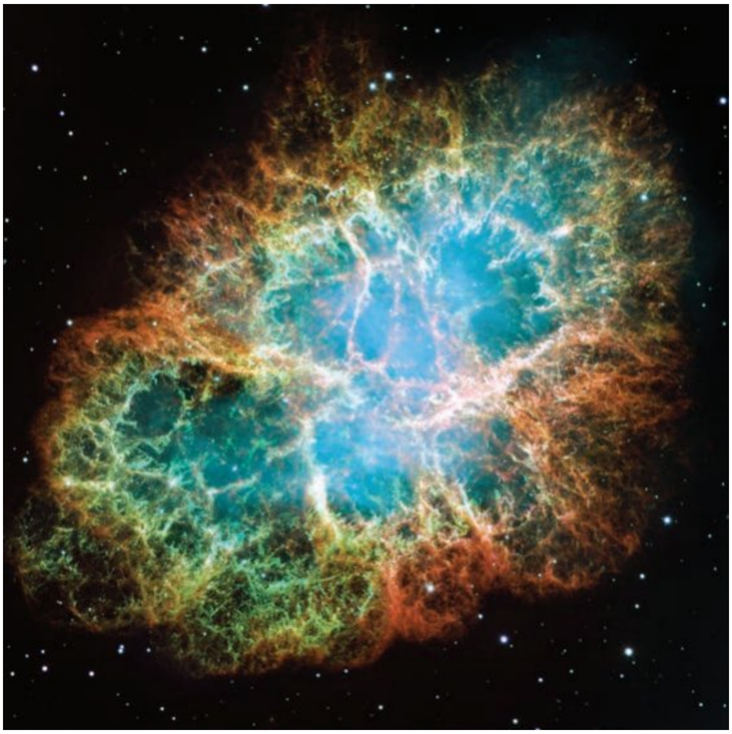

**Figure 4.25** A mosaic image of the Crab Nebula taken by the Hubble Space Telescope. This expanding remnant of a star's supernova explosion is six light years wide.

## Supernovas

When a supergiant runs out of fuel, it collapses under its own gravity and produces an enormous explosion called a **supernova**. All the elements heavier than iron, such as uranium and gold, are theorised to have been created during these spectacular explosions. Usually, if a star is less than 40 times the mass of our Sun, it collapses into a neutron star, while a star that has a mass greater than 40 times the mass of our Sun will become a black hole.

## Black holes

If the mass of a star prior to the supernova explosion is great enough, the amount of gravity can be so enormous that the core of the remaining star collapses into a tiny amount of space. This is called a **black hole**. We cannot see black holes because they do not emit light, but we can observe them indirectly by the effects that they have on objects around them. Some black holes have a diameter of only a few kilometres but the mass of 10 000 Suns! There is a supermassive black hole at the centre of the Milky Way **Galaxy**, and astronomers predict that most spiral galaxies have a black hole at their centre.

### Quick check 4.4

1. Recall which factor determines the path that a star takes through its lifetime.
2. List the order of phases that a Sun-like star will go through in its lifetime.

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## Explore! 4.3

### Spaghettification and worm holes

Black holes have captured the imagination of astronomy enthusiasts, science fiction writers and astrophysicists alike since their existence was hypothesised in the early 1900s. There are many theories surrounding black holes and how light and matter can interact with them.

1 Research the ideas behind spaghettification and worm holes, and summarise the main concepts in a few paragraphs.
2 Propose what it might look like to watch something travel into a black hole.

## Explore! 4.4

### Exploring black holes

The first direct image of a black hole was taken by the Event Horizon Telescope (EHT) in 2019. The black hole is in the centre of galaxy M87, and a network of eight radio observatories on four continents collected data for 10 days to capture the image. Scientist Dr Katie Bouman developed an algorithm called CHIRP to process the enormous amount of data gathered by the EHT project.

**Figure 4.26** The black hole at the centre of galaxy Messier 87

The image is not a photograph, instead the algorithm created it using the data. The black hole itself can't be seen because light can't escape from it. The golden ring in the image is the event horizon, the boundary around a black hole beyond which no light or other radiation can escape the black hole's massive gravitational pull. Objects that pass into the event horizon go through spaghettification.

## Explore! 4.5

### LIGO

The Laser Interferometer Gravitational-Wave Observatory (LIGO) is designed to directly detect gravitational waves. Gravitational waves are ripples in space–time (the 'fabric' of the universe) that are produced by extreme events, such as the collision of two black holes. LIGO uses laser interferometry to measure tiny distortions in space caused by passing gravitational waves.

The observatory consists of two facilities, located in Hanford, Washington, and Livingston, Louisiana, USA, which work in unison to detect gravitational waves from cosmic sources. LIGO's detection of gravitational waves in 2015 marked the beginning of the new field of gravitational-wave astronomy and created new opportunities for observing the universe.

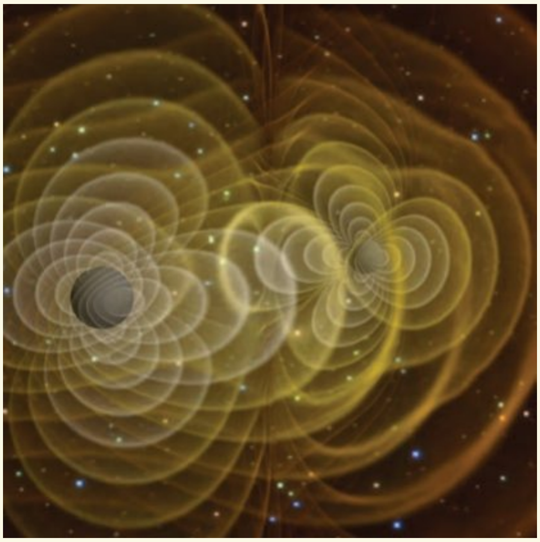

**Figure 4.27** This picture of a 3D simulation of merging black holes was created by a supercomputer at the NASA Ames Research Center. The development of fast computers has allowed astrophysicists to explore the universe in an entirely new way, through the detection of gravitational waves.

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## Hertzsprung–Russell diagrams

**H–R diagram (Hertzsprung–Russell diagram)**
a graph where the star luminosity is plotted against spectral type/temperature

A Hertzsprung–Russell or **H–R diagram** is a plot of star luminosity (energy output) against star temperature/colour. In Figure 4.28 you can see a diagonal band of coloured dots that represent stars in the main sequence. Red giants, supergiants and white dwarfs have their own sections on the H–R diagram.

Remember, the luminosity scale gives us an idea of how bright a star is compared to our Sun. Stars with a luminosity of 1 are as bright as our Sun.

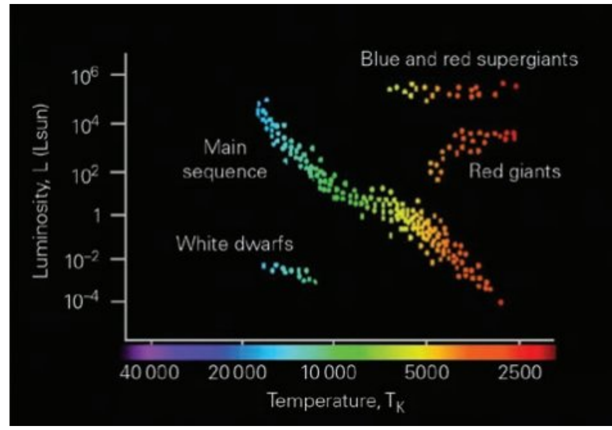



**Figure 4.28** A Hertzsprung–Russell diagram plots star brightness (luminosity) against surface temperature.

### Section 4.2 questions

QUIZ

**Retrieval**

1 **Recall** the temperature and luminosity of our Sun.

**Comprehension**

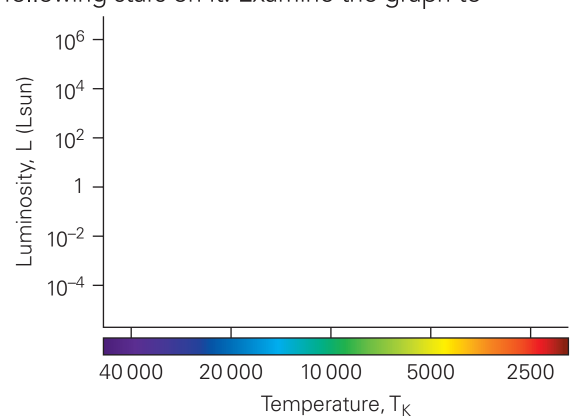
2 **Describe** the process by which a star forms.

3 **Explain** the two factors that determine how bright a star appears from Earth.

**Analysis**

4 Copy and use the H–R diagram below to plot the following stars on it. Examine the graph to answer the following questions.

| Star | Temperature (K) | Luminosity (Sun = 1) |
|---|---|---|
| Sirius | 9940 | 25.4 |
| Canopus | 7350 | 10 700 |
| Arcturus | 4290 | 170 |
| Alpha Centauri | 5790 | 1.5 |
| Vega | 9602 | 40 |
| Rigel | 11 000 | 120 000 |
| Betelgeuse | 3500 | 140 000 |




a Which of the stars you have plotted is a red supergiant?

b Which of the stars you have plotted is most like our Sun?

c What colour is Canopus? How do you know?

d How many times brighter than the Sun is Sirius?

e Will Rigel's lifetime be longer or shorter than the Sun's? Explain your answer.

**Knowledge utilisation**

5 **Propose** a reason why nobody has ever seen a black hole. How do we know that they are there?

6 **Create** a summary of the observable features of stars and how they relate to each other.

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# 4.3 Beyond the Milky Way

**Learning goal**

**1.** To be able to describe the major components of the universe.

WORKSHEET
Beyond the Milky Way

VIDEO
Galaxy classification

All the individual stars that you can see in the night sky with the naked eye are within the Milky Way Galaxy. It can be difficult to imagine the immense distances in space unless there is some perspective. Our closest star is the Sun and it takes 500 seconds (about eight minutes) for light to travel from the Sun to Earth (a distance of 150 000 000 km). The closest star to our solar system is Alpha Centauri. Light takes 4.4 years to travel from Alpha Centauri to Earth. Our solar system is positioned on an outer arm of the Milky Way and it takes light 106 000 years to travel across the Galaxy. Our closest galaxy is the Andromeda Galaxy, and it takes light 2.5 million years to travel to Earth from Andromeda. There are over two trillion galaxies in the **observable universe** (that is, the part of the universe we can see). In 1936, the astronomer Edwin Hubble classified the Local Group as a group of 12 galaxies, which includes the Milky Way and the Andromeda Galaxy. Since then, as we learn more, the Local Group has grown to 36 galaxies.

**observable universe**
the spherical region of the universe that can be observed from Earth or space telescopes; it encompasses everything close enough that light has had time to reach Earth

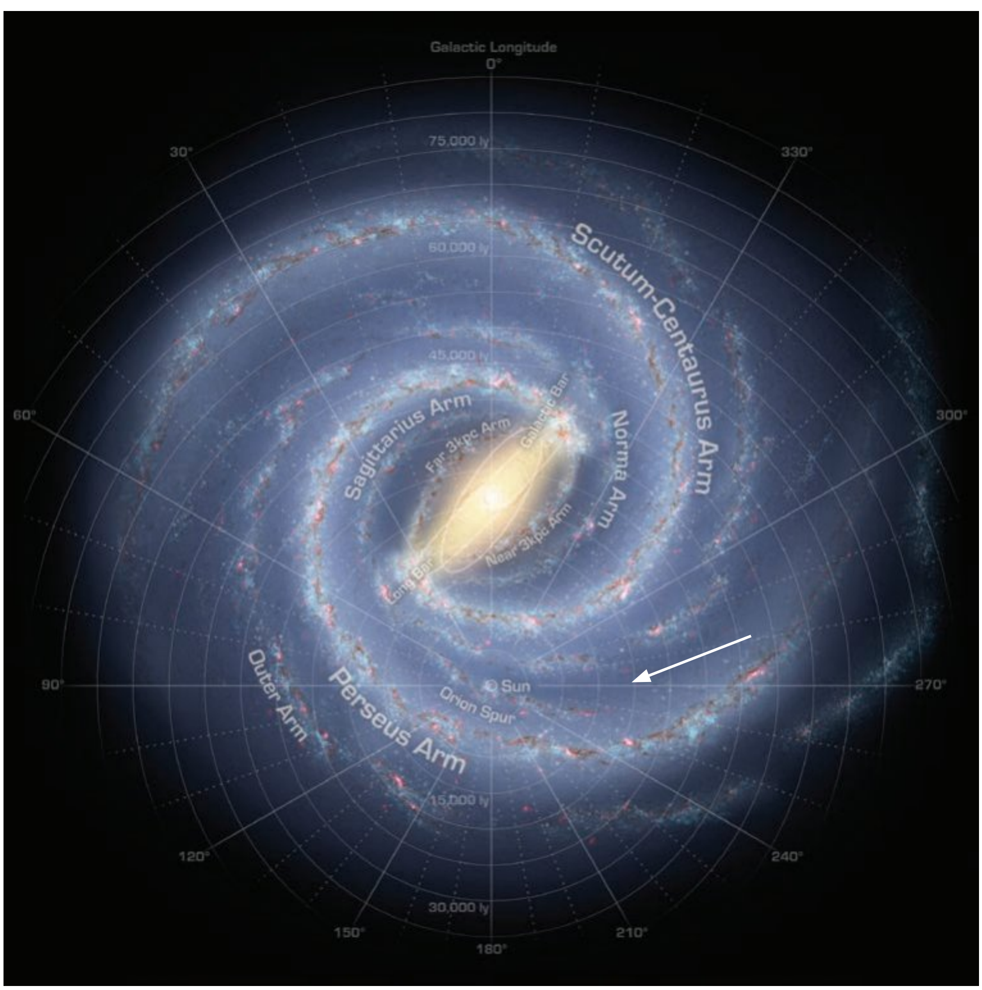


**Figure 4.29** Our solar system sits on the Orion arm of the Milky Way.

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## Making thinking visible 4.1

**See, think, wonder: Eagle Nebula**

Figure 4.30 shows star-forming pillars called the Pillars of Creation, which can be found inside the Eagle Nebula. The image is composed of 32 different images from four separate cameras. The missing part at the top right is because one of the four cameras has a magnified view of its portion so the images from this camera were scaled down to match those from the other three cameras.

The photograph was made with light emitted by different elements in the cloud, which appear as different colours in the composite image: green for hydrogen, red for sulfur and blue for oxygen.

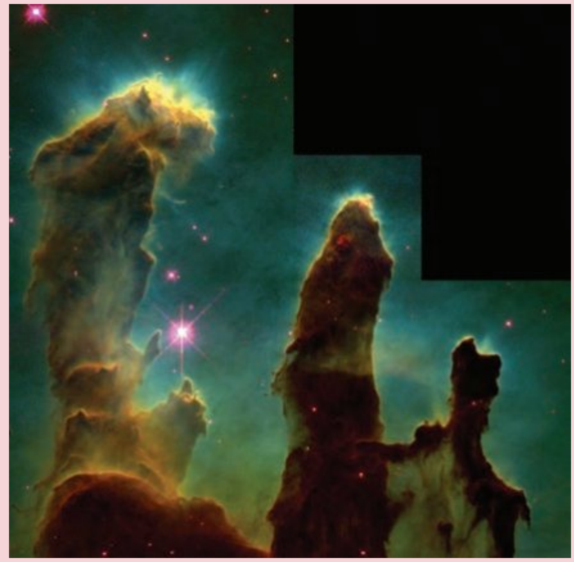


**Figure 4.30** Star-forming pillars in the Eagle Nebula, as seen by the Hubble Space Telescope's Wide Field and Planetary Camera 2

1 Can you describe what is visible in the photo?
2 What thoughts come to your mind when you observe it?
3 Are there any questions that arise from your observations?

The *See, think, wonder* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

## Galaxies

Galaxies are classified by their shape according to the Hubble galaxy classification scheme. Galaxies can be classified as elliptical, lenticular, spiral or irregular.

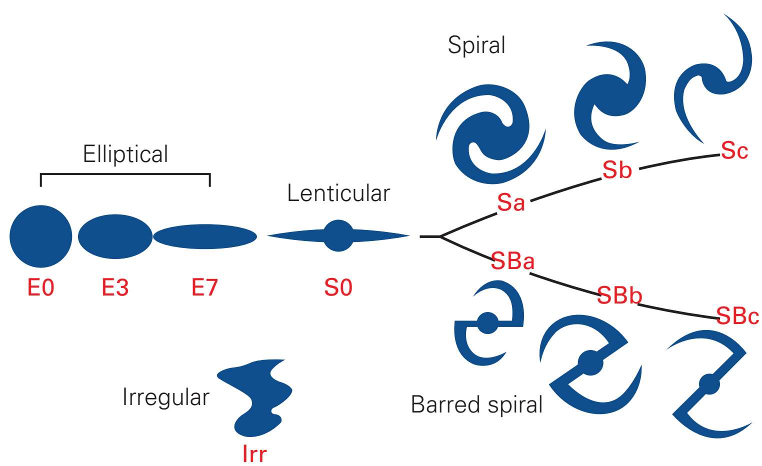
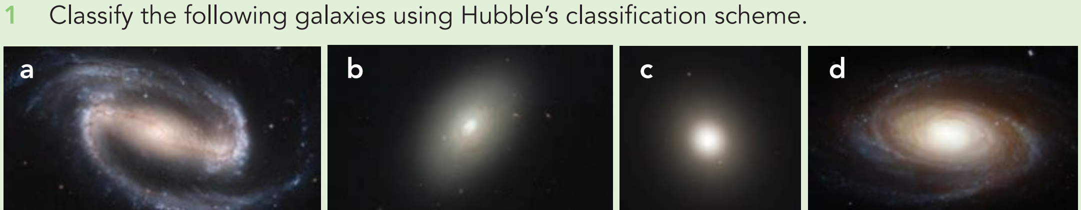



**Figure 4.31** Hubble's galaxy classification scheme

## Quick check 4.5

1 Classify the following galaxies using Hubble's classification scheme.

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## Try this 4.1

**Classifying galaxies**

Astronomers now have so many photos of galaxies that they simply do not have the time to classify them all. A group of astronomers has set up a crowd-sourced astronomy project called Galaxy Zoo that allows anyone to take part in some real science. You can try this too.

Search for Zooniverse Galaxy Zoo on the internet and you can have a go at classifying galaxies for yourself. You will be shown a galaxy and asked a series of questions about what you can see and the shape of the galaxy. Do not be afraid that you will get it wrong – the galaxies are shown about 30 different times to make sure that the responses are consistent.

## Astronomical distances and the speed of light

Light travels at a speed of 300 million metres every second, or $3 \times 10^8$ m $s^{-1}$. A **light year** is a unit of distance equivalent to how far light travels in a year, which is equal to 9.46 trillion kilometres.

**light year**
the distance that light travels in one year (about 10 trillion km)

## Try this 4.2

**Cheese and light**

Use your microwave to calculate the speed of light!

1 Open your microwave and remove the rotating platform.
2 Line a dinner plate with cheese singles and place it in the microwave.
3 Turn on the microwave for about 10 seconds or until small hotspots start to form on the layer of cheese.
4 Take the plate out of the microwave and measure the distance between two of the hotspots. This value will be half of the wavelength of the microwave radiation.
5 Locate the frequency of your microwave in hertz (Hz), which should be listed inside the door.
6 Use the formula $v = f\lambda$, where $v$ is the speed in m $s^{-1}$, $f$ is the frequency in hertz and $\lambda$ is the wavelength in metres, to calculate the speed of light (remember to multiply your hotspot measurement by two to get the wavelength). Compare it to the actual value.

**Be careful**
Handle with care as cheese may be extremely hot.

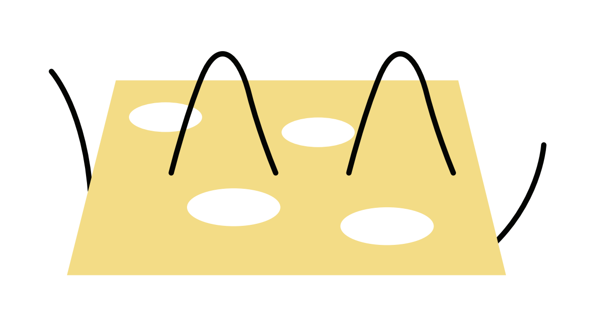

**Figure 4.32** A microwave wave heating up a slice of cheese

## Parallax

One method of measuring distances in space is by using **parallax**. If you hold your index finger in front of you at arm's length and close one eye, then swap eyes and close the other one, your finger will appear to move because you are essentially observing your finger from a different location. The same thing happens when we look at the stars in the night sky from a different position in space. As Earth travels around the Sun, our position in space changes and we see the stars arranged slightly differently. We can measure the angle between the apparent location of a nearby star and a 'fixed' distant star. This is called the parallax

**parallax**
the effect by which the position of an object seems to change when it is observed from different locations

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**astronomical unit**
the distance between Earth and the Sun

**baseline**
a line between the two viewpoints used to calculate parallax angle (1 AU is the baseline used for calculating star parallax)

**parsec**
the distance at which a star appears to move one arcsecond in six months (equal to 3.26 light years or 30 trillion km)

**arcsecond**
1/3600th of a degree

angle. Using the distance between Earth and the Sun (the **astronomical unit** or AU) as the **baseline** and some trigonometry, we can work out how far the star is from Earth.

This technique enables us to measure distant stars in **parsecs** (pc): one parsec is equal to 3.26 light years or 30 trillion kilometres. A star that is one parsec away will have a parallax angle of one **arcsecond**, which is one 3600th of a degree (there are 60 arcminutes in one degree and 60 arcseconds in one arcminute).

Using parsecs to measure distance makes it easier to calculate distances with the following formula:

$$\text{Distance to star (in pc)} = \frac{1}{\text{parallax angle (in arcseconds)}}$$

The further away a star is, the less it appears to move due to parallax, and the smaller the parallax angle becomes. This gives a limit to the distance that we can measure using the parallax method, because when stars are too far away, their parallax angle is too small to measure. The limit to which we can use parallax is around 100 parsecs.

**Parallax**

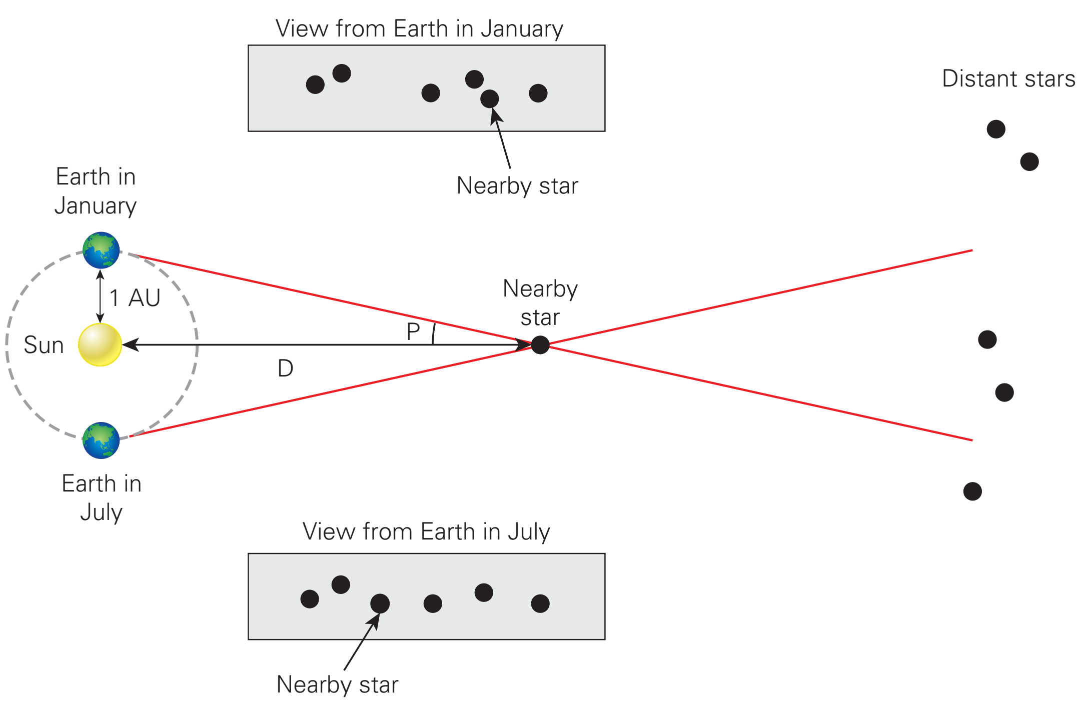


**Figure 4.33** Astronomers can work out the distance to nearby stars by comparing their apparent location relative to the background of distant stars (which are unaffected by parallax).

## Quick check 4.6

1. Does a light year measure time or distance?
2. What is the limit out to which star distance can be measured using the parallax method?
3. Will a closer star have a larger or smaller parallax angle?

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## Investigation 4.1

### Parallax

**Aim**

To investigate the use of parallax angles to reliably calculate distance.

**Materials**

- an 'object' (something that can be placed in the middle of the school oval and be visible from the perimeter)
- 2 rulers
- large protractor
- trundle wheel

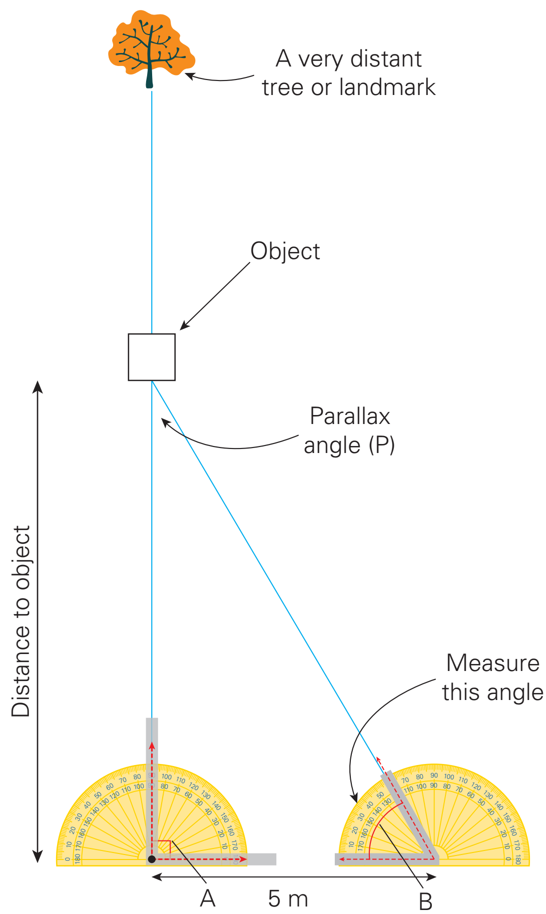
**Method**

**Part 1: Prepare the results table**

Copy the results table into your science journal. You will be collating your results with the class to analyse the reliability of this method.

**Part 2: Set up the distances**

1 Your teacher will place an object in the middle of the school oval (the whole class will determine the distance to this one object).
2 Find a location near the perimeter of the oval where the object lines up with a distant landmark; for example, a tree, the edge of a fence, a gate, the edge of a building or a flagpole.
3 At this location, use the two rulers and protractor to make a right angle, angle (A) perpendicular to the line going through the object and the landmark, as shown in the diagram.
4 Measure out a 5-metre line along this perpendicular direction (this will be your baseline).
5 At the end of the 5-metre line, use the two rulers and protractor to measure angle (B) (between the baseline and the ruler directed towards the object). (You may have to lie on your stomach to line up the objects by sight.)




**Results**

1 Calculate the parallax angle (*P*) by subtracting the angle (B) from 90°.
2 Use trigonometry $D = \dfrac{5}{\tan(P)}$ to calculate the distance (*D*) to the object.
3 Use the trundle wheel to measure the actual distance to the object.
4 Calculate the relative error.
5 Combine data on a class board or spreadsheet.
6 Draw a scatterplot to analyse the relationship between the distance to the object and its parallax angle.
7 Add a line of best fit to the graph if possible. Note the type of line that fits best to reflect the relationship between the two variables.

*continued …*

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*continued …*

| | Baseline distance (m) | Angle B (°) | Angle *P* = 90 – angle B (°) | Calculated distance to the object (m) | Measured distance to the object (m) | Relative error $\frac{\text{Measured distance} - \text{Calculated distance}}{\text{Measured distance}} \times 100$ |
|---|---|---|---|---|---|---|
| Group 1 | 5 | | | | | |
| Group 2 | 5 | | | | | |
| Group 3 | 5 | | | | | |
| Group 4 | 5 | | | | | |
| Group 5 | 5 | | | | | |
| Group 6 | 5 | | | | | |
| Mean | 5 | | | | | |

**Analysis**

Describe the relationship between the parallax angle and the calculated distance.

**Evaluation**

**Reliability**

1 Describe the amount of relative error for your own calculations and the mean relative error for the class group.

**Limitations**

2 Instrument error is one factor that could affect the precision of the experiment. Were other factors that could affect the validity of the results successfully controlled during the experiment? Justify your reasoning.

**Improvements**

3 Suggest any other changes that could be made to the method to improve the validity of the results in future experiments.

## The Doppler effect

When you hear an ambulance travelling past you, the pitch of the siren changes as it passes. When the ambulance is travelling towards you, the sound wave is a little more squashed than usual which results in a higher frequency wave. You hear it as a higher pitch. When the ambulance is travelling away from you, the sound wave is a little more stretched than usual which results in a lower frequency wave. You hear it as a lower pitch. This phenomenon is called the **Doppler effect**.

The same phenomenon happens with light waves if an object is travelling fast enough. When the object is travelling towards you, the light it emits is of a higher frequency, which translates to the light appearing more blue. This is called **blue shift**. When the object is travelling away from you, the light it emits is of a lower frequency, which translates to the light appearing more red. This is called **red shift**.

When astronomers look at spectra from distant galaxies, they find that the emission lines are almost always shifted towards the red part of the spectrum. This tells us that most galaxies in the universe are moving away from us and the universe is expanding.

VIDEO
The Doppler effect

**Doppler effect**
a change in the frequency of sound or light waves emitted from an object when it moves towards or away from an observer

**blue shift**
a spectrum shifted towards shorter wavelengths

**red shift**
a spectrum shifted towards longer wavelengths

## Travelling large distances

Our Earth is not going to be around for ever. It may become uninhabitable because of human activity, it may get enveloped by our Sun expanding into a red giant in five billion

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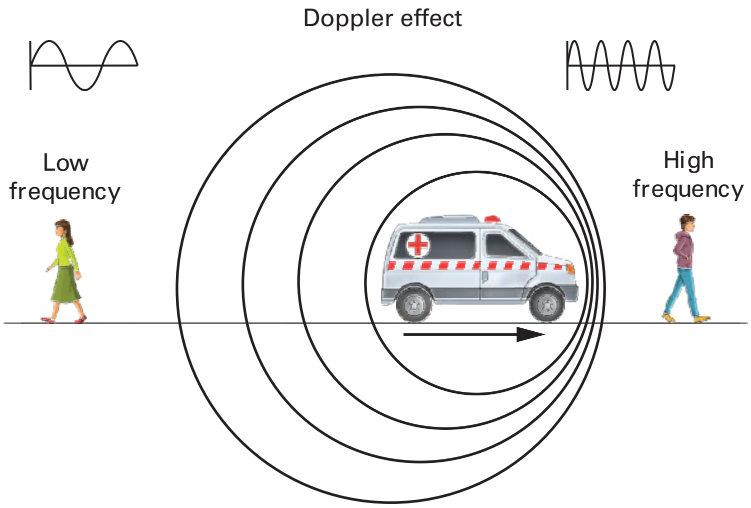


**Figure 4.34** Sound waves are squashed together as the ambulance travels into them, so we hear a higher pitch as the ambulance drives towards us. Sound waves are spread out as the ambulance moves away from them, so we hear a lower pitch as the ambulance drives away.

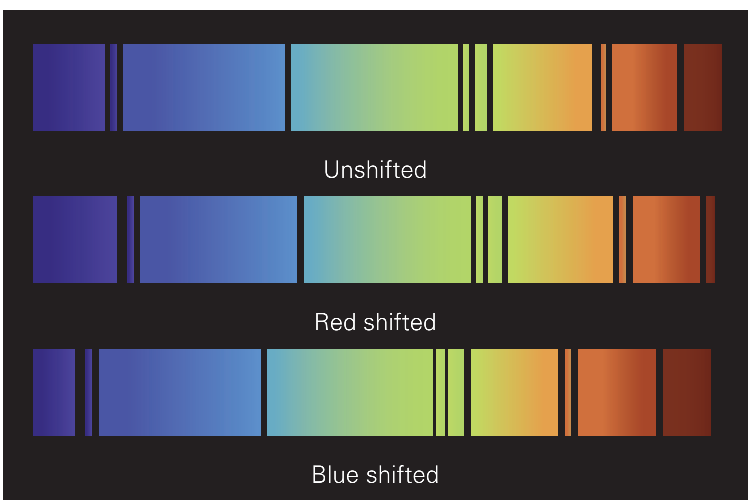


**Figure 4.35** The black lines from a galaxy's absorption spectrum are shifted towards red if the galaxy is moving away from us and towards blue if it is moving towards us.

years, or it may be destroyed by a giant meteor or nearby supernova. For humanity to get the chance to leave Earth to look for somewhere else to live, we will need to find a way to travel large distances and leave our solar system.

Interstellar travel (travelling outside our solar system) throws up quite a few problems. These problems relate to the vast distances that we would need to travel to find and inhabit a new planet. Light takes just over four years to reach the closest star to our solar system, Alpha Centauri. We cannot travel even remotely near the speed of light with current technology. Even if we develop such technology in the future, travelling close to the speed of light has its own problems: it would require an enormous amount of energy to accelerate a conventional spaceship leaving Earth to 99% of the speed of light, and an equally enormous amount of energy to decelerate at journey's end.

Finding **exoplanets**, planets that orbit other stars, is a lot harder than you might imagine. We can easily observe stars because they emit their own light. Planets only reflect light from the star they orbit, so are many orders of magnitude dimmer than a star. We cannot see the light from most planets outside our solar system because we are just too far away from them, so the only way we can tell that they are there is indirectly, such as when they pass in front of their own star and block out a tiny portion of its light (like a mini eclipse).

Despite this difficulty, astronomers have found over 5000 exoplanets! The problem we then encounter is finding out whether humans could live on these planets. A liveable planet would need to be made of rock (so that we can land on it) and have an atmosphere so we do not die from the radiation in space (but not so thick that the greenhouse effect makes it unbearably hot). The planet would need to be in what is called the **Goldilocks zone**: not too hot and not too cold.

**exoplanet**
a planet outside our solar system, orbiting a star other than our Sun

**Goldilocks zone**
the habitable zone around a star where the temperature is not too hot and not too cold

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Out of all the exoplanets that have been discovered, only a small number could potentially be habitable. However, astronomers have predicted that there might be more than 10 billion exoplanets orbiting Sun-like stars just in our own galaxy.

Given the immensely large distances to these potentially habitable planets, the only way to explore them may be to send out one-way space missions. With current technology, spacecraft need fuel to travel.

## Science as a human endeavour 4.1

### Hot Jupiters

Hot Jupiters are a class of exoplanets that are similar in size and composition to Jupiter, the largest planet in our solar system, but have orbits that bring them very close to their host stars. As a result, they have extremely high temperatures, sometimes even higher than 700°C. Their short orbital periods make them easy to detect using current exoplanet detection methods.

**Figure 4.36** Dr Jake Clark

In 2023, Dr Jake Clark, an astrophysicist from the University of Southern Queensland in Toowoomba, discovered a hot Jupiter exoplanet called TOI-778 b. The exoplanet experiences a very short year, orbiting its dwarf star sun in less than a week.

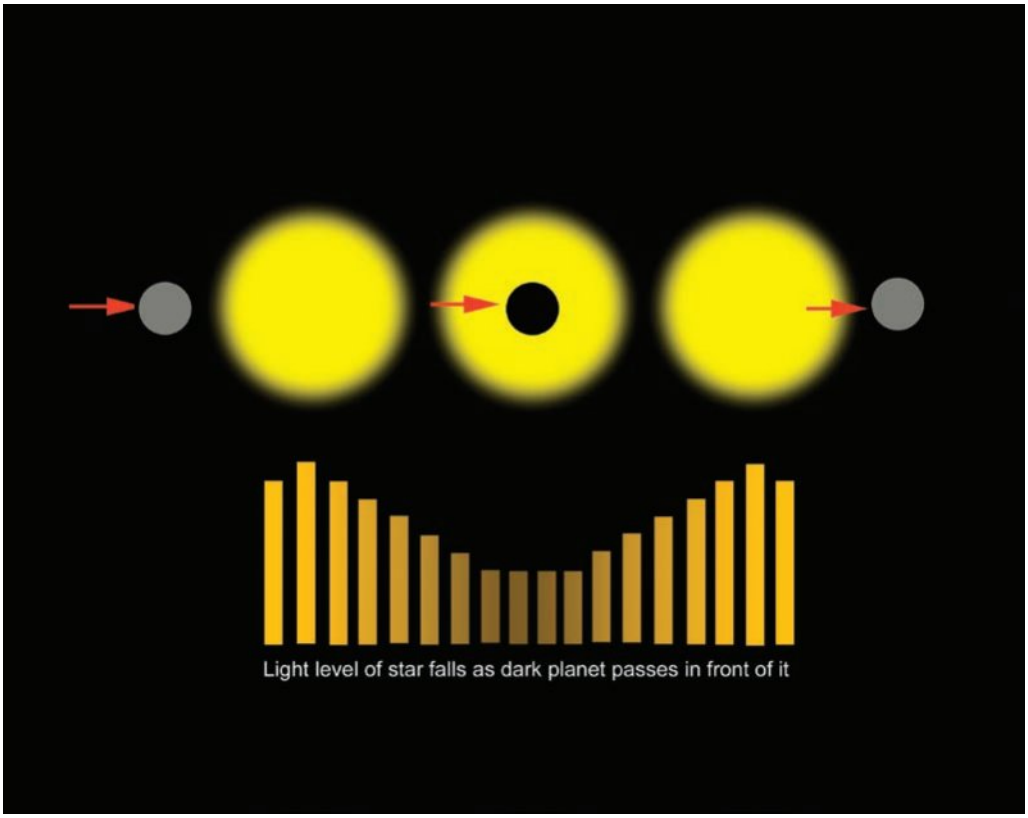


**Figure 4.37** Astronomers use transit photometry to detect exoplanets.

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To be able to accelerate very quickly, you need to take more fuel, but extra fuel makes the spacecraft heavier, decreasing the acceleration. Even if in the future we discover a way to travel large distances without carrying fuel, the journey to other star systems will still probably be much longer than a human lifetime. There are a few solutions to this problem. One might be to send a population of humans that would have several generations out on huge spacecraft to explore the stars. These explorers would have to deal with things like a changed physiology due to living in space. Another solution might be to send people away in suspended animation and wake them up when they get to their destination. A third solution might be to not send humans at all and instead send advanced robots or androids. It is not just a world of opportunities, but a universe of possibilities that awaits us!

## Try this 4.3

**Australian astrophysicists**

Research the following Australian astrophysicists and their contributions to international astronomy:

- Doctor Abigail Allwood
- Professor Lisa Kewley
- Kirsten Banks
- Professor Brian Schmidt
- Professor Tamara Davis
- Doctor Jessie Christiansen.

**Figure 4.38** Jessie Christiansen at Palomar Observatory in California

## Section 4.3 questions

QUIZ

### Retrieval

1 **Define** a light year.

2 **Recall** the units used to measure parallax angle and star distance (for stars less than 100 light years away).

3 An astronomer collects data from a star in January and then again in July and finds that its parallax angle is 0.8 arcseconds. **Calculate** the distance to the star. Express your answer in parsecs and light years.

### Comprehension

4 **Explain** why an ambulance siren changes to a slightly lower pitch as it drives past you.

5 **Describe** what is meant by the term 'Goldilocks zone'. How does it apply to humans being able to live outside our solar system?

6 **Explain** how astronomers determined that the majority of galaxies we can observe are travelling away from us.

### Analysis

7 **Contrast** red shift and blue shift.

### Knowledge utilisation

8 **Evaluate** the potential of humans finding a way to leave our solar system.

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# 4.4 The Big Bang

WORKSHEET
The Big Bang

**Learning goals**

1. To be able to describe the major changes in the universe that have occurred since the Big Bang.
2. To be able to describe the evidence that provides support for the acceptance of the Big Bang theory.

**Big Bang**
the rapid expansion of matter that marked the origin of the universe

**singularity**
a point at which infinitely dense matter occupies an infinitely small space

**cosmic microwave background**
electromagnetic radiation left over from the early stages of the universe

The **Big Bang** is a theory that most people have probably heard of and accept as the explanation of how the universe began. But how do we know what happened such a long time back, and what evidence have astronomers discovered to support it?

## Evidence for the Big Bang

The Big Bang theory suggests that the universe was created 13.7 billion years ago from a very small, yet very dense **singularity**. Three main pieces of evidence support the Big Bang theory:

- Almost all galaxies are red shifted, which means that almost all galaxies are travelling away from each other. This suggests that the universe is expanding and that, if you extrapolate backwards in time, the universe had a beginning.
- The abundance of smaller elements in the universe is consistent with them being created in a Big Bang and not inside stars through nuclear fusion.
- Radiation left over from the Big Bang, called **cosmic microwave background**, is consistent with the rate of cooling calculated from such an explosion.

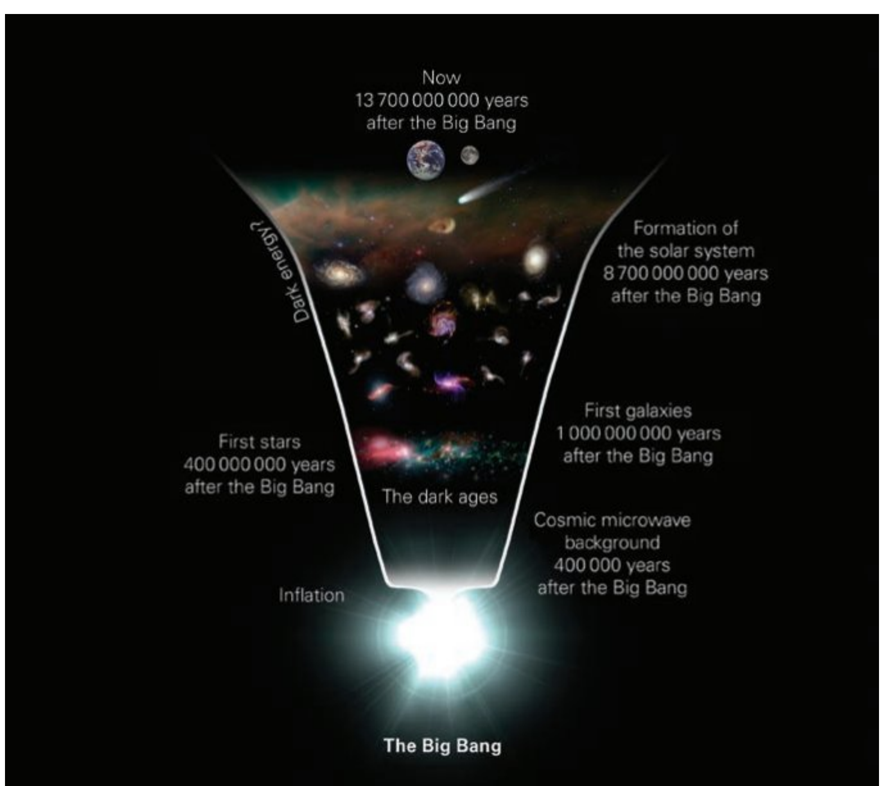


**Figure 4.39** The history of the universe

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## In the beginning

The Big Bang theory suggests that the universe was created 13.7 billion years ago from a singularity which expanded rapidly, creating both space and time. In the first stage of the universe's existence, the first 300 000 or so years, atoms could not yet exist because of the extreme density and temperature of the young universe. Matter existed as plasma, the ionised fourth state of matter, in which ions and electrons are separated. During this phase, all the photons emitted were scattered by the plasma and so we cannot observe photons before this point in time. This early period is referred to as the 'dark ages' of the universe. The point in time where ions and electrons could bond together is called the **epoch of recombination**. The term 'recombination' can be misleading as it does not mean that protons and electrons were combined before, but rather it is a historical convention as the term came about before the Big Bang model became the primary theory for the origins of the universe.

## Cosmic microwave background

Radiation is the name that we give to all frequencies of the electromagnetic spectrum, including gamma rays, X-rays, microwaves, ultraviolet waves, visible spectrum light, infrared waves and radio waves. Radiation was emitted from the Big Bang, and we can still observe that radiation today. It exists in the form of very low frequency waves in the microwave part of the spectrum, and was discovered in the 1960s by accident. Two radio astronomers noticed a subtle continuous buzzing that came from the skies and initially thought that it was some type of interference coming from their antenna. They soon realised they were detecting the cosmic microwave background.

Cosmic microwave background is considered the most ancient view of the universe because it dates to 380 000 years after the Big Bang, when the universe had cooled enough for photons to escape the plasma and travel freely. This light has been travelling through space ever since and constitutes the oldest light we can observe. It provides us with a snapshot of the early universe, including its temperature, density and small fluctuations that eventually led to the formation of galaxies and large-scale structures.

If you threw a tennis ball in space it would continue in its motion in a straight line according to Newton's first law. In a similar way, when photons are emitted in space they will keep moving until they hit something. Because it takes light time to travel, when we look at the light from the nearest star cluster, Alpha Centauri, it has taken 4.4 years to travel to Earth, so we are looking at it as it was 4.4 years ago. When we observe the cosmic microwave background, we are looking back in time to the earliest observable radiation in the universe. These photons have been travelling towards Earth for 13.7 billion years!

**epoch of recombination** the point in time when electrons and ions could combine to form atoms

### Did you know? 4.3

**Detecting the first light**

The photons emitted in the early stages of the universe are red shifted. This has resulted in the light becoming less intense and less visible to our instruments.

In the early universe, the expansion was much faster than it is today, causing the light from early photons to be red shifted even further. This light has since become weak and red shifted so is difficult to detect using telescopes. The light from the early universe has also been absorbed and scattered by clouds of gas and dust, making it even more difficult to detect.

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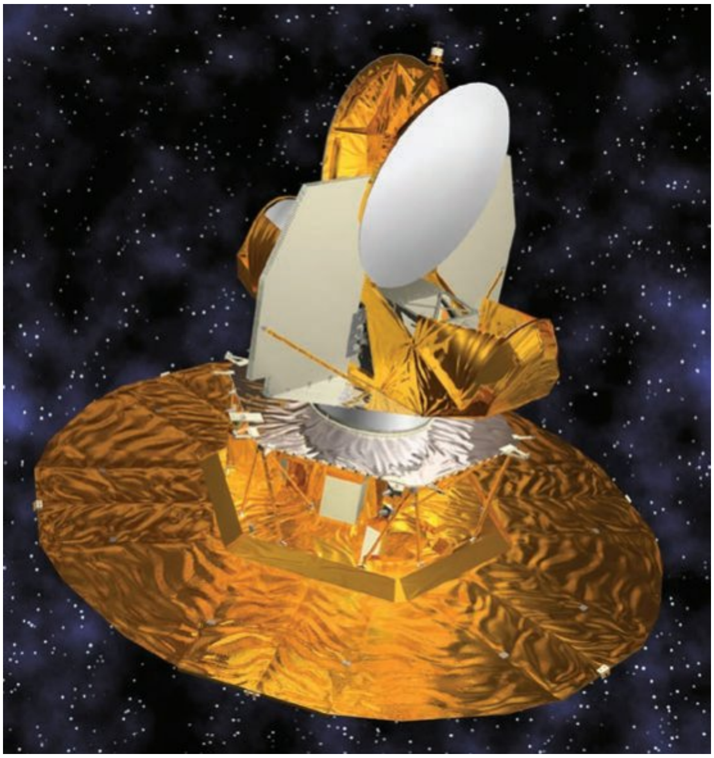

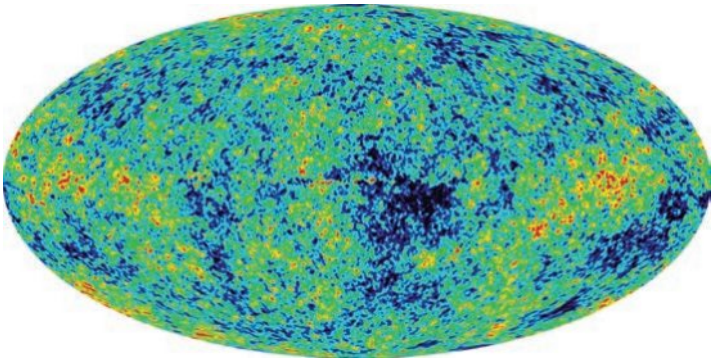

Figure 4.40 The Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft (top) operated in the early 2000s to collect temperature data from the cosmic microwave background (bottom).

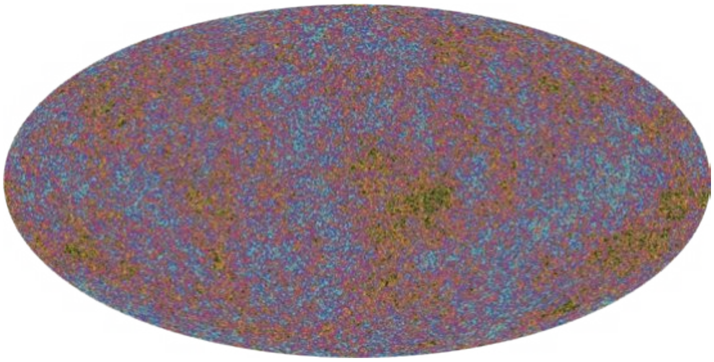

Figure 4.41 Data collected from the European Space Agency's Planck satellite between 2009 and 2013 mapped the cosmic microwave background. This is our oldest view of the universe.

**Quick check 4.7**

1 Explain why we cannot see photons emitted in the early stages of the universe.

## Expansion

In the first few minutes after the Big Bang, the universe was composed of a hot, dense plasma of hydrogen and helium. As the universe expanded and cooled, matter began to come together through gravitational attraction to form larger structures such as gas and dust clouds. Within these clouds, the density and temperature increased, leading to nuclear fusion and the formation of stars.

Over time, stars produced elements heavier than helium in their cores, which then formed into planets, asteroids and other objects when these stars exploded as supernovas or shed their outer layers as planetary nebulae. The Sun has been found to contain a number of these heavier elements, so it is thought that it and the planets of the solar system formed from a nearby supernova that exploded in the early stage of the universe. Because the Sun formed from the remains of an earlier star, it is called a secondary star. Large collections of stars in the early universe clustered together to form galaxies. These galaxies have continued to move apart as the universe expands.

## Dark matter and dark energy

One of the great mysteries that astronomers are currently working on is finding out about dark matter and dark energy.

Gravity is a property of mass, or matter. All objects have gravity, and the more mass, the more gravity. Astronomers have measured the amount of gravity in the universe indirectly; that is, they can measure it by observing the effects that it has on things around it. They have found that there is more gravity in the universe than the amount that can be attributed to matter. Astronomers theorised that there must

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## Try this 4.4

**Animating the Big Bang**
Use animation or comic strip software to create an explanation of the Big Bang for other Year 10 students.

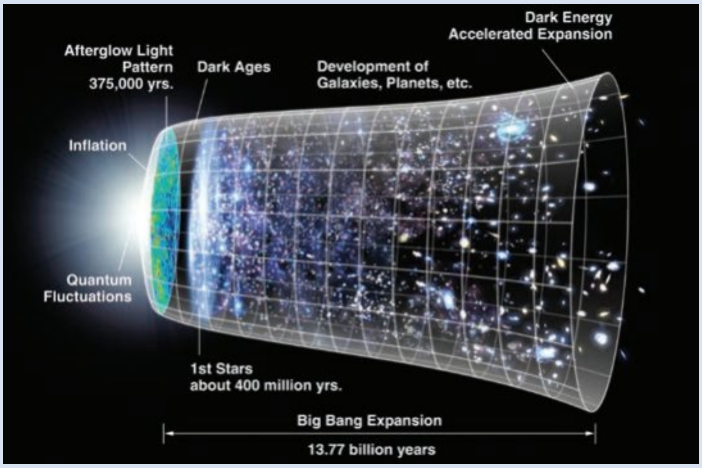


**Figure 4.42** A representation of the universe over 13.77 billion years

**dark matter** matter that does not emit light and is responsible for unidentified gravity in the universe

**dark energy** a theoretical force responsible for accelerating the expansion of the universe

be some other type of matter causing this extra gravity, calling it **dark matter**. In 1965, Vera Rubin proved that dark matter existed when she observed a difference in the predicted and observed motion of galaxies. She concluded that invisible gravity sources were pulling planets and stars in certain directions.

We know that the universe is expanding because light from other galaxies is red shifted. But galaxies are not just moving away from all other galaxies, they are doing so at an accelerating rate. It seems that there is some sort of unobservable pressure that is making the universe expansion rate accelerate. This unknown pressure has been termed **dark energy**. It is amazing to think that in the future, the universe may have expanded so vastly that all other galaxies will be outside our observable universe, so we will not actually be able to see anything beyond our own galaxy!

## Explore! 4.6

**Validating the existence of dark matter**
Vera Rubin's discovery of the existence of dark matter was validated through multiple lines of evidence. Research how the following pieces of evidence helped to support the existence of dark matter:

- Rotation curves
- Gravitational lensing
- Cosmic microwave background radiation
- Numerical simulations.

**Figure 4.43** American Astronomer Vera Rubin

## Explore! 4.7

**The search for extraterrestrial intelligence**
Given the immense size of the universe, it seems likely that life has also arisen in other places in the universe. The SETI program (Search for Extraterrestrial Intelligence) was developed to monitor radio waves from space to potentially find other intelligent life in our Galaxy.

1. Research SETI and describe the projects currently under way.
2. Describe the type of data that is collected and explain what we can learn from it.
3. If you are interested, join SETI@home and let your computer download and analyse data to contribute to the SETI program.

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## Explore! 4.8

### The observable universe

The observable universe refers to the part of the universe that can be observed through telescopes and other technology, given the speed of light and the age of the universe.

Currently, it has an estimated diameter of about 93 billion light years and contains approximately two trillion galaxies, each containing billions of stars and other celestial objects. It also contains larger structures such as galaxy clusters and cosmic microwave background.

The observable universe is limited by the horizon, which is the maximum distance that light has had time to reach us since the Big Bang. Beyond the horizon, the universe is thought to continue, but it cannot be observed directly.

**Figure 4.44** A map of the observable universe. From left to right, the known celestial bodies are arranged according to their proximity to Earth. In the far right, cosmic microwave background radiation is present.

**recessional velocity** the rate at which a star is moving away from Earth

**Hubble's law** the farther away a galaxy is from Earth, the faster it is moving away from us

## Age of the universe

Edwin Hubble made his observations about galaxies in the 1920s and observed that many 'clouds' of dust and gas were actually distant galaxies. He noticed that these distant galaxies were different sizes and concluded that the smaller ones must be further away. While this assumes that all galaxies are the same size, which they are not, it is nevertheless a pretty good approximation at these distances.

Hubble calculated the **recessional velocity** of the galaxies (that is, the speed that they are travelling away from us) by recording the red shift of their spectra. The further the spectral lines are shifted towards red, the faster the galaxy is moving. Hubble found that the further a galaxy is from us, the faster it is travelling away from us, so he proposed a relationship between distance and recessional velocity. This relationship is called **Hubble's law** and is given by the formula $v = H_0D$, where $v$ is the recessional velocity, $D$ is the distance from Earth and $H_0$ is a constant that we call Hubble's constant. Hubble's original measurement of $H_0$ was 500 km s$^{-1}$ Mpc$^{-1}$ (Mpc is megaparsec), or 160 km s$^{-1}$/million-light-years. However, over time, the constant has been measured more and more accurately, and the current value is 73.8 km s$^{-1}$ Mpc$^{-1}$.

Hubble's law demonstrates two points:

- The universe is expanding everywhere and in all directions.
- The expansion of the universe given by the Hubble constant can be traced backwards to where $D = 0$ to find the age of the universe.

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Figure 4.45 Edwin Hubble, one of the most important astronomers of all time

## Misconceptions about the Big Bang

A few misconceptions arise about the Big Bang – partly because of the name 'Big Bang' and partly because it is just a difficult concept to comprehend.

One slightly misleading concept is the idea of the singularity that existed before the Big Bang.

### Making thinking visible 4.2

**The complexity scale: The Big Bang**

1 Write down any information you have about the Big Bang, including facts, observations and ideas.
2 Place each statement on the complexity scale, which ranges from simple to complex.
3 Provide an explanation for why you chose to place each statement where you did on the complexity scale.
4 Reflect on the exercise and consider what new insights and questions you have gained about the Big Bang.

The *The complexity scale* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

'Singularity' might sound like it means that the whole universe was located at a single point. In fact, space–time did not yet exist, so the singularity was not in a specific spot – it was everywhere. Essentially, the Big Bang did not happen somewhere, it happened everywhere.

The other misleading part is the word 'bang', which implies some sort of explosion. In fact, a more accurate description would be to call it the 'big stretch'.

### Investigation 4.2

**Modelling the expanding universe**

**Aim**

To model the expanding universe with a balloon and evaluate the limitations of the model.

**Materials**

- balloon
- small dot stickers
- permanent marker
- piece of string around 40 cm long
- ruler
- paperclip
- stopwatch

**Method**

**Part 1: Prepare the results table**

Draw the table shown in the results section into your science journal.

**Part 2: Set up the model**

1 Partially blow up the balloon to about 10 cm in diameter and secure the end with a paperclip (do not tie the balloon as you will need to further inflate it later).

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2 Stick six dots on the balloon at random points and label one H (for home) and the others A, B, C, D and E. The home dot represents the Milky Way and the other dots represent neighbouring galaxies. You may add more than five neighbouring galaxy dots if you like.

**Part 3: Measure the variables**

1 Use the string and ruler to measure the distances HA, HB, HC, HD and HE. Record them in the results table under $D_1$.

2 Remove the paperclip, then fully inflate the balloon, timing how long it takes you to do this with the stopwatch. Tie the balloon off.

3 Measure the five distances again and record them in the results table under $D_2$.

**Results**

| Position on balloon | $D_1$ (cm) | $D_2$ (cm) | Mean speed (cm $s^{-1}$) |
|---|---|---|---|
| HA | | | |
| HB | | | |
| HC | | | |
| HD | | | |
| HE | | | |

**Processing data**

1 Calculate the mean speed that each dot was moving away from the home dot in the time ($t$) it took you to blow up the balloon, by using mean speed $= \frac{(D_2 - D_1)}{t}$.

2 Draw a scatterplot to analyse the relationship between mean speed (on the $y$-axis) and the $D_2$ (on the $x$-axis).

3 Add a line of best fit to the graph if possible. Note the type of line that fits best to reflect the relationship between the two variables.

**Analysis**

1 Describe the trend or pattern that is found when the line of best fit was applied to the graph. What type of relationship was found?

2 Suggest how you apply this relationship to understanding the movement of galaxies and expansion of the universe.

**Evaluation**

**Limitations**

1 Predict the misconception that might arise if you drew the galaxies on with the marker rather than using stickers.

2 Evaluate the limitations of using a balloon as a model for 3D space, and suggest a better model.

3 Can a valid conclusion regarding the expansion of the universe be drawn from modelled experiments such as this one? Support your statement using data and limitations of the model.

**Improvements**

4 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the reliability or validity of the data.

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## Section 4.4 questions

QUIZ

**Retrieval**

1 **Recall** the age of the universe.

2 **State** the assumption that Hubble made about galaxies and what he concluded about galaxies that appeared smaller than others.

3 An astronomer observed a distant galaxy to be travelling at a recessional velocity of 370 km $s^{-1}$. Use the current value of Hubble's constant (73.8 km $s^{-1}$ $Mpc^{-1}$) to **calculate** its distance from us. Give your answer in both megaparsecs and light years.

**Comprehension**

4 **Explain** the concept of the observable universe.

**Analysis**

5 **Organise** the following parts of the electromagnetic spectrum from lowest frequency to highest: infrared, gamma, radio, X-ray, microwave, visible, ultraviolet.

**Knowledge utilisation**

6 **Create** a drawing with labels to demonstrate the enormous size of the universe.

**Figure 4.46** The Orion Nebula in a composite image of visible light and infrared, taken by the Hubble Space Telescope.

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# Chapter review

## Chapter checklist

You can download this checklist from the Interactive Textbook to complete it.

| Success criteria | | Linked questions | Check |
|---|---|---|---|
| 4.1 | I can describe First Nations Australians' knowledges of celestial bodies and explanations of the origin of the universe. | 7 | |
| 4.1 | I can describe recent advances in astronomy. | 12 | |
| 4.1 | I can identify the different technologies used to collect astronomical data and the types of data collected. | 13 | |
| 4.2 | I can describe how stars' light spectra and brightness is used to identify compositional elements of stars, their movements and their distances from Earth. | 8 | |
| 4.3 | I can describe the major components of the universe. | 17 | |
| 4.4 | I can describe the major changes in the universe that have occurred since the Big Bang. | 18 | |
| 4.4 | I can describe the evidence that provides support for the acceptance of the Big Bang theory. | 3 | |

SCORCHER

## Review questions

### Retrieval

1 **Recall** the evidence that Ptolemy used to explain his geocentric model.
2 **Recall** the evidence that Copernicus used to disprove the geocentric model.
3 **Recall** the evidence that supports the Big Bang theory.
4 An astronomer makes two observations of a star six months apart and measures a parallax angle of 0.1 arcseconds. **Calculate** the distance to the star. Convert your answer into light years and kilometres.
5 **Recall** how parallax can be used to measure distances in space.
6 **Recall** the definition of a red giant.
7 **Recall** whether the Sun is male or female in many First Nations Australian cultures.

Figure 4.47 An artist's engraving of Ptolemy looking to the sky

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### Comprehension

8 **Describe** the relationship between star brightness, size and length of lifetime. Explain why this is the case.
9 Astronomers have found that the spectral lines from a distant galaxy are shifted towards the red part of the spectrum. **Summarise** what this tells us about the galaxy and what it implies about the universe.
10 **Explain** why we cannot see photons emitted in the early stages of the universe.
11 **Explain** how cosmic microwave background is considered evidence for the Big Bang.
12 **Describe** some recent advances in astronomy.

### Analysis

13 **Compare** optical and radio telescopes.
14 **Contrast** red shift and blue shift.
15 **Contrast** the heliocentric and geocentric models of the universe.

### Knowledge utilisation

16 **Discuss** the chances of finding intelligent life elsewhere in the universe. Use evidence to justify your answer.
17 **Discuss** the major components of the universe.
18 **Discuss** the major changes that have occurred in the universe since the Big Bang.

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## Data questions

The universe is home to billions of stars, many much larger and much brighter than the star we call the Sun. Figure 4.48 presents a selection of stars in our universe and shows their surface temperature and luminosity. As a reference, the Sun has a luminosity of 1 and a surface temperature of approximately 5800 K. The stars in Figure 4.48 belong to four different categories depending on their properties: the main sequence, white dwarfs, red giants and blue or red supergiants.

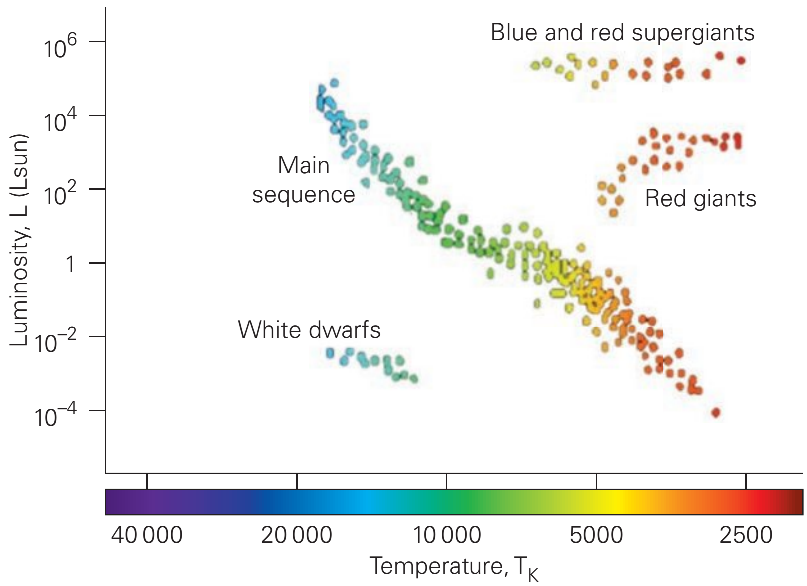


**Figure 4.48** A Hertzsprung–Russell diagram illustrating the surface temperature and luminosity of various stars in the universe

### Apply

1 **Identify** the category of star to which our Sun belongs.

2 **Determine** which category of star is most luminous.

3 The *x*-axis provides the star surface temperature in units of kelvin (°C = K − 273). Given the surface temperature of the Sun is 5800 K, **calculate** the surface temperature in degrees Celsius.

### Analyse

4 **Identify** the trend of surface temperature and luminosity of stars in the main sequence.

5 **Contrast** the properties of white dwarfs and red giants.

6 **Identify** any patterns occurring in the properties of blue and red supergiants.

### Interpret

7 A large star has been discovered and classified as a main sequence star with a surface temperature of 25 000 K. **Deduce** the luminosity of this star compared to the Sun.

8 New data have suggested that this new star (from Question **7**) is almost 100 000 years old, its surface temperature is cooling and it is becoming slightly more luminous. **Predict** the category this star will belong to as it changes properties from the main sequence.

9 **Compare** the properties of all four categories of star. Do you think the size of a main sequence star will ultimately determine whether it becomes a supergiant, giant or dwarf?

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# STEM activity: Creating a representation of our solar system to scale

## Background information

How do you create an image that shows, as accurately as possible, the distance between our Sun and Earth (150 million km)? Have you stopped to think about those tremendous distance numbers? Why not represent our solar system to scale?

Humans are used to handling small numbers and units. We talk about centimetres, metres or kilometres; and minutes, hours, days, months or years. However, in astronomy we see tremendously large numbers in space and time which escape our understanding and are difficult for us to imagine. In this activity you are invited to create a representation of our solar system to scale to gain a better understanding of its size.

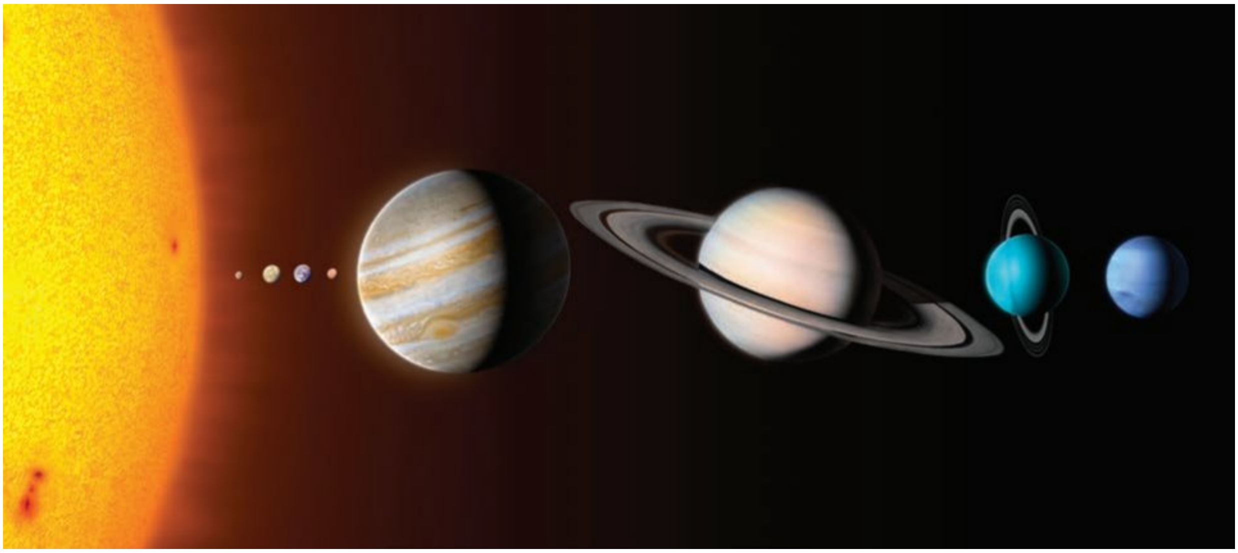

Figure 4.49 A representation of our solar system where the distances are not to scale, but the sizes are to scale

**Design brief:** Design a scale model of the universe and present this information in the form of a vlog (video blog or video log).

## Activity instructions

The solar system is much bigger than most people think. In this activity you will collaborate in groups to create a representation of our planetary system to scale, using hands-on materials while recording your journey. The scale model must include all the planets and known dwarf planets. You will need to make sure that your scale model helps others gain a better idea of the vastness and true size of our solar system. To do this you will need to make sure that you find a way (for example, a formula) to convert distances and diameters of planets into something humans can comprehend. How do we do that?

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Here are a couple of suggestions:

- Imagine that we convert the distance from the Sun to our Earth from 150 million km to 2 metres instead. Can you see how much easier it is to visualise and comprehend the 'metre' than the 'millions of kilometres'? Now you can repeat this same conversion for all planets on the solar system using the table provided. That will let you start comparing distances for these celestial bodies in a much more meaningful way. You can finally visualise the scale of the vastness of our solar system.
- Having the correct distances is a good step but does not give the full picture. Consider converting the diameter of our planet (12 756 km) to a more manageable number. What about 10 cm? Then convert the diameters of the other bodies in our solar system.

Use your new measurements to create a 2D version of the solar system, showing Earth and all other planets and dwarf planets. Record a vlog of all the stages of your 2D solar system and edit this video to be used as an educational resource.

## Suggested materials

## Model

- large reel of measuring tape
- colouring pencils, cardboard and paper to create your planets
- protractor
- scissors
- movie maker software and recording device

NOTE: You may need to use the school oval to really represent the distances involved.

## Research and feasibility

1 Using the information in Table 4.4, research how you could create a formula to assist you to convert all values from millions of kilometres to more manageable units (metres or centimetres). What skills do you need to perform that task? Record all information on your vlog.

2 Discuss in your group the feasibility of presenting the scale model within the restrictions of school. List your ideas of how to demonstrate the vast size of the solar system.

3 Record your research and results as the Research and feasibility section of your vlog.

## Design and sustainability

4 Analyse Table 4.4 and make a statement about how the orbital period of a celestial body is affected by its distance from the Sun. Explain your reasoning.

5 The dwarf planet Haumea has been described as 'eccentric' by its discoverers. Analyse the table and determine which bit of data shows how this dwarf planet is very different from other dwarf planets.

6 Planets orbit around the Sun on elliptic orbits.

  a Compare and contrast the average distance from the Sun of planets and dwarf planets.

  b How do the orbits of dwarf planets compare (visually) to the orbit of inner planets in our solar system? You can draw or sketch your answer if you like.

7 Record your analysis as a Design and sustainability section of your vlog.

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| Name of planet | Average distance from Sun (km) | Diameter (km) | Time to spin on axis (a day) | Time to orbit Sun (a year) | Distance scale (m) | Diameter scale (cm) |
|---|---|---|---|---|---|---|
| Mercury | 57 900 000 | 4878 | 59 days | 88 days | | |
| Venus | 108 160 000 | 12 104 | 243 days | 224 days | | |
| Earth | 149 600 000 | 12 756 | 23 hours, 56 mins | 365.25 days | 2 | 10 |
| Mars | 227 936 640 | 6794 | 24 hours, 37 mins | 687 days | | |
| Jupiter | 778 369 000 | 142 984 | 9 hours, 55 mins | 11.86 years | | |
| Saturn | 1 427 034 000 | 120 536 | 10 hours, 39 mins | 29 years | | |
| Uranus | 2 870 658 186 | 51 118 | 17 hours, 14 mins | 84 years | | |
| Neptune | 4 496 976 000 | 49 532 | 16 hours, 7 mins | 164.8 years | | |
| **Dwarf planets** | | | | | | |
| Ceres | 413 900 000 | 950 | 9 hours, 5 minutes | 4 years, 220 days | | |
| Pluto | 4 436 820 000 to 7 375 930 000 | 2370 | 6 days, 9 hours | 248 years | | |
| Haumea | 5 260 000 000 to 7 708 000 000 | 1960 × 1518 × 996 | 4 hours | 258 years | | |
| Eris | 5 665 500 000 to 14 634 000 000 | 2326 | 7 hours, 46 minutes | 557 years | | |

**Table 4.4** Some information about planets and dwarf planets within our solar system

## Create

8 Create your 2D solar system model. Make sure to include your scale.

9 Record the whole creation of your 2D model in the Create section of your vlog.

## Evaluate and modify

10 Edit your vlog into a video file that can be shared.

11 Reflect on how effective your vlog is in demonstrating the vastness of our solar system.

12 Present your vlog to the class and discuss the use of vlogs to share information, and the effectiveness of its use.

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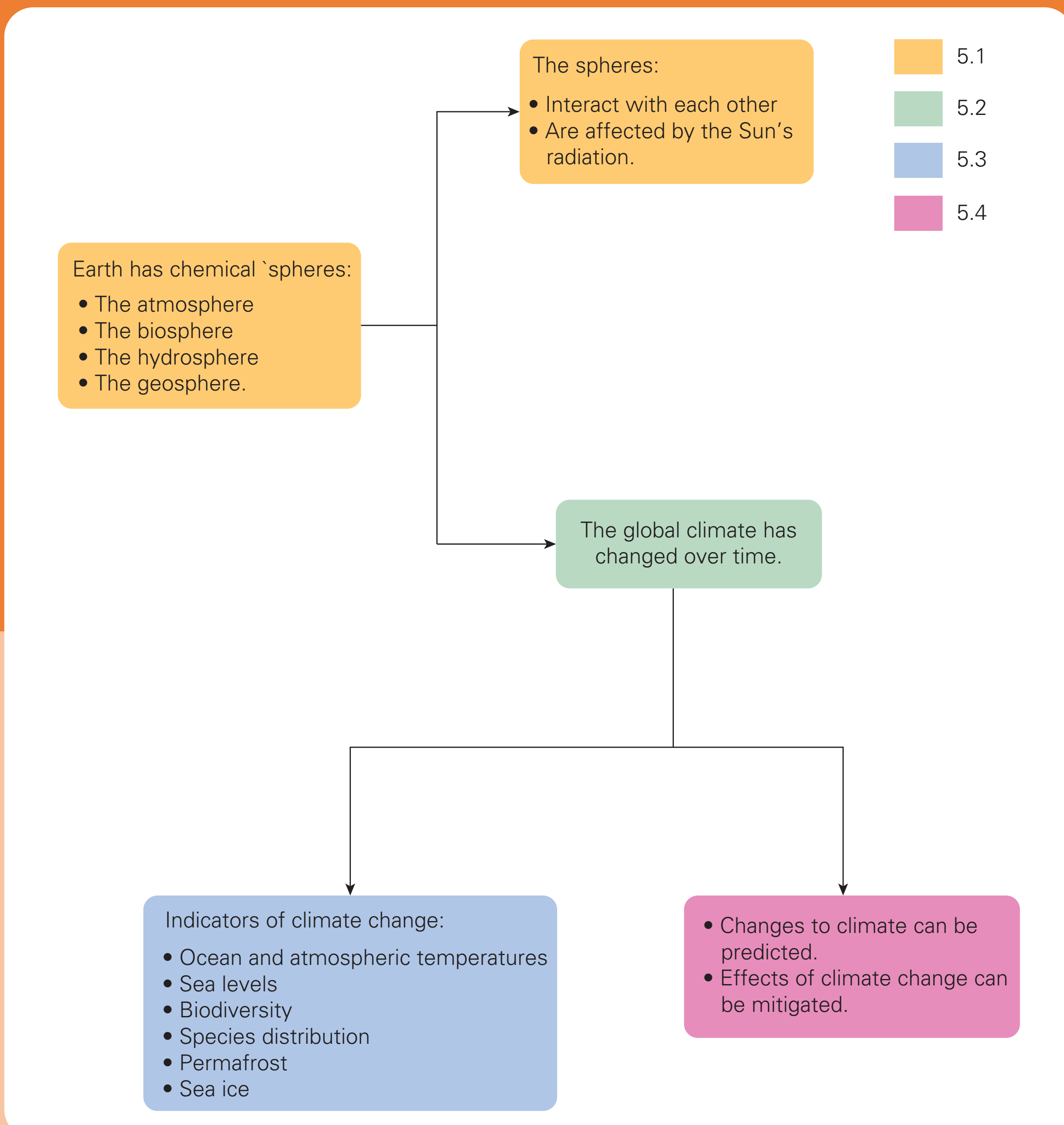
# Chapter 5
# Our dynamic climate

## Chapter introduction

Earth is a complex system consisting of interconnecting spheres and the cycles that link them together. Many climatic processes are the result of interactions between the spheres, which create a dynamic global climate. Changing interactions have caused climate to change in the past, to be changing in the present and to be predicted to change in the future. In this chapter, you will learn about how the natural cycles of climate change are being affected by humans. You will understand the factors that regulate, and the evidence for, global climate change and learn how scientists predict changes to Earth's climate.

# Concept map

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## Curriculum

| Use models of energy flow between the geosphere, biosphere, hydrosphere and atmosphere to explain patterns of global climate change (AC9S10U04) | |
|---|---|
| examining the role of radiation from the sun and how its interactions with the atmosphere, ocean and land are the foundation for the global climate system | 5.1 |
| identifying changes in global climate over time, exploring visualisations and using simulations to explore why energy balances have changed | 5.2 |
| examining the factors, including energy, that drive deep ocean currents, their role in regulating global climate and their effects on marine life | 5.2 |
| investigating indicators of climate change such as changes in ocean and atmospheric temperatures, sea levels, biodiversity, species distribution, permafrost and sea ice | 5.3 |
| predicting changes to the Earth system and identifying strategies designed to reduce climate change or mitigate its effects | 5.4 |
| investigating how quantum computers enhance modelling of complex weather and climate systems | 5.4 |



## Glossary terms

Anthropogenic
Atmosphere
Biosphere
Climate
Geosphere
Glacial period
Greenhouse effect
Greenhouse gases
Hydrosphere
Interglacial period
Lithosphere
Weather

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# 5.1 Earth's interacting spheres

**Learning goals**

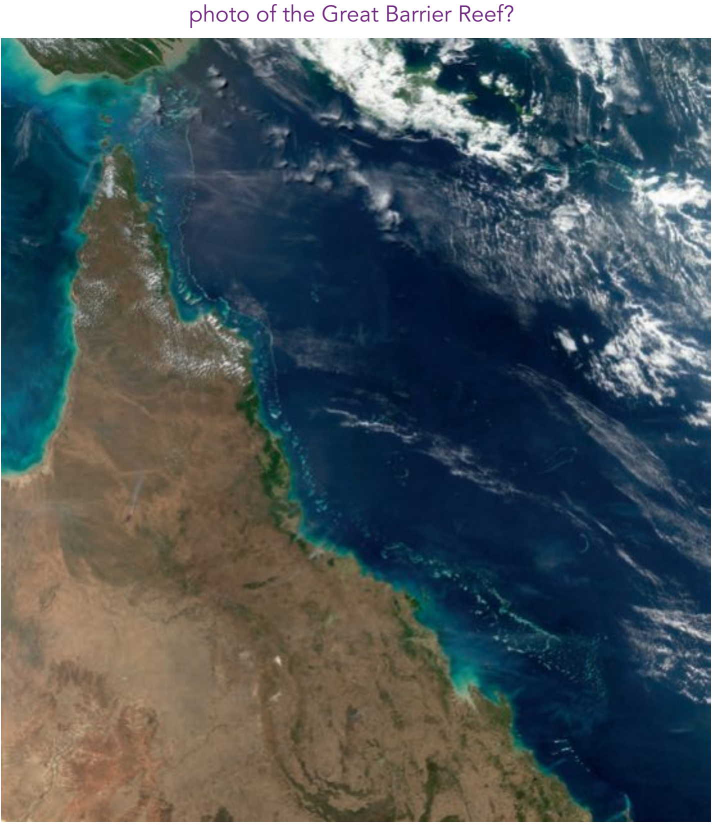
1. To be able to distinguish between Earth's chemical spheres: atmosphere, biosphere, geosphere and hydrosphere.
2. To be able to state that the Sun's radiation and its interactions with Earth's spheres are the foundation for the global climate system.

WORKSHEET
Sphere interactions

VIDEO
Earth's spheres

Earth can be considered a system made of various interconnected components that interact and influence one another. These components include the atmosphere, hydrosphere, lithosphere and biosphere. Each of these spheres has unique physical, chemical and biological properties, but they are not isolated from one another. Instead, they are interconnected through processes like the carbon cycle, nutrient cycling and energy flow. These processes ensure that the Earth system operates in a delicate balance, with changes in one sphere having consequences for the others.

**Figure 5.1** Can you spot all of the spheres in this photo of the Great Barrier Reef?



## Chemical spheres

### The atmosphere

The **atmosphere** is the layer of gases that surrounds Earth. It is composed of various gases, including nitrogen (78%), oxygen (21%), and trace amounts of other gases such as argon, carbon dioxide and neon. The atmosphere is responsible for regulating Earth's temperature and protecting it from harmful radiation, and it plays a critical role in the water cycle. It is divided into several layers, including the troposphere, stratosphere, mesosphere, thermosphere and exosphere, each with distinct characteristics and properties.

**atmosphere**
the mixture of gases above the surface of Earth

**Quick check 5.1**

1. Name the gas which is the most abundant in Earth's atmosphere.
2. Recall the functions of Earth's atmosphere.

#### The troposphere

The troposphere is the lowest layer of Earth's atmosphere, extending from Earth's surface up to an altitude of approximately 6 to 20 kilometres. It is where most weather occurs and is the layer in which we live and breathe. The troposphere is composed mainly of nitrogen and oxygen, along with trace amounts of other gases, such as water vapour, carbon dioxide and methane.

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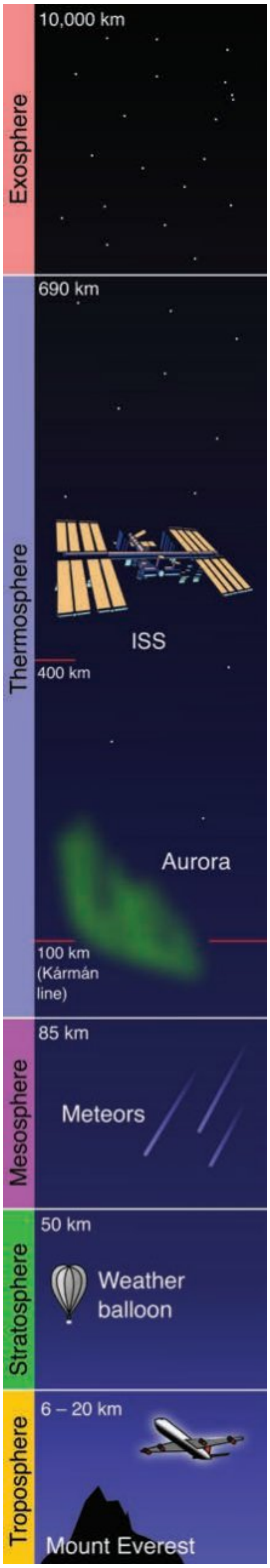


Figure 5.2 The five layers of Earth's atmosphere

The temperature in the troposphere decreases with altitude, which is why the highest temperatures are near Earth's surface and the lowest temperatures are at the top of the layer. This temperature gradient leads to convection currents, which drive weather patterns and atmospheric circulation. The troposphere is critical for supporting life on Earth, as it provides the oxygen we breathe, regulates Earth's temperature and plays a vital role in the carbon and water cycles.

### The stratosphere

The stratosphere is the layer of Earth's atmosphere above the troposphere, extending from approximately 20 to 50 kilometres in altitude. It is characterised by a relatively high concentration of ozone, which absorbs harmful ultraviolet radiation from the Sun. The temperature in the stratosphere increases with altitude because the ozone layer absorbs solar radiation, which creates a stable layer that inhibits mixing with the troposphere below.

This layer is also home to the jet stream, a high-altitude, fast-moving wind that influences weather patterns. The stratosphere plays a crucial role in regulating Earth's temperature.

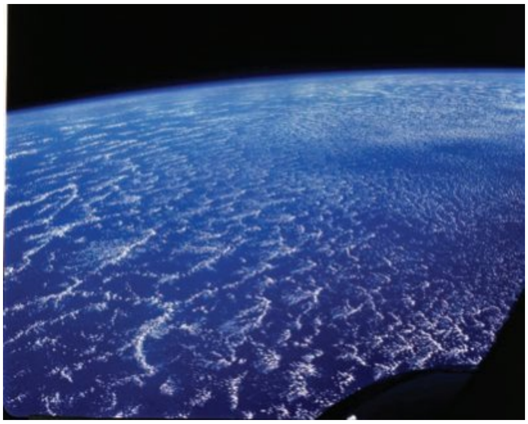

Figure 5.3 A large network of stratocumulus clouds. The blue band in the horizon is the troposphere.

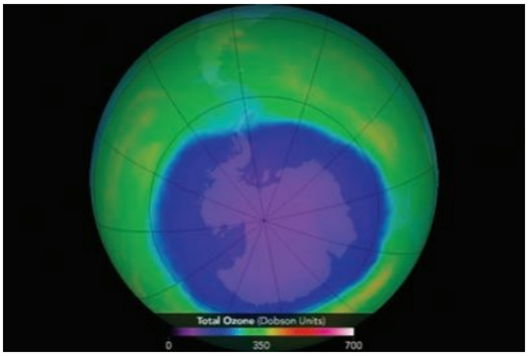


Figure 5.4 Human activities such as the release of chlorofluorocarbons (CFCs) have caused damage to the ozone layer, leading to the formation of the ozone hole, which poses a threat to human health and the environment.

Figure 5.5 The Northern Hemisphere jet stream

## Quick check 5.2

1 List some features of the troposphere.
2 Give the function of the ozone layer in the stratosphere.

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## Explore! 5.1

**The Antarctic hole in the ozone layer**

In 1985 scientists found that parts of the ozone layer above the continent of Antarctica had broken down. They also noticed that similar thinning of the ozone layer was happening over parts of Australia, and that this correlated with an increase in cases of skin cancer. They needed to find out why this had happened and if it could be reversed. Do some research and answer the following.

1. Compare the atomic structures of oxygen gas ($O_2$) and ozone gas ($O_3$).
2. Identify the main function of the ozone layer in more detail to explain the impact of ozone thinning.
3. Research the causes of ozone thinning.
4. Describe the purpose of the Montreal Protocol.
5. In October 2022, a UN-backed scientific panel released a report saying the ozone layer is on track for a full recovery. When do they predict this will happen by?

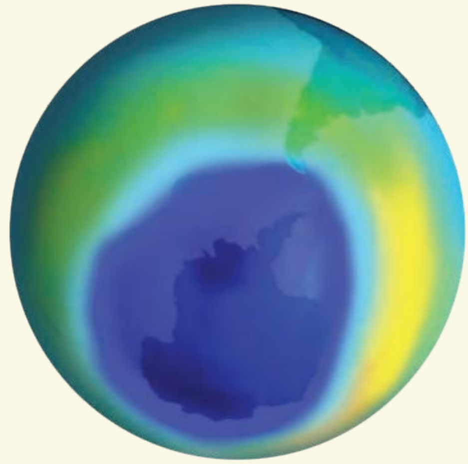

**Figure 5.6** The hole in the ozone layer above Antarctica. The bluish-purple areas show the least amount of ozone.

## The biosphere

The **biosphere** is the thin layer of Earth where life can exist. It is made up of all the living organisms on the planet, including plants, animals and microorganisms, as well as the physical environments in which they live.

The biosphere extends from the deepest parts of the ocean to the highest peaks of the mountains, and from the polar ice caps to the Equator. It is a complex and interconnected system, with organisms relying on each other for survival and functioning together to maintain the delicate balance of the planet's ecosystems.

**biosphere**
all the areas on Earth and in its atmosphere that contain life

**hydrosphere**
all of the water found on Earth (e.g. lakes and rivers)

**Figure 5.7** Human activities, such as pollution and deforestation, can have significant impacts on the biosphere and disrupt the balance, leading to negative consequences for living organisms.

### Quick check 5.3

1. What is the biosphere?
2. Flying birds are part of the atmosphere, true or false? Justify your choice.

## The hydrosphere

The **hydrosphere** refers to all the water on Earth, including oceans, rivers, lakes, groundwater and even water in the atmosphere. It plays a critical role in supporting life on Earth, as all living organisms require water to survive.

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The hydrosphere also plays a key role in regulating Earth's climate, as it absorbs and distributes heat throughout the planet. Additionally, the movement of water in the hydrosphere, such as through the water cycle, helps to shape Earth's surface and create important habitats for various organisms.

**Figure 5.8** The hydrosphere faces numerous threats such as pollution, overuse and climate change.

**Quick check 5.4**

1 What is the hydrosphere?
2 Give an example of something that is part of the hydrosphere.

## The geosphere

The **geosphere** refers to the solid and fluid rock and mineral parts of Earth, including the crust, mantle and core. It is the largest of Earth's four major spheres, and it plays a crucial role in supporting life on the planet. The geosphere is responsible for providing the foundation for Earth's surface features, including mountains, valleys and plateaus. It is also home to valuable natural resources, such as minerals and fossil fuels, which are essential to human societies.

**geosphere** includes Earth's magma, lava, rocks and minerals

**lithosphere** the geological parts of Earth's crust and upper mantle only

The **lithosphere** is often included in discussions of Earth's global systems. It specifically refers to the outermost layer of Earth's crust and the uppermost section of the mantle.

**Figure 5.9** The geosphere is constantly undergoing changes due to natural processes like plate tectonics, erosion and volcanic activity, which can lead to earthquakes, landslides and other hazards.

In contrast, the geosphere encompasses all the minerals and rocks on Earth, extending from the crust to the inner core. The lithosphere is divided into numerous tectonic plates that rest atop the underlying mantle. Many seismic and volcanic events occur along the boundaries between these plates.

**Quick check 5.5**

1 What is the geosphere?
2 Give an example of something that is part of the geosphere.

## Spheres and the global climate system

The Sun's radiation forms the foundation of Earth's climate system. Radiation that reaches Earth's surface interacts with the different spheres and drives various atmospheric, oceanic and land processes that collectively determine the global climate. The Sun's radiation heats air and water, evaporates water into the air, and drives wind and ocean currents. These interactions create weather patterns and climate zones, which can be seen in Figure 5.10. The absorption and reflection of the Sun's radiation by Earth's atmosphere and surface also regulate Earth's temperature, influencing global climate.

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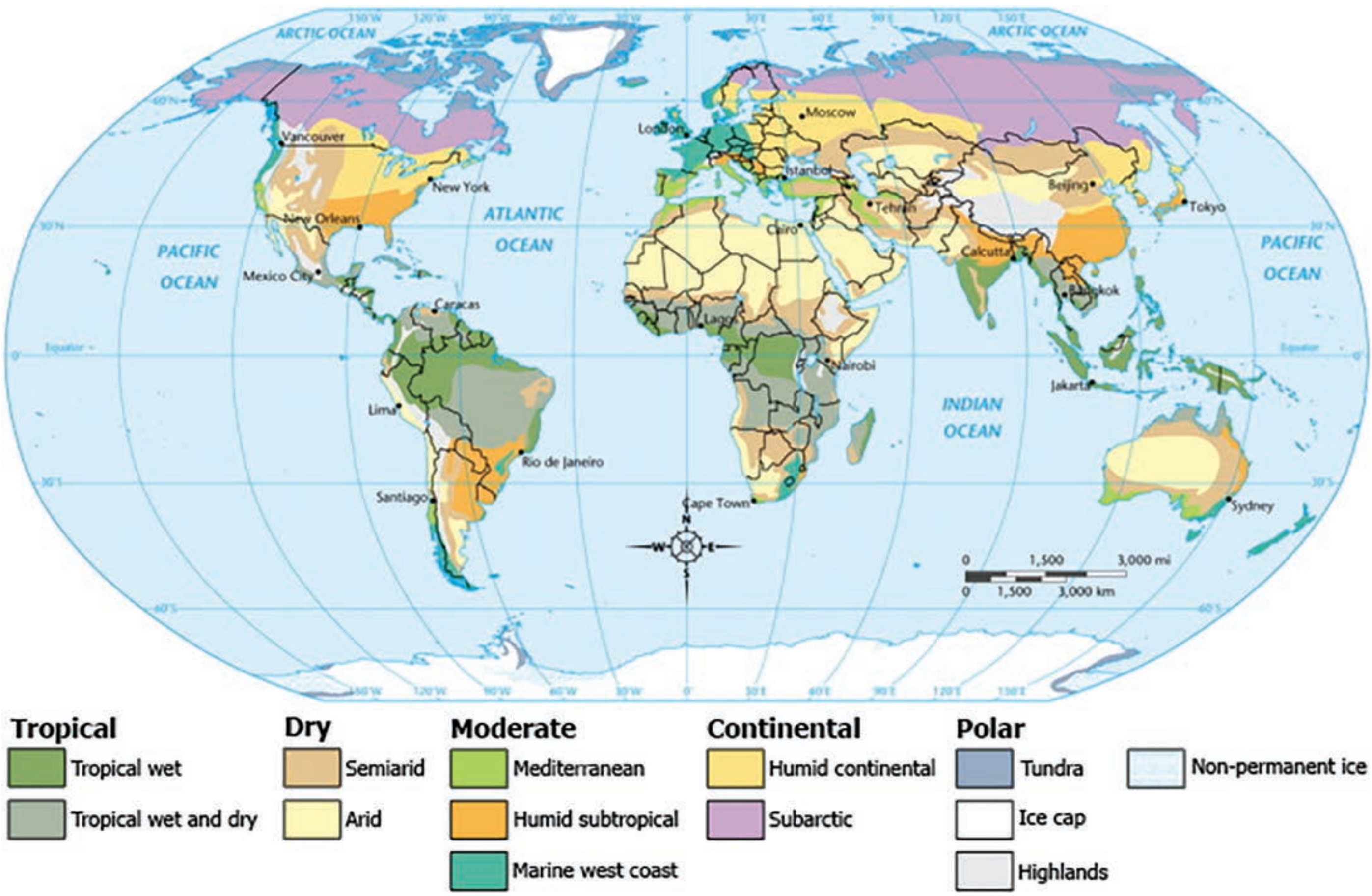


**Figure 5.10** Global climate zones

## Quick check 5.6

1. Describe how the Sun is the primary source of energy for Earth's climate system.
2. Identify the major climate zone of Australia.

## Section 5.1 questions

QUIZ

### Retrieval

1. **Recall** the correct definition for each chemical sphere.
   - a Atmosphere
   - b Biosphere
   - c Lithosphere
   - d Hydrosphere
2. **Identify** the correct sphere for the following examples.
   - a Glacier
   - b Tectonic plates
   - c Earthworms
   - d Ozone

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3 **Recall** the layer of the atmosphere where most of the weather occurs.
4 **Recall** the second most abundant gas in Earth's atmosphere.
5 **Identify** which of Earth's spheres would contain matter that has arrived from space.

**Comprehension**

6 **Explain** the problems associated with a hole in the ozone layer.
7 **Describe** the role of Earth's atmosphere in terms of sustaining life on Earth.

**Analysis**

8 **Compare** the geosphere with the lithosphere.
9 **Identify** examples of the chemical spheres present in Figure 5.11.
10 **Identify** the sphere interactions taking place in Figure 5.12.
11 **Analyse** why a healthy river containing dissolved nitrogen, oxygen and carbon dioxide, algae and other organisms, and mineral and rock fragments, contains components from all the chemical spheres.

**Knowledge utilisation**

12 **Decide** which spheres clouds belong to and then justify your answer.
13 **Discuss** how a natural disaster, such as an earthquake, can affect the chemical spheres. Try to include all four spheres in your answer.


**Figure 5.11** Chemical spheres


**Figure 5.12** Sphere interactions

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# 5.2 Changing climates

**Learning goals**
1. To be able to identify changes in global climate over time.
2. To be able to explain the role that deep ocean currents have on global climate.

WORKSHEET Increasing global temperatures

## Climate versus weather

The difference between **weather** and **climate** is merely the time frame. Weather describes the conditions of the atmosphere in terms of temperature, cloud, rain and wind over a short period of time (minutes to months). The climate of an area is how the area behaves over a much longer period of time, usually 30 or more years. Different areas can have different climates; for example, the climate in Queensland is very different from the climate in Tasmania.

Different areas of the world have differing climates due to the:

- uneven distribution of the Sun's rays because of the curvature of the Earth
- proximity to the sea; land takes less energy to heat than water, so land temperatures rise quickly during the day and fall quickly during the night. The sea tends to remain cool during the day but retains its warmth at night
- tilt of Earth's axis, which causes seasons
- features on the land such as mountains. Air cools when it expands so when air passes over a mountain its temperature drops. This is why mountain tops are often covered in snow or cloud
- type of soil or plant life.

**weather**
the atmospheric conditions (such as temperature, cloud, rain or wind) at a particular time over a particular area

**climate**
the average or prevailing weather conditions of an area over long periods of time

VIDEO Climate change

## The role of deep ocean currents

Most the Sun's radiation is absorbed by the ocean, particularly in tropical waters. The ocean plays a critical role in Earth's climate system as it doesn't just store heat, it also distributes it around the globe.

Evaporation is a key component of this heat exchange. When ocean water absorbs the Sun's radiation, it heats up and evaporates into the atmosphere, leading to an increase in temperature and humidity. This increased

### Did you know? 5.1

**The East Coast Low**
Eastern Australia experiences more storms in summer because of the presence of a weather pattern called the East Coast Low (ECL). An ECL is a low-pressure system that forms along the eastern coast of Australia, particularly in summer, bringing heavy rainfall and strong winds. ECLs are a result of warm ocean temperatures, high-pressure systems and the coastal topography of eastern Australia. These conditions provide the energy and moisture needed to generate intense storms, making the region particularly vulnerable to severe weather events during the summer months.

**Figure 5.13** Lightning over the Gold Coast

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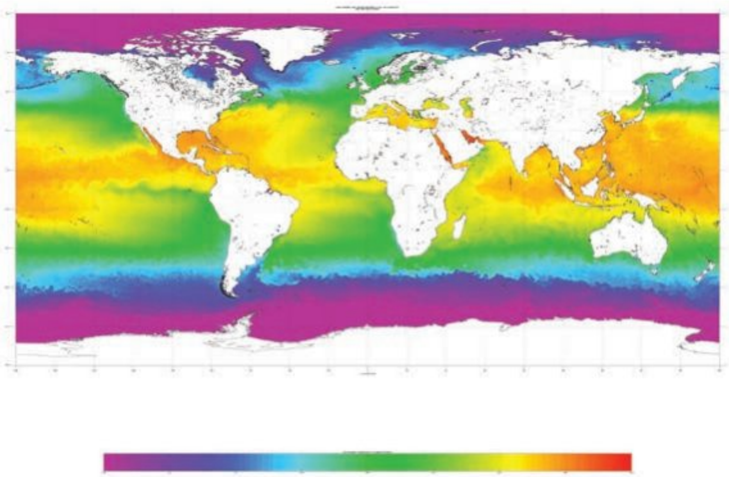

Figure 5.14 Global sea-surface temperatures taken from the National Oceanic and Atmospheric Administration (NOAA) Office of Satellite and Product Operations. The colourmap ranges from −2.0°C (purple) to 34.6°C (red).

humidity then condenses into clouds, which can lead to stormy weather. Storms are carried by trade winds and travel long distances, distributing heat and moisture around Earth. This exchange of heat and moisture between the ocean and the atmosphere helps to regulate the global climate.

Deep ocean currents play a significant role in driving weather patterns, especially in areas away from the Equator. Ocean currents are influenced by a complex interplay of factors, including wind, temperature gradients, salinity, Earth's rotation and tides. They help regulate global temperature by transporting heat from the Equator to the poles. This transfer of heat helps distribute the warm Equatorial waters to the colder polar regions, balancing the temperature difference between the two regions and mitigating extreme temperature differences between the two areas. If ocean currents were not present, the equatorial regions would experience extremely high temperatures, while the polar regions would experience extreme cold, making much of Earth's land inhospitable to life.

The major ocean currents typically form circular patterns, flowing clockwise in the Northern Hemisphere and anticlockwise in the Southern Hemisphere, mainly following coastlines. By distributing heat, ocean currents can affect local and regional climates, and they play a major role in the global climate system. In addition, deep ocean currents also mix water and nutrients from the ocean's surface to its depths, helping to improve the overall health and productivity of oceanic ecosystems.

### Quick check 5.7

1. Define the term 'weather'.
2. Give one reason why climates on Earth differ.
3. Describe how deep ocean currents regulate global temperatures.

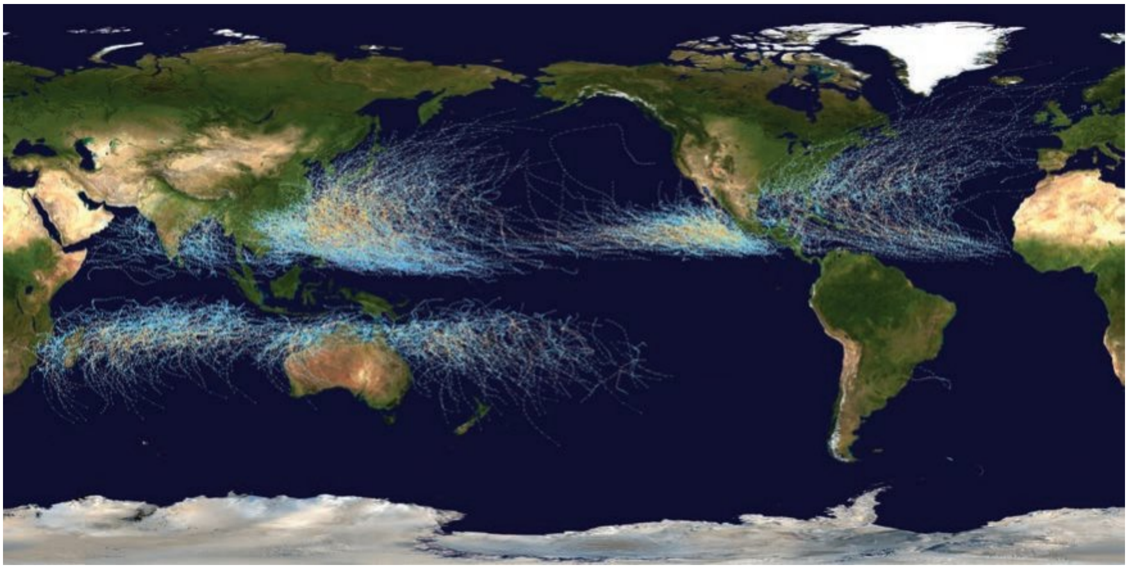

Figure 5.15 A map of tropical cyclone tracks. The higher evaporation rates in the tropics contribute to the higher rainfall and more active weather patterns in that region.

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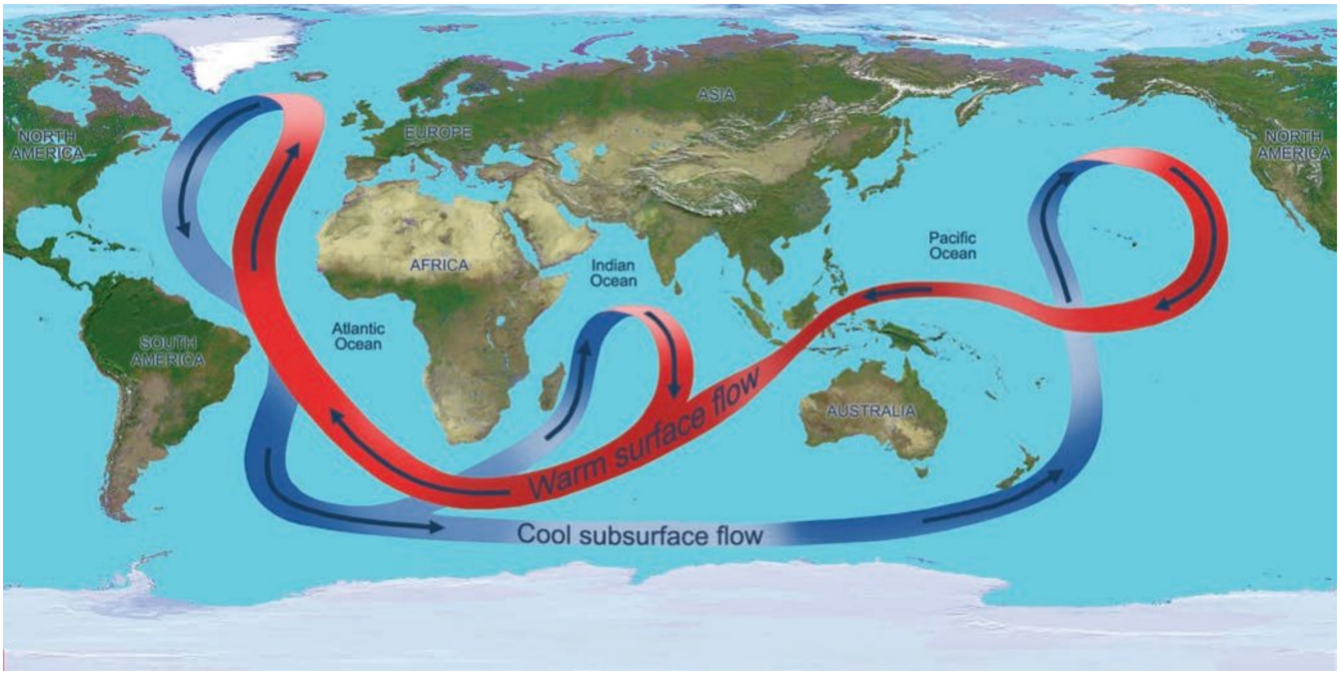


**Figure 5.16** The most well-known deep ocean current is the thermohaline circulation, also known as the 'global conveyor belt'. This current carries warm water from the tropical regions to the colder regions in the North Atlantic, releasing heat into the atmosphere, and then returns as cold, dense water to the equatorial regions to start the cycle again. This heat exchange has a significant impact on the climate of regions far from the Equator and helps to distribute heat throughout Earth's surface, leading to a more stable global climate.

## Climate change

Climate change occurs when a significant change to normal weather patterns has been sustained for a long time – between tens and millions of years. Climate change occurs due to natural causes, such as changes in the Sun's intensity, volcanic eruptions and variations in ocean currents.

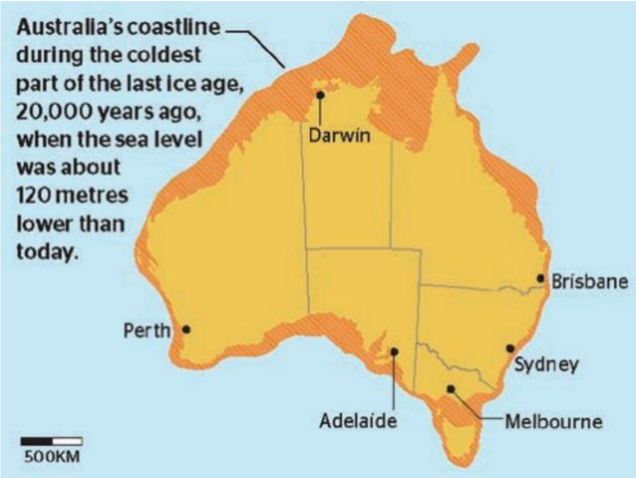


**Figure 5.17** In the last ice age, ice sheets locked up much of Earth's water, making the coastline of every continent far lower than it is today.

Earth's climate is dynamic and has undergone significant changes throughout history. In the past, Earth has experienced many ice ages, where the planet was far colder than it is today, as well as warmer periods, when temperatures were higher than they are today.

A **glacial period** is when a reduction in global temperatures is sustained for a long period of time. The last glacial period started around 115 000 years ago and ended around 11 700 years ago. During this period, sea levels were much lower than now due to the presence of vast ice sheets. As a result, it was possible to walk from Tasmania to mainland Australia across a land bridge. However, as sea levels rose, the land bridge was submerged, creating the Bass Strait.

**glacial period**
a period in Earth's history when a reduction in global temperatures is sustained for a long period of time

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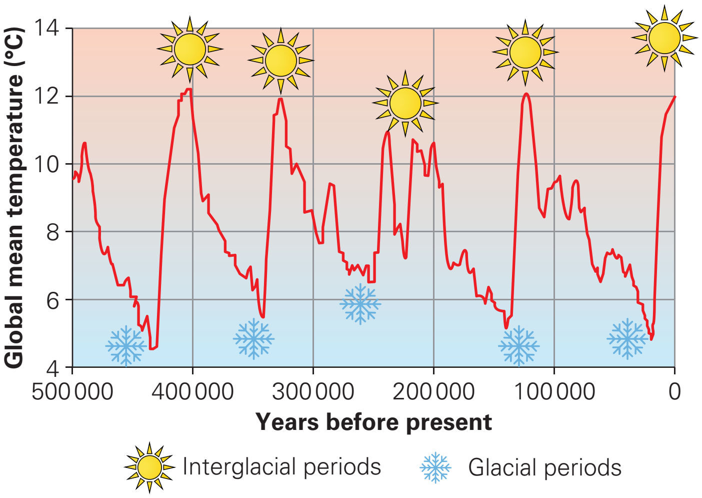


**Figure 5.18** Earth has undergone natural cycles of warming and cooling.

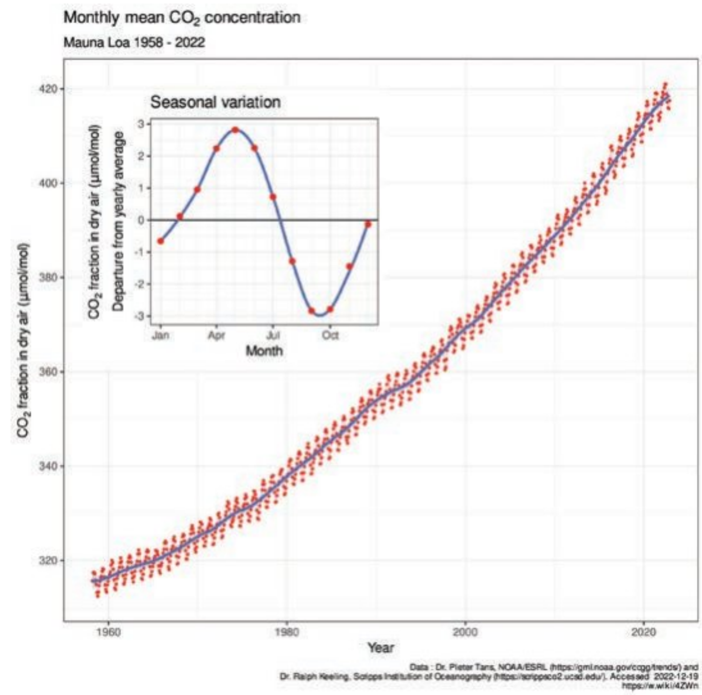


**Figure 5.19** The changes in energy balances, such as the burning of more fossil fuels, have contributed significantly to global climate change. The Keeling curve shows the concentration of carbon dioxide in parts per million (ppm) from 1958 to 2022 using measurements taken from an observatory in Hawaii. The concentration of carbon dioxide in the atmosphere has increased from 280 ppm before 1800 to well over 420 ppm in 2022.

**interglacial period**
a period in Earth's history when an increase in global temperatures is sustained for a long period of time

**anthropogenic**
caused or influenced by people

**greenhouse gases**
gases that contribute to the greenhouse effect

We are currently experiencing an **interglacial period**, and Earth's climate has remained relatively stable throughout this period, with only small fluctuations. However, the current rate of global warming is much faster than the natural climate change observed in the past and is being caused by human activities. This is known as **anthropogenic** climate change.

Anthropogenic climate change is linked to the burning of fossil fuels, deforestation and industrial processes. The release of **greenhouse gases**, such as carbon dioxide, methane and nitrous oxide, into the atmosphere is the primary cause of this accelerated climate change. These gases trap heat from the Sun in Earth's atmosphere, leading to a faster warming of the planet. Over the past 100 years, Earth's average temperature has risen between 0.4°C and 0.8°C; 2016 was the hottest year and 2019 was the second hottest since records began. The years since 2014 have been the warmest years on record.

### Quick check 5.8

1 Define climate change.
2 State the name of the term for when Earth is undergoing a period of cooling.
3 State the name of the term for when Earth is undergoing a period of warming.

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Table 5.1 summarises the influences that humans are having on the climate and how climate change is affecting global systems.

**greenhouse effect** the trapping of the Sun's warmth by a layer of gases in the lower atmosphere

WIDGET Greenhouse effect

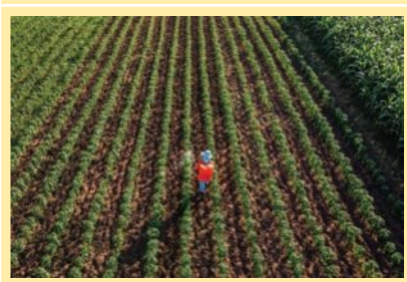
| Human influence | How the climate is affected | |
| --- | --- | --- |
| Deforestation | Fewer trees result in less carbon dioxide being taken in from the atmosphere through photosynthesis. If the wood is burned, this contributes further to the **greenhouse effect**.<br><br>Trees release large amounts of water vapour during transpiration. Fewer trees mean less water vapour in the atmosphere and therefore less rain. |   |
| Agriculture | Cows and sheep produce methane when digesting grass. More cattle means more emissions.<br><br>Agriculture accounts for 11% of Australia's greenhouse gas emissions, and 70% of that comes directly from livestock. |  |
| Burning fossil fuels | Burning fossil fuels produces carbon emissions, which alters the carbon cycle.<br><br>Nitrogen oxides (NOx) are also produced when fossil fuels burn, causing smog and acid rain. |  |
| Fertilisers | Adding fertilisers containing nitrates to the soil speeds up their conversion into nitrous oxide, another greenhouse gas. |  |

**Table 5.1** A summary of some human influences on climate change

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## Making thinking visible 5.1

**Generate-sort-connect-elaborate: Climate change**

Map your understanding of climate change.

1 Create a list of ideas that come to mind when contemplating climate change.
2 Arrange your ideas in a mind map based on their importance. Place important or relevant concepts near the centre and less important ones towards the outside of the page.
3 Draw connecting lines between ideas that share similarities. Write a brief statement describing the connections between your ideas.
4 Elaborate on any of the ideas you have by introducing new concepts that extend your initial ideas.

Keep adding new ideas until you feel that you have a comprehensive understanding of climate change.

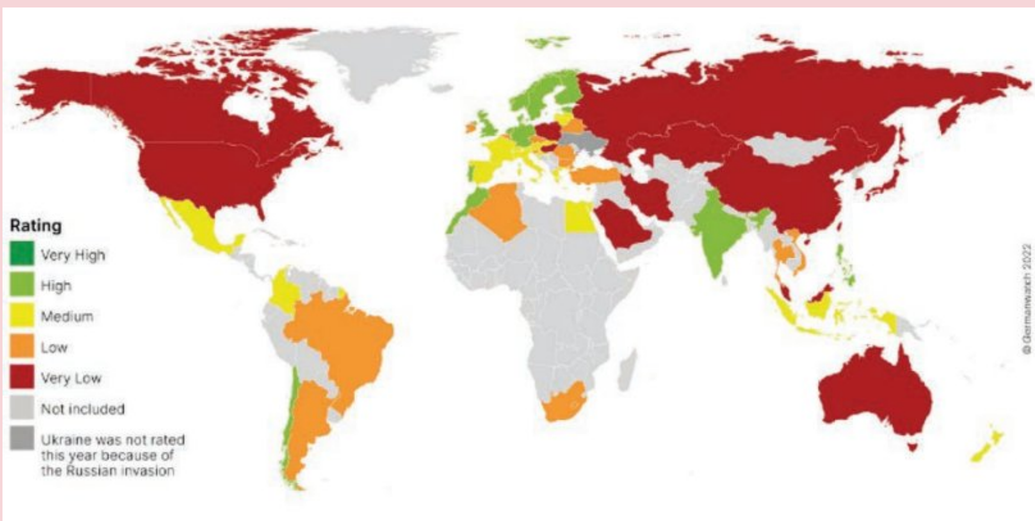


**Figure 5.20** Australia's environmental protection efforts continue to be among the lowest in the world. Australia ranks 55th out of 63 possible places in the Climate Change Performance Index 2023.

The *Generate-Sort-Connect-Elaborate* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

## Explore! 5.2

**Cow burps**

Beef and dairy cattle contribute significantly to climate change through the following processes:

- **Methane emissions**. Cows produce methane through their digestive process known as rumination.
- **Land use change**. Beef and dairy production often requires the conversion of natural habitats, such as forests and grasslands, into agricultural land for growing feed crops and for pasture. This conversion leads to the loss of carbon-absorbing vegetation and soil, and releases carbon into the atmosphere.
- **Fertiliser use**. Growing crops to feed cattle requires the use of fertilisers, which produce nitrous oxide.
- **Transportation emissions**. Beef and dairy products are often transported long distances, contributing to emissions from transportation.

**Figure 5.21** Most methane from cows is emitted through their burps, although some comes from flatulence too. In 2022, a design group called Zelp (Zero Emissions Livestock Project) won a design competition for creating a cow mask that converts methane emissions into $CO_2$ and water vapour.

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## Quick check 5.9

1 Name three greenhouse gases.
2 Recall the main greenhouse gas that is produced by agriculture.

## Section 5.2 questions

QUIZ

**Retrieval**

1 **Define** the term 'climate'.
2 **Identify** the correct words to complete the sentence: Earth is currently experiencing *an interglacial/a glacial* period.
3 **State** one way that humans have influenced the climate on Earth.

**Comprehension**

4 **Describe** some differences in climate between Queensland and Tasmania.
5 **Describe** the relationship between global temperatures and the glacial and interglacial periods.
6 **Explain** the impact that deep ocean currents have on global climate.

**Analysis**

7 **Compare** global warming and climate change.
8 **Differentiate** between weather and climate.

**Knowledge utilisation**

9 **Discuss** how human activities have accelerated climate change.
10 **Evaluate** the effect of an unexpected volcanic eruption on climate change predictions.

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# 5.3 Indicators of climate change

DOC
WORKSHEET
Analysing Antarctic ice core data

VIDEO
Indicators of climate change

**Learning goal**

1. To be able to describe the indicators of climate change.

To better understand the impacts of climate change and track progress in mitigating its effects, scientists use a variety of indicators to monitor changes in the climate system. These indicators provide a picture of the state of the climate.

## Changes in ocean and atmospheric temperatures

Ocean and atmospheric temperatures reflect the overall temperature of the planet's surface. Any long-term increase in atmospheric and ocean temperatures will affect many aspects of Earth's systems, including ocean circulation, sea level and weather patterns, leading to climate change. Rising temperatures result in increased rainfall, the melting of glaciers and ice sheets, and rising sea levels. Increased temperatures in the atmosphere result in more energy being available to create extreme weather events such as storms and cyclones. Temperature changes are monitored by a variety of instruments, including satellite measurements, ocean buoys and weather stations, providing evidence for climate change and the ongoing impact of human activities.

## Sea levels

As global temperatures increase, polar ice caps melt and cause a rise in sea levels. Ocean water in equatorial regions expands as it warms, contributing to further sea level rises. Increasing sea levels can cause coastal flooding and erosion and affect coastal ecosystems and communities. Sea level measurements are made using equipment such as satellite altimeters and tide gauges.

**Figure 5.22** Coastal infrastructure will be destroyed by sea level rises and an increase in extreme weather events.

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VIDEO
El Nino southern oscillation

## Did you know? 5.2

### La Niña events are getting worse

La Niña is a climatic phenomenon characterised by the cooling of the central and eastern tropical Pacific Ocean. It is the counterpart to El Niño, which is characterised by warming of the same region. La Niña events can have significant impacts on global weather patterns, causing alterations in temperature, precipitation and wind patterns.

Some of the effects of La Niña include increased rainfall in some areas, drought in others and changes in atmospheric circulation patterns that can affect tropical storms. La Niña is one of the important factors that scientists consider when making long-range weather and climate forecasts.


**Figure 5.23** Global weather impacts of La Niña

La Niña events are a natural part of Earth's climate system, but their severity and frequency may be influenced by climate change, as rising global temperatures can disrupt the balance of ocean and atmospheric conditions that drive these events.

**Figure 5.24** La Niña typically increases the chance of above-average rainfall for northern and eastern Australia during summer. The impact of the 2022 La Niña on rainfall in Australia was exacerbated by the warming of the Indian Ocean, which has been attributed to human-caused climate change. This warming likely contributed to record rainfalls and devastating floods.

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## Practical skills 5.1

### Salinity and density

When seawater freezes in winter, only the water freezes – the salt is left behind in the unfrozen seawater below. Waters with higher concentrations of salt are denser and sink to the ocean floor. Different densities are the main cause of ocean currents, circulating seawater from the sea floor to the surface and all around the globe. This water carries with it thermal energy, organic matter and nutrients.

With rising temperatures, less seawater is freezing, which is reducing the density of the oceans. These global ocean currents could eventually cease all together. If seawater circulation slows, and organic matter and nutrients also stop circulating, the impact on the survival of marine life would be huge.

### Aim

To determine how the concentration of salt in water (salinity) affects its density.

### Materials

- 10 mL measuring cylinder
- 100 mL measuring cylinder
- 5 × 100 mL beakers
- 5 pipettes
- food colouring (blue, green, yellow and red)
- salt
- water
- weighing boats
- balance

### Method

1. Copy the results table into your science journal.
2. Using a 100 mL measuring cylinder, measure 60 mL of water and pour it into one of the 100 mL beakers. Repeat four more times so you have five beakers each with 60 mL of water. Label the beakers 1 to 5.

| Solution | Mass of salt (g) | Volume of water (mL) | Amount of food colouring (drops) |
|---|---|---|---|
| 1 | 5 | 60 | 2 of blue |
| 2 | 10 | 60 | 2 of green |
| 3 | 15 | 60 | 2 of yellow |
| 4 | 20 | 60 | 1 of yellow, 1 of red |
| 5 | 25 | 60 | 2 of red |

3. Add the required drops of food colouring from the table above to each beaker.
4. Using the weighing boats and balance, measure the five different masses of salt. Pour the salt into the correct-coloured beaker.
5. Stir the solutions to make sure all the salt has dissolved.
6. Using a pipette, draw up 2 mL of solution 5 and add to the 10 mL measuring cylinder.
7. Using a pipette, draw up 2 mL of solution 4. Place the pipette along the inside of the measuring cylinder, near the solution added previously. Drop solution 4 drop by drop, allowing it to roll down the side of the measuring cylinder.
8. Repeat step **7** for solutions 3, 2 and 1, adding each in turn to the 10 mL measuring cylinder.

*continued …*

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*continued …*

**Results**

1 Complete the results table.

| Solution | Mass of salt (g) | Mass of water (g) | Mass of the solution (g) (mass of salt + mass of water) | Volume of solution (mL) | Density of the solution (g $mL^{-1}$) (mass of solution ÷ volume) |
|---|---|---|---|---|---|
| 1 | 5 | 60 | | 60 | |
| 2 | 10 | 60 | | 60 | |
| 3 | 15 | 60 | | 60 | |
| 4 | 20 | 60 | | 60 | |
| 5 | 25 | 60 | | 60 | |

2 Sketch a coloured diagram of the measuring cylinder you created.

3 Plot a graph of mass of salt on the $x$-axis and density on the $y$-axis.

**Analysis**

1 Use your graph to describe the link between amount of salt and the density of a solution.

2 Discuss how rising global temperatures affect the concentration of salt in the oceans and how this relates to climate change.

**Conclusion**

State a conclusion about how water salinity affects water density. Support your statement by using your experimental data.

## Biodiversity and species distribution

Climate change is one of the biggest threats to global biodiversity. It can alter the distribution and abundance of species, leading to changes in the composition and structure of ecosystems. Rising temperatures can shift the ranges of species and alter their migration patterns, disrupt the timing of seasonal events such as flowering and migration, and change the distribution of disease-causing organisms. Climate change has led to shifting climatic zones, resulting in species moving towards the poles and to cooler, higher elevations on land and deeper ocean waters for some marine species. On average, species are moving towards the poles at 17 km per decade on land and 78 km per decade in the ocean.

Different species are responding to climate change at different rates, leading to changes in the structure of ecosystems. As species move to new locations, they interact with species they may have never encountered before, forming new ecological communities. At the same time, species that had previously relied on each other for food or shelter may be forced apart, disrupting established ecological relationships and potentially leading to ecosystems collapsing.

**Figure 5.25** Blue dragons (*Glaucus atlanticus*) are small venomous sea slugs found in warm and temperate waters. As ocean temperatures continue to increase, its distribution is expanding. While some species may benefit from climate change in the short term, the long-term effects are often negative and can lead to declines in biodiversity.

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## Explore! 5.3

### Citizen science

Citizen science is scientific research in which the general public participate in collecting data. This can include monitoring wildlife populations, tracking the spread of invasive species or contributing observations to astronomical studies. The goal is to involve citizens in the scientific process, allowing the collection of large amounts of data that would normally be difficult.

Research the citizen science project Redmap to see how everyday Australians have documented the species on the move around Australia's coasts over the past decade and how this is contributing to our knowledge about climate change.

**Figure 5.26** Australia's volunteer tagging database Infofish Australia recently became the first citizen science tagging program in the world to tag one million fish. Over the past 36 years, over 17 000 taggers contributed over 198 600 days (or 544 years) of effort to reach the milestone.

## Permafrost

Permafrost, or permanently frozen ground, is sensitive to temperature changes and can provide information about past and present climate conditions. Scientists are monitoring the temperature of permafrost as it starts to melt as temperatures increase. When permafrost melts, it releases trapped carbon dioxide and methane, both of which are greenhouse gases. The presence, thickness and temperature of permafrost provide scientists with valuable information about the rate of climate change and the potential impacts of these changes.

**Figure 5.27** Thawing permafrost

## Sea ice

Sea ice is highly sensitive to changes in air and water temperature. As global temperatures increase, sea ice melts, and this affects global weather patterns, ocean currents and coastal communities. The extent and thickness of sea ice in the polar regions provide scientists with information about the rate of climate change: a decrease in sea ice over time can indicate a warming trend. Sea ice also reflects a significant amount of sunlight back into space, so its decline can contribute to further

**Figure 5.28** Melting sea ice

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Figure 5.29 Ice reflecting the midnight sun in the Arctic Ocean

warming by reducing the amount of reflected sunlight and increasing the amount of sunlight absorbed by the ocean. This is a positive feedback loop, ultimately leading to increased ice melting and sea level rise.

## Quick check 5.10

1. Give one indicator that scientists can use to monitor climate conditions.
2. Identify the main problem of melting polar ice caps.
3. Identify the problem caused by decreased ocean density as a result of reduced freezing of ice in winter.

## Explore! 5.4

### Changing reefs

Climate change has a significant impact on coral reefs, which are some of the most biodiverse ecosystems on the planet.

The main effects of climate change on coral reefs include:

- **Ocean acidification**. Increases in atmospheric carbon dioxide also increases the acidity of the oceans. This makes it more difficult for corals to build and maintain their calcium carbonate skeletons, leading to their degradation.
- **Coral bleaching**. Corals rely on symbiotic single-celled organisms called protists to provide their nutrition. As the temperature of the ocean increases, corals become stressed and expel the protists, leading to coral bleaching.
- **Changes in ocean circulation**. Changes in ocean currents caused by warming of the ocean can affect the availability of food and nutrients for corals.
- **Sea level rise**. As the sea level rises, corals are increasingly at risk of being unable to grow vertically fast enough to maintain their depth at or below the surface. Living under the lower light conditions at greater depth will reduce their growth and threaten survival and increase their exposure to other stressors such as pollutants and disease.

These impacts of climate change on coral reefs will also have consequences for the millions of people who rely on them for food, income and coastal protection.

Figure 5.30 Corals and fish in the Great Barrier Reef

Figure 5.31 Bleached branching coral

Research some of the reasons why coral bleaching is so disastrous for the environment.

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## Try this 5.1

**Make an infographic**

Create a digital infographic to highlight the multiple lines of evidence from polar ice caps, ocean temperatures and extreme weather that explain how climate change is impacting Earth.

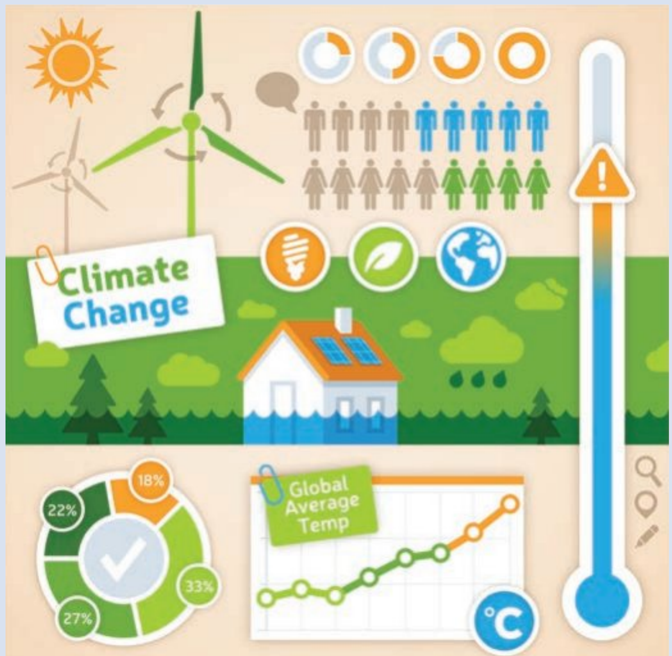


**Figure 5.32** Infographic inspiration

Infographics should:

- communicate information concisely
- be visually appealing with a good use of colour and images
- be well organised so viewers can easily see the information
- contain relevant data from credible sources.

QUIZ

## Section 5.3 questions

**Retrieval**

1 **Name** two indicators of climate change.
2 **Recall** what permafrost is.
3 **Identify** the reasons why coral bleaching is so disastrous for an environment.

**Comprehension**

4 **Describe** how permafrost can be used as an indicator of climate change.

**Analysis**

5 **Critique** the following statement: Global warming will not affect biodiversity.

**Knowledge utilisation**

6 **Discuss** how global warming could cause sea levels to rise.
7 **Discuss** why less seawater freezing in winter affects ocean currents.

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# 5.4 Predicting changes and mitigating impacts

**Learning goals**

1. To be able to describe how we can collect data and predict changes to the Earth system.
2. To be able to identify strategies used to reduce climate change or mitigate its impacts.

WORKSHEET Evaluating impacts on climate change

VIDEO Computer modelling

Being able to predict changes to the Earth system is important for preparing for the impacts of climate change. This involves collecting data and then using modelling and simulations to understand how Earth's climate and ecosystems are changing and will change in the future, given certain assumptions. The models consider the complex interactions between Earth's spheres and provide information about how the Earth system is likely to respond to various scenarios.

## Collecting data

Scientists use satellites to produce global data about ocean temperatures, sea levels, and forest and ice cover. Different properties of Earth's surface and atmosphere can be measured to provide a continuous stream of data that is used to monitor global climate changes.

To measure ocean temperatures, satellites use radiometers that can detect the infrared (heat) and microwave radiation emitted by the ocean surface. This radiation is proportional to the temperature of the surface, so the data can be used to create maps of ocean temperature patterns.

Sea level data is generated by satellite altimeters, which use radar to measure the height of the ocean surface relative to a reference point, providing information on the rise or fall of sea levels over time.

Satellites also use optical and microwave sensors to monitor changes in forest and ice cover. These instruments can detect changes in

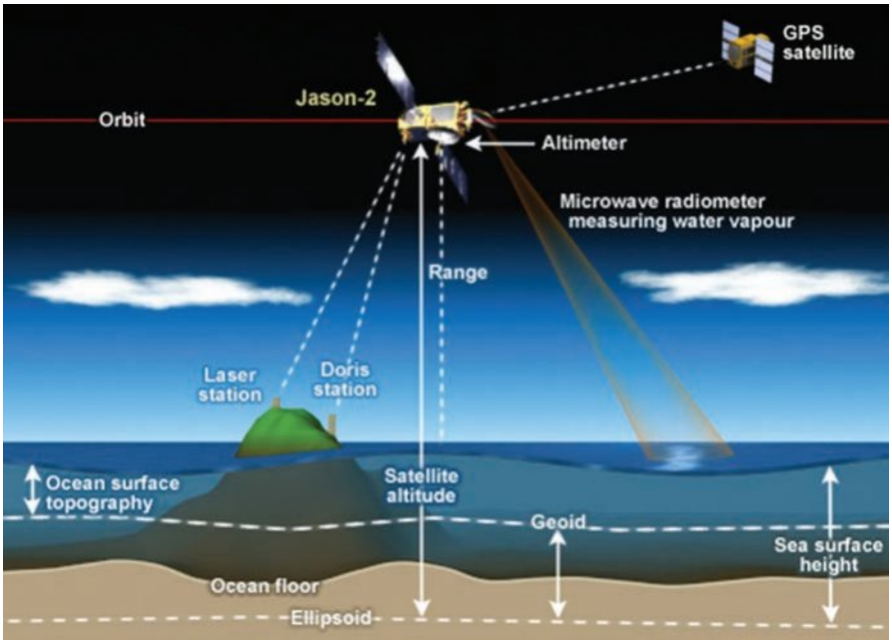


**Figure 5.33** Satellite radar altimeters measure sea levels by measuring the time it takes a radar pulse to make a round-trip from the satellite to the sea surface and back.

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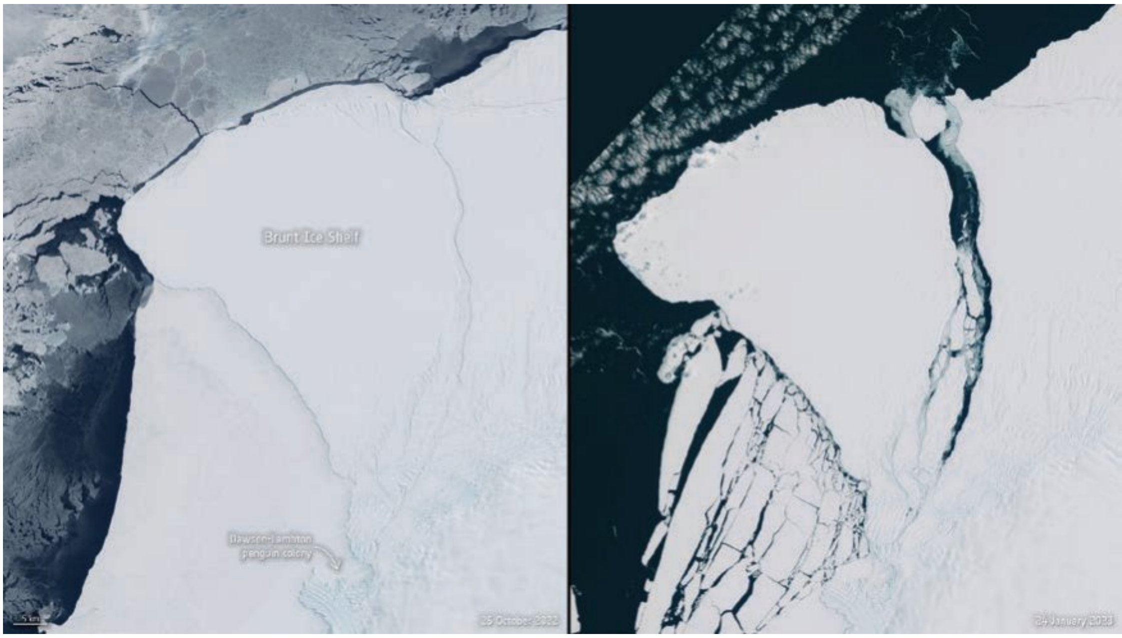


Figure 5.34 The two-satellite mission Copernicus Sentinel-2 has produced before and after photos of the ice slab that broke away from the Brunt Ice Shelf, Antarctica. The image on the left shows cracks on the ice shelf on 25 October 2022 and the image on the right shows the ice breaking away on 24 January 2023.

the reflection and emission of radiation from Earth's surface, which indicate the amount of vegetation or ice present. This data can be used to track deforestation and the rate of ice melting.

The data generated by satellites is used to monitor the effects of climate change by providing a record of changes over time.

## Using computer modelling to predict changes

Predicting changes to the Earth system is a challenging task, as it involves understanding and representing many complex processes and feedbacks that operate on a wide range of timescales.


Figure 5.35 A supercomputer at the German Climate Computing Centre crunches data about Earth's climate to predict the future effects of climate change.

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Computer modelling has improved our knowledge and ability to predict how phenomena such as climate change and atmospheric pollution will develop in the future. Computer simulations can be used to make predictions about Earth's climate thousands and millions of years into the future to see what impact actions taken now will have on the climate in the future. With their high processing power, computers can run numerous simulations repeatedly in a short period of time, something that could take a human over a lifetime to complete. By running numerous simulations, predictions made by computer modelling are much more accurate than those made manually by humans.

Table 5.2 lists some of the applications of computer modelling.

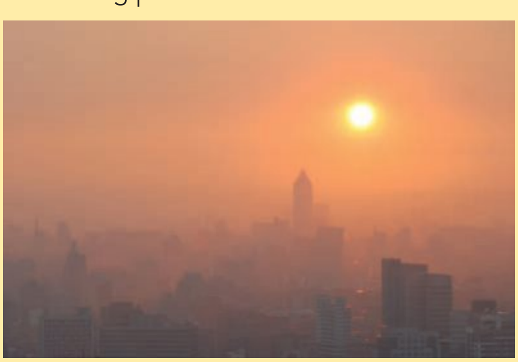
| Application of computer modelling | Description |
|---|---|
| Predicting the weather  | You will see this used every day if you watch the news. Multiple simulations are run by computers. Meteorologists (scientists who study the weather) use these simulations to predict the weather conditions for that week (and beyond). |
| Predicting climate change  | Models predicting climate change are based on observational data and fundamental physical laws such as Newton's laws. Perhaps the most complex climate models are the general circulation models (GCMs). Data on climate change reported in the media is generated from numerous simulations of the GCMs. |
| Monitoring pollution levels  | Atmospheric dispersion modelling predicts the behaviour of pollutants in the air over a specific period of time. It is used by governments to monitor air quality as well as to make predictions of the effects of chemical spills. |

**Table 5.2** Some of the applications of computer modelling

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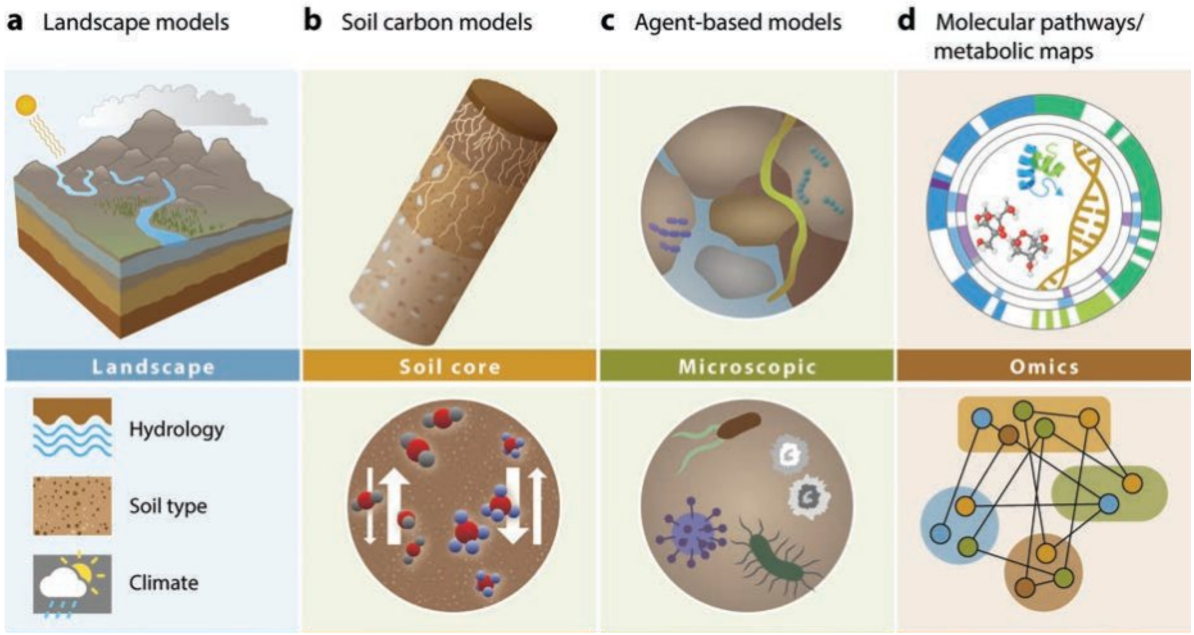


**Figure 5.36** Climate change models can predict changes at a range of different levels: from effects on entire landscapes to individual species' genomes.

Rapidly emerging quantum computers will be able to enhance the modelling of complex weather and climate systems by using quantum algorithms to perform simulations that are beyond the reach of classical computers. Unlike classical computers, which store and process information using binary bits that are only in one of two states (0 or 1), quantum computers use quantum bits (qubits) which exist in multiple states simultaneously. This allows quantum algorithms to perform certain tasks such as simulations much faster than classical algorithms.

These simulations will help improve our understanding of how weather patterns and climate interact and change over time, allowing for more accurate forecasting and prediction of weather patterns and the impacts of climate change. Quantum computers will be able to process large amounts of data faster and more efficiently, enabling more detailed simulations.

## No model is perfect

Even though there is scientific consensus that climate change is real and is largely driven by human activities, there is still some uncertainty about how things will change in the future. This uncertainty leads to the use of different models and approaches to predict the impacts of climate change based on different scenarios.

Each climate change model uses different assumptions and has different limitations. Models are limited by the amount and quality

### Quick check 5.11

1. Why do scientists use computer modelling to predict phenomena?
2. Give one application of computer modelling.
3. How will quantum computers enhance climate modelling?

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of input data, and by the fact that real-world processes are subject to complex and random events that lead to unpredictable variations. As a result, models produce different projections of how the climate will change in the future. Therefore, scientists use multiple models to address this uncertainty. Using multiple models gives a more comprehensive understanding of the potential impacts of climate change and helps guide governmental decision-making about how to mitigate its effects. As more data is collected and our understanding of climate change improves, new models are continually being developed and refined.

## Making thinking visible 5.2

**Circle of viewpoints: Climate change**

Climate change denial is the rejection of the scientific consensus on the reality, causes and potential impacts of global warming, despite overwhelming evidence. Climate change models are contested by some people in society for a variety of reasons, including political, economic and ideological motivations. Some people may question the validity of climate change models because they challenge their long-held beliefs or economic interests. Others may be sceptical of scientists and question the impartiality and accuracy of the data and methods used to develop climate models.

There is also a belief among some people that the models are too complex and that their predictions are unreliable. These people may also reject the idea of human-caused climate change altogether, and therefore not accept the projections produced by climate change models. Misinformation about climate change has also played a role in contesting the models. Some individuals deliberately spread false information to discredit the models and cause people to doubt the science of climate change.

While some contest the models, most climate scientists agree that the models provide valuable insights into the future of the climate and are an essential tool for understanding the impacts of human activities on the planet.

1 Generate a list of viewpoints that individuals belonging to different groups in society could hold regarding climate change (e.g. farmers, politicians, climate scientists).
2 Select one of the viewpoints to consider, using the following statements:
   - I am considering climate change through the viewpoint of ... [insert the selected viewpoint].
   - I believe ... [describe the subject matter from the chosen viewpoint]. Assume their character.
   - A query that arises from this perspective is ... [pose a question from the chosen viewpoint].

In your class, you may then want to engage in an evidence-based debate about the role of human activity in global climate change.


**Figure 5.37** Greta Thunberg is a Swedish climate activist who is known for her strong stance on the need to address climate change. She has been an outspoken critic of those who deny climate change.

The *Circle of viewpoints* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

## Quick check 5.12

1 Why are computer models not perfect?
2 Give some reasons why people contest climate change models.

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## Explore! 5.5

**Reducing the impact of climate change**

Climate change is a significant global challenge that is affecting the planet in many ways, from rising temperatures and sea levels to extreme weather events and changing ecosystems. Research how the following strategies reduce climate change or mitigate its effects:

- Reducing greenhouse gas emissions
- Carbon capture and storage
- Reforestation and forest preservation
- Sustainable agriculture
- Energy conservation
- Public and active transportation
- Carbon pricing.


**Figure 5.38** A carbon tax is a tax on the carbon content of fossil fuels, such as coal, oil and natural gas. Its aim is to incentivise the shift towards cleaner energy sources.

## Explore! 5.6

**Carbon farming**

Carbon farming refers to a set of land management practices that aim to reduce greenhouse gas emissions from agriculture and other land uses while improving the health and productivity of ecosystems. Carbon farming's aim is to sequester (store) carbon in soil and vegetation to reduce atmospheric carbon dioxide.

Traditional Owners are implementing carbon-farming practices that support the management and restoration of natural ecosystems while also mitigating the effects of climate change. Communities are using their traditional knowledge of the land to implement reforestation projects, which not only restore forests but also sequester carbon and therefore reduce the effects of climate change. They are also using their traditional land management practices such as controlled burning to reduce greenhouse gas emissions and improve ecosystem health.

**Figure 5.39** Trees planted in the Daintree rainforest by the Australian Rainforest Foundation will store carbon.

The Aboriginal Carbon Foundation is a non-profit organisation run by First Nations peoples that provides carbon farming services. The foundation was established in 2010 with the primary aim of promoting sustainable land management practices that reduce greenhouse gas emissions while also generating economic benefits for Indigenous communities.

QUIZ

## Section 5.4 questions

**Retrieval**

1 **Name** the complex models used to make predictions about climate change.
2 **Recall** why quantum computers will be able to process more information than classical computers.
3 **Recall** how satellites measure sea levels.

**Comprehension**

4 **Explain** why computer models are useful in predicting future events.
5 **Describe** one strategy that can be used to mitigate the impacts of climate change.

**Analysis**

6 **Critique** the following statement: Global climate models are perfect.

**Knowledge utilisation**

7 **Discuss** the reasons why some people might not believe climate change is occurring.

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# Chapter review

## Chapter checklist

You can download this checklist from the Interactive Textbook to complete it.

| Success criteria | | Linked questions | Check |
|---|---|---|---|
| 5.1 | I can identify and describe the different spheres of Earth and its atmosphere. | 2, 10 | |
| 5.1 | I can state that the Sun's radiation and its interactions with Earth's spheres are the foundation for the global climate system. | 4 | |
| 5.2 | I can identify changes in global climate over time. | 6, 8, 11 | |
| 5.2 | I can explain the role that deep ocean currents have on global climate. | 7 | |
| 5.3 | I can describe the indicators of climate change. | 12 | |
| 5.4 | I can describe how we can collect data and predict changes to the Earth system. | 13 | |
| 5.4 | I can identify strategies used to reduce climate change or mitigate its impacts. | 16 | |

## Review questions

SCORCHER

### Retrieval

1 The majority of the Sun's radiation that reaches Earth is absorbed by the ground and oceans. **Recall** what happens to the rest of the Sun's radiation.
2 **State** the four global spheres.
3 **Identify** one reason why different areas on Earth have different climates.
4 **Recall** the foundation for the global climate system.

### Comprehension

5 **Describe** the effects of cyclones on each of Earth's chemical spheres.
6 **Explain** why you could once walk from Tasmania to Victoria.
7 **Describe** a potential impact of changes in deep ocean currents on global climate patterns.
8 **Construct** a graph to show how carbon dioxide concentrations have changed over the past two decades.

### Analysis

9 Copy and complete the following table to **contrast** the ozone layer and greenhouse gases.

| | Ozone layer | Greenhouse gases |
|---|---|---|
| Function | | |
| Location | | |

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10 **Analyse** the sphere interactions that are taking place in Figure 5.40.

Figure 5.40 Possible sphere interactions

11 **Analyse** the changes in carbon dioxide concentration in the atmosphere since the Industrial Revolution.

12 **Identify** the reason why low-lying areas are most at risk from climate change.

### Knowledge utilisation

13 **Discuss** the advantages of using satellites to collect data about global climate.

14 There is debate as to whether climate change is a significant risk to life on Earth. **Decide** whether you agree, based on what you have learned in this chapter. Justify your opinion with facts and evidence.

15 When scientists observe a change in the frequency of extreme weather events, they hypothesise the cause from scientific models. **Evaluate** the following hypothesis: If the El Niño weather pattern occurs more frequently, then there will be more droughts due to decreased rainfall.

16 **Discuss** which strategy that is used to mitigate climate change (given in Explore! 5.5) would be the most successful in your home town. Give reasons for your answer.

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## Data questions

The Keeling curve in Figure 5.41 illustrates the change in atmospheric carbon dioxide concentration from 1960 to 2005 as measured from the atmosphere above Hawaii, USA. A media outlet is using this data as evidence to suggest that 'climate is changing as there is increasing atmospheric carbon dioxide'.

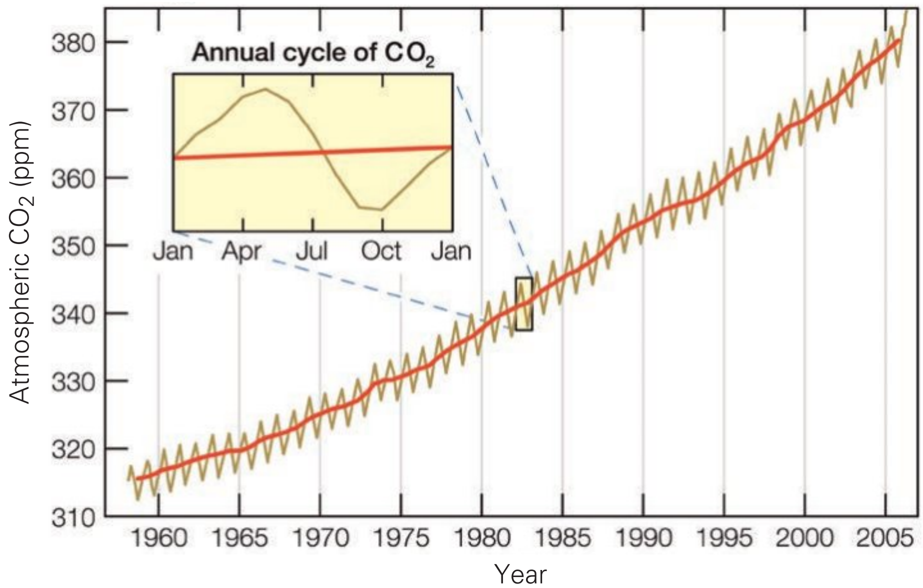


**Figure 5.41** Keeling curve showing the atmospheric carbon dioxide concentration over time

### Apply

1 **Identify** the year which had the lowest average atmospheric $CO_2$ in the atmosphere.
2 Use the red line to **determine** the concentration of atmospheric $CO_2$ in 1965.
3 **Determine** the annual cycles observed for the brown line.

### Analyse

4 **Distinguish** the difference between the brown line and the red line.
5 **Identify** the general trend of carbon dioxide concentration as time increases.
6 **Identify** the causes of the pattern/patterns occurring in the brown line.

### Interpret

7 Can the data in Figure 5.41 be used to **justify** the statement 'There is increasing atmospheric carbon dioxide'?
8 Can the data in Figure 5.41 be used to **justify** the statement 'Climate is changing'?
9 **Infer** the atmospheric concentration of $CO_2$ in 2030, using the trend you have observed in Question **5**.

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# STEM activity: Using aerial imagery to track environmental change

## Background information

Aerial photographs were pioneered by the French photographer and balloonist Gaspard-Félix Tournachon in 1858, four decades after the invention of the camera. Soon, governments over the world realised the potential of aerial imagery in gathering information for military use and monitoring territories. Early military aerial photographers fixed small adjustable cameras on the chests of mail pigeons and flew them over enemy positions. Aerial imagery techniques developed rapidly, from using balloons to using aeroplanes with coupled cameras, high-resolution satellite imagery and, most recently, highly sophisticated drones.

Today, we can also use high-tech satellites to gather other high-quality data from our ever-changing world. For example, you probably use a mobile device with an in-built GPS module capable of giving you directions to pretty much all corners of the globe. Importantly, we can now use this amazing technology to help us monitor our impact in our environment.

There is very little doubt that satellite and aerial imagery will play many important roles in our future. We could use aerial imagery to monitor deforestation in Australia or protect endangered animals. It could be used to survey vulnerable ecosystems or develop more sustainable cities.

**Design brief:** Design a method to use aerial imagery to track environmental change and make environmental impact predictions.

## Activity instructions

You are an environmental researcher working for your local council along with a team of other professionals, including engineers, policymakers and designers. The Land Management Team asked you to design an interactive tool capable of tracking environmental change over time in specific areas within the council boundaries. They want to demolish several buildings in the area for development and requested your opinion about possible implications for nearby rivers and creeks. You understand the potential for satellite imagery use (available free on Google Earth) in this situation, and you decide to give your advice after creating a time-lapse video (or series of images) that shows changes in landscape use over time. (Teachers, please check the Online Teaching Suite for a detailed guide and example for this activity.)

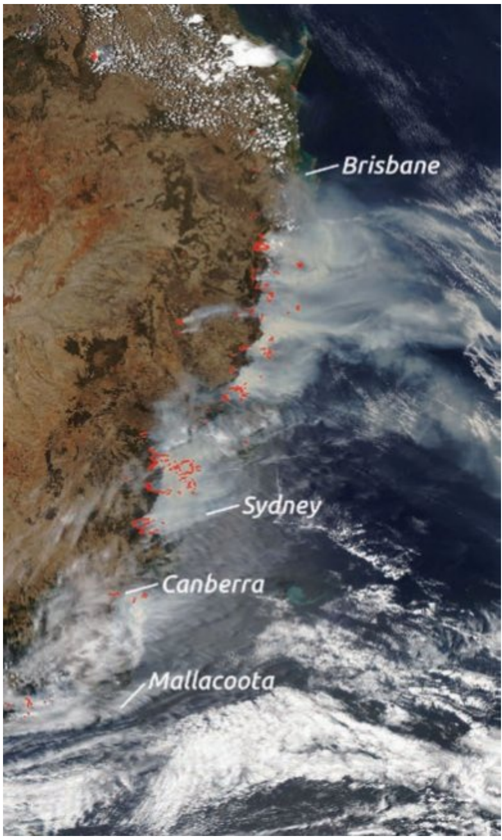


**Figure 5.42** Imagery from NASA Aqua Satellite showing MODIS and VIIRS data of Australian bushfires. Fire detections are shown in red.

## Suggested materials

- Google Earth Pro (free to download)
- web browser (any)
- iMovie, Movie Maker or GIFMaker.org (recommended)

## Research and feasibility

1 Outline the advantages and disadvantages of using satellite imagery to assess environmental change within your region.

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Describe the expertise (skills) needed to gather and decode these images and the potential benefits to the local economy of using them (for example, possible jobs created or improvement to traffic conditions).

| Advantages | Disadvantages |
|---|---|
| e.g. Economy – predict areas for growth | e.g. Environmental – incorrect use of images without considerations |
| | |
| | |

**Figure 5.43** Rice terraces in Bali, a quarry, farmland and suburban houses viewed from above

2 Discuss and reflect on the knowledge needed to make predictions about the environmental impact of development.

3 Research and select a local area with a river or creek, and either a combination of natural and built environment or a natural environment, where a development could be proposed.

## Design and sustainability

4 List all the environmental issues faced currently by your chosen area and predicted in the future based on current and future infrastructure.

5 As a group, discuss a future development that could be completed in the chosen area. Make a sketch of the future development and annotate the changes; make a list of environmental impacts of the development.

6 Decide on the best possible technology to use to create a time-lapse sequence of how the environment has changed from the past to now.

## Create

7 Create a time-lapse sequence of the area and list at least 10 noticeable changes that have occurred in the landscape of your chosen area. What benefits or disadvantages have these changes brought to the local community?

8 Add your future development diagram to your time-lapse video and show likely the environmental impact of your development ideas.

## Evaluate and modify

9 In your own words, explain how you could use the skills gained in this activity to enhance environmental conservation in your region.

10 As a class, evaluate the time-lapse sequences created by your peers and reflect on the challenges associated with anonymous aerial image gathering. In your opinion, are there any privacy concerns or implications associated with this technology? What measures are taken to improve privacy for people in relation to aerial image gathering?

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# Chapter 6
# Motion

## Chapter introduction

Earth and everything on it are constantly moving. This chapter will explore the ways in which we can describe motion scientifically. This chapter explores distance, displacement, speed, velocity and acceleration and how these quantities can be displayed graphically. To change an object's motion, a net force is required. How forces affect motion are described by Sir Isaac Newton's three laws of motion. Newton's laws of motion provide the foundation of knowledge to analyse all forms of motion from sport to car crashes. They can also be used to analyse First Nations Australians' technologies which make tasks more efficient.

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# Concept map

| | |
|---|---|
| Orange | 6.1 |
| Green | 6.2 |
| Blue | 6.3 |

**Motion**

Can be described by: (6.1)

- Distance
- Displacement
- Speed (average and instantaneous)
- Velocity (average and instantaneous)
- Acceleration.

Can be visualised by: (6.2)

- Distance–time graphs
- Displacement–time graphs
- Velocity–time graphs.

Is governed by: (6.3)

- Newton's first law of motion: Inertia
- Newton's second law of motion: $F = ma$
- Newton's third law of motion: Every action has an equal and opposite reaction.

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## Curriculum

| Investigate Newton's laws of motion and quantitatively analyse the relationship between force, mass and acceleration of objects (AC9S10U05) | |
|---|---|
| investigating a moving object to analyse and propose relationships between distance and time, speed, force and acceleration | 6.1, 6.2, 6.3 |
| using mathematical representations including graphs and algebraic formulas to quantitatively relate force, speed, acceleration and mass | 6.1, 6.2, 6.3 |
| constructing an argument, supported by data, to support lower speed limits near schools or for trucks in urban environments | 6.1 |
| investigating how First Nations Australians achieve an increase in speed and subsequent impact force through the use of spearthrowers and bows | 6.3 |
| modelling how a change in net force acting on an object affects its motion and relating to the purpose of safety features such as seatbelts, airbags and crumple zones in vehicles | 6.3 |
| investigating the application of Newton's laws in sport and how these are applied to improve an athlete's performance or safety | 6.3 |
| investigating how driverless vehicles apply Newton's laws of motion to brake in time | 6.3 |



## Glossary terms

Acceleration
Average speed
Average velocity
Constant velocity
Deceleration
Displacement
Distance
Force
Gradient
Inertia
Instantaneous speed
Instantaneous velocity
Mass
Net force
Newton's first law of motion
Newton's second law of motion
Newton's third law of motion
Origin
Speed
Stationary
Vector
Velocity
Weight

# 6.1 Describing motion

**Learning goals**

1. To be able to distinguish between quantities of distance and displacement.
2. To be able to convert between units of m $s^{-1}$ and km $h^{-1}$.
3. To be able to calculate and distinguish between quantities of speed, velocity and acceleration.
4. To investigate the application of speed to safety issues.

WORKSHEET Describing motion

## Distance

In motion, **distance** refers to the length an object travelled along a path. The symbol *d* is used to denote the distance an object has travelled, and it is measured in SI units (International System of Units) of metres (m). For example, the soccer ball in Figure 6.1 has travelled a distance of 20 metres (3 + 4 + 5 + 3 + 5).

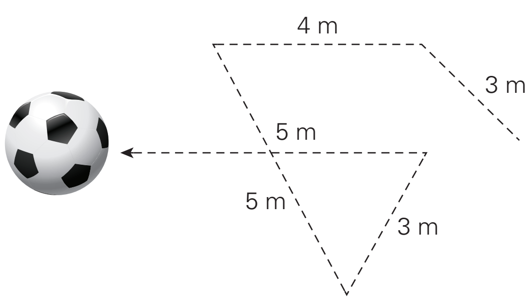


**Figure 6.1** Distance travelled by a soccer ball

## Displacement

**Displacement** is different to distance in that displacement is the length and direction of an object from its origin, regardless of its path. That is, an object's displacement is how far its final position is from its starting position and in what direction. Displacement is denoted by the symbol *s* and is measured in SI units of metres. It has both magnitude and direction, which makes displacement a **vector**.

**distance (*d*)**
total length travelled measured in metres

**displacement (*s*)**
the length and direction of an object from its origin, measured in metres

**vector**
a quantity having both magnitude and direction


**Figure 6.2** Often a compass bearing is used to describe the direction of displacement, but simpler directions like left, right, up, down, backwards and forwards are sometimes used.

**Making thinking visible 6.1**

**Looking ten times two: Brisbane in motion**

Look at the image in Figure 6.3 for at least 30 seconds and let your eyes wander.

1 List 10 objects you can see in the image, or that would occur within the pictured city, that might have motion. Look at the image in Figure 6.3 again for at least 30 seconds.

2 What words could be used to describe the motion of the objects that you have listed in Question **1**? What units of measurement would be used?

**Figure 6.3** Motion in Brisbane city

The *Looking ten times two* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

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VIDEO
Distance versus displacement

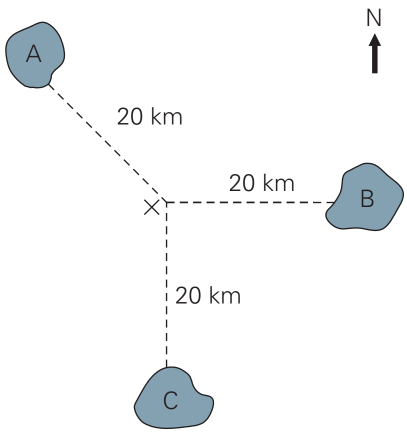



**Figure 6.4** If the sailor ended up on island B, their displacement would be 20 km east from the origin.

Figure 6.4 shows a scenario where the direction of travel matters. The starting point is the cross in the middle. A sailor knows they have sailed 20 kilometres (km), but they would not know where they are unless they know the direction they were sailing. Sailing 20 kilometres from the origin might mean the sailor ends up on any three of the different islands. Knowledge of direction matters!

## Distance versus displacement

Displacement provides different length information to that provided by distance. For example, a cat might walk 10 metres, but its displacement would be zero metres if it had returned to its original position. Knowing an object's displacement is often more helpful in finding it than knowing the entire journey the object took to get there.

Consider a cat's journey in Figure 6.5. It walks east from point A to point B for six metres, and then west to point C for two metres. Its total distance covered is 6 m + 2 m = 8 m, but it has only displaced from its origin 6 m – 2 m = 4 m east. Distance provides information of the whole journey, while displacement gives information on the difference between the start and end positions.

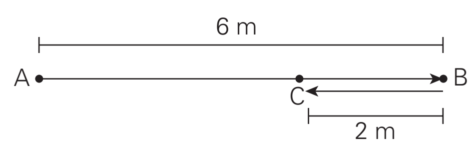
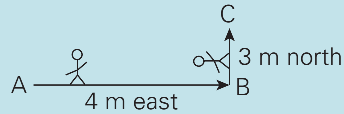



**Figure 6.5** The walk described can be represented using arrows, where the length of the arrow symbolises the magnitude, and the direction of the arrow shows the direction of motion.

### Worked example 6.1

**Distance and displacement**

A person walks 4 metres east and then 3 metres north. This can be represented in a simple diagram as follows.




1 What is the distance travelled by the person?
2 What is the displacement?

| Working | Explanation |
|---|---|
| 1 Distance | |
| $d$ = 3 m + 4 m = 7 m | Add the two distances travelled to find the total distance that the person has travelled. |

*continued …*

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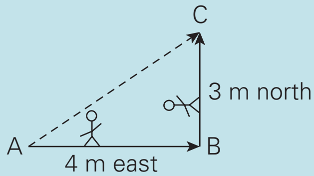
*continued …*

**2** Displacement

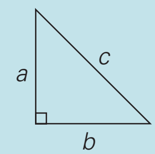



Using Pythagoras's theorem, find the distance from A to C.

$$\begin{aligned} AC &= \sqrt{4^2 + 3^2} \\ &= \sqrt{16 + 9} \\ &= \sqrt{25} \\ &= 5\text{ m} \end{aligned}$$

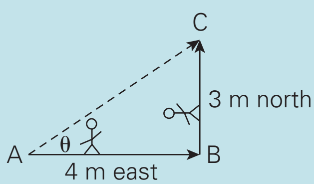
Use Pythagoras's theorem to find the distance from A (the starting point) to C (the end point).

$$a^2 + b^2 = c^2$$




$$c = \sqrt{a^2 + b^2}$$

Use trigonometry to find the direction of travel.




$$\tan\theta = \frac{3}{4}$$

$$\theta = \tan^{-1}\left(\frac{3}{4}\right)$$

= 36.9 degrees north of east

Therefore, the displacement *s* is 5 metres 36.9 degrees north of east.

Remember that you also need the direction travelled from the starting position to the final position.

We use inverse trigonometric functions to find unknown angles in right-angled triangles.

## Did you know? 6.1

**The first metre**

Figure 6.6 This 'provisional metre' was installed on a wall of a building in Paris in around 1796.

Throughout history, many systems have been used to measure distance. Our metric system began during the French revolution of the late 1700s when the French Academy of Sciences proposed the creation of a standard unit of length that could be used anywhere in the world. The meridional distance from the North Pole to the Equator passing through Paris was defined as 10 000 km, and the metre was defined as one ten-millionth of this distance. Examples of the 'provisional metre' were erected on walls in Paris in 1796–1797 to inform the population of this new unit of measurement (it was provisional while final measurements of the meridian were being made). A one-metre platinum–iridium bar was produced in 1889 and kept in Paris as the international standard for the measurement.

*continued …*

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*continued …*

Prototype bars were made as a reference for other parts of the world. The original prototype is still displayed in France at the International Bureau of Weights and Measures, but in 1960 the definition of a metre was changed to one based on the wavelength of particular orange light radiated by krypton-86. Then in 1983, the General Conference on Weights and Measures redefined one metre as the distance that light travels through a vacuum in $\frac{1}{299\,792\,458}$ seconds.

**Quick check 6.1**

1 Differentiate between the terms 'distance' and 'displacement'.

2 A classmate travels between classrooms. From their initial classroom, they travel west 100 metres and then north 50 metres, where they arrive at the intended classroom.
   a Represent this journey in a diagram.
   b Calculate the distance travelled by the student.
   c Calculate the displacement of the student, to the nearest metre. Remember to also give a bearing in your answer.
   d The student then travels back to the initial classroom. Calculate their displacement.

## Speed

We all use words or phrases to describe how quickly something travels, or maybe even to determine how long it will take to get from one place to another. **Speed** is a general term for how fast something travels. Speed is a measure of the distance ($d$) travelled, in SI units of metres, divided by the amount of time ($t$) it took to travel that distance, in SI units of seconds. Thus, speed is commonly measured in SI units of metres per second (m s$^{-1}$), but depending on the speed being observed, it is common to state speed in more appropriate units such as kilometres per hour (km h$^{-1}$), or even metres per minute (m min$^{-1}$), centimetres per hour (cm h$^{-1}$) or kilometres per second (km s$^{-1}$).

**speed**
change in distance divided by time


**Figure 6.7** Examples of different speeds. a) A rocket travels at a speed of at least 8 km s$^{-1}$ to reach space, b) A greyhound can reach a top speed of approximately 20 m s$^{-1}$, c) A snail moving in cm min$^{-1}$, d) We usually measure car speed in km h$^{-1}$.

Consider the examples of motion shown in Figure 6.7.

Speed is calculated as follows:

$$\text{average speed } (\text{m s}^{-1} \text{ or km h}^{-1}) = \frac{\text{distance travelled (m or km)}}{\text{time taken (s or h)}}$$

$$\text{speed} = \frac{d}{t}$$

A simple way to remember this equation is by using the average speed triangle shown in Figure 6.8.

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Using the average speed triangle, you can derive formulas for:

- speed $= \frac{d}{t}$
- change in time $t = \frac{d}{\text{speed}}$
- change in distance $d = \text{speed} \times t$.

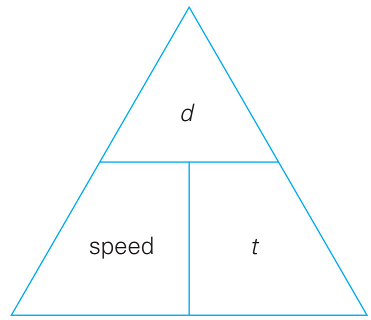


**Figure 6.8** To use the average speed triangle, cover the variable you want to calculate. If the other variables are on the same row, multiply them together. If they are on different rows, divide the top variable by the bottom variable.

## Worked example 6.2

**Average speed**

Consider two of the runners who are competing in a 100-metre sprint at a school athletics carnival. Runner 1 finishes in a time of 12.5 seconds. Runner 2 runs the race with an average speed of 7 m $s^{-1}$.

**1** Who wins the race?

**2** How long does it take runner 2 to cross the finish line? Round your answer to one decimal place.

| Working | Explanation |
|---|---|
| **1** Who wins? | |
| $d = 100$ m<br>$t = 12.5$ s<br>speed = ? | List the relevant information for runner 1. |
| speed $= \frac{d}{t} = \frac{100 \text{ m}}{12.5 \text{ s}}$<br>$= 8$ m $s^{-1}$ | Calculate the average speed using the formula for average speed. |
| Runner 1: speed = 8 m $s^{-1}$<br>Runner 2: speed = 7 m $s^{-1}$<br>Since runner 1 has a higher average speed, they finish before runner 2 does. Therefore, runner 1 wins the race. | Compare the average speed of each runner. |
| **2** Runner 2 time | |
| $t$ = ?<br>speed = 7 m $s^{-1}$<br>$d = 100$ m | List the information you have for runner 2. |
| $t = \frac{d}{\text{speed}} = \frac{100 \text{ m}}{7 \text{ m s}^{-1}}$<br>$= 14.3$ s | Calculate the time taken for runner 2 to complete the race using a rearranged average speed formula. |
| It takes 14.3 seconds for runner 2 to complete the 100 metre race. | Interpret the solution, ensuring that you have correct units and decimal places. |

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## Converting units

While the SI unit for speed is m s$^{-1}$, it is common to state speed in units of km h$^{-1}$, particularly for vehicle movement. It will be important to convert km h$^{-1}$ to m s$^{-1}$ later in this chapter, to use quantities such as velocity and acceleration. To make this conversion, kilometres should be converted to metres, and hours should be converted to seconds:

1 kilometre = 1000 metres

1 hour = 3600 seconds

### Quick check 6.2

1 A cat and a dog are in a 60-second race. Whoever travels the furthest in 60 seconds wins the race. The cat travels at an average speed of 4 m s$^{-1}$. The dog travels a total distance of 500 metres in that time.

a Does the dog or the cat travel further? Does the dog or cat win the race?

b What is the average speed of the dog to two decimal places?

$$1\frac{\text{km}}{\text{h}} = \frac{1000\text{ m}}{3600\text{ s}} = \frac{1}{3.6}\frac{\text{m}}{\text{s}}$$

Multiplying both sides by 3.6 and rearranging the sides to make 1 m s$^{-1}$ the subject gives:

1 m s$^{-1}$ = 3.6 km h$^{-1}$

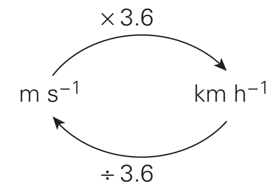


**Figure 6.9** Converting m s$^{-1}$ into km h$^{-1}$

To convert m s$^{-1}$ to km h$^{-1}$, multiply by 3.6.

To convert km h$^{-1}$ to m s$^{-1}$, divide by 3.6.

### Try this 6.1

**Converting speed**

Consider the speed of a train in Queensland travelling at 120 km h$^{-1}$. Convert this speed to m s$^{-1}$.

Is this result what you expected? Can you think of a scenario that would be appropriate to measure speed using m s$^{-1}$ instead of km h$^{-1}$?

### Did you know? 6.2

**The light year**

Light travels at a constant speed of $3 \times 10^8$ m s$^{-1}$ in a vacuum and almost as fast in air. The distance light travels in one year through space is one light year or 9.46 trillion kilometres. The light year is used to measure distances to stars and galaxies. For example, the brightest star in the night sky is Sirius, and it is 8.6 light years away. The nearest large galaxy is Andromeda, a mere 2.5 million light years away. Earth is 0.0000158 light years from the Sun. That means it takes eight to nine minutes for light from the Sun to reach Earth!

**Figure 6.10** Light travels at $3 \times 10^8$ m s$^{-1}$.

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## Average versus instantaneous

Speed can be described as either **average speed** or **instantaneous speed**.

Average speed is the total distance an object travels divided by the time it takes to do so. The speed of the object may change as it moves. Instantaneous speed is the speed something is travelling at a given point in time.

Instantaneous speed can be determined using a radar gun or a speed detector. A speed detector calculates the average speed but over such a small timeframe that it is essentially capturing the speed at that instant, so it is called instantaneous. Another example of the measurement of instantaneous speed is a speedometer in a car.

## Velocity

**Velocity** is a term used to describe how fast something travels in a particular direction. Like speed, the common units associated with velocity are m $s^{-1}$ or km $h^{-1}$. However, unlike speed, velocity is a measure of the change in displacement of an object within a certain amount of time rather than a change in distance. Velocity includes more information than speed because it includes direction; it is used as a measure of how quickly something travels in a specific direction. Aeroplane pilots and ship captains need to know their velocity so they can accurately navigate towards their destination.

Calculating velocity is similar to using the formula for speed, except distance travelled is replaced by displacement. As with speed, velocity can be classified as **instantaneous velocity** or **average velocity**.

**Figure 6.11** Speed detectors can capture the speed of an object in a fraction of a second.

**Figure 6.12** Terminal velocity is the highest attainable speed of a skydiver. It occurs when a skydiver is in freefall and the downward force of gravity is balanced by the upwards force of air friction, so they are no longer accelerating. This skydiver's terminal velocity is roughly 60 m $s^{-1}$ down to Earth.

Mathematically, velocity can be described in the following ways:

$$\text{average velocity} = \frac{\text{displacement}}{\text{time taken}}$$

$$v_{av} = \frac{s}{t}$$

**average speed**
change in distance over a time interval

**instantaneous speed**
the speed at a given point in time

**velocity ($v$)**
change in displacement divided by change in time

**instantaneous velocity**
the velocity of an object measured at a particular moment in time

**average velocity**
the rate at which an object is displaced or changes position over a time interval

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## Worked example 6.3

**Average speed versus average velocity**

Consider the triangle in Figure 6.13 between Adelaide, Brisbane and Alice Springs. Imagine two aeroplanes that need to get from Alice Springs to Brisbane. Plane 1 travels directly to Brisbane. Plane 2 must stop in Adelaide before flying to Brisbane. It takes both planes 4.00 hours to reach Brisbane. The true bearing of Brisbane from Alice Springs is 106 degrees clockwise from north.

1 What is the average speed of each plane?
2 What is the average velocity of each plane?
3 Which plane travels faster in the air?


**Figure 6.13** Travelling between Adelaide, Brisbane and Alice Springs

| Working | Explanation |
|---|---|
| **1** Average speed | |
| Plane 1: $$\text{speed} = \frac{1965}{4.00} = 491\,\text{km h}^{-1}$$ Plane 2: $$\text{speed} = \frac{(1330 + 1603)}{4.00} = 733\,\text{km h}^{-1}$$ | For average speed, use this formula: $$\text{speed} = \frac{d}{t}$$ |
| **2** Average velocity | |
| Plane 1: $v_{av} = \frac{1965}{4.00} = 491$ km h$^{-1}$ 106 degrees clockwise from north<br>Plane 2: $v_{av} = \frac{1965}{4.00} = 491$ km h$^{-1}$ 106 degrees clockwise from north | For average velocity, use this formula: $$v_{av} = \frac{s}{t}$$ |
| **3** Comparing speeds | |
| Plane 2 is faster in the air. | The plane with the greater average speed travels faster as it covers more ground in the same amount of time. |

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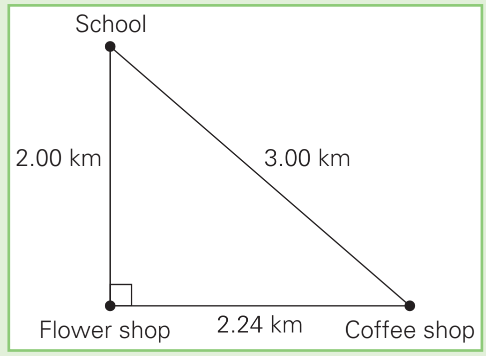
## Quick check 6.3

Two students, Leon and Mira, leave school to meet at the local coffee shop for a hot chocolate after school. Leon decides to jog to the coffee shop, but also stops at a flower shop along the way. Mira decides to walk from school directly to the coffee shop. They arrive at the coffee shop at the same time, 30 minutes after they leave school. Use the diagram to answer the following questions.




1 Calculate how much further Leon travels than Mira.
2 If it takes them both 30 minutes to reach the coffee shop, calculate:
   a Mira's average speed
   b Leon's average speed
   c their average velocities.

## Acceleration

Acceleration describes the situation where an object speeds up (accelerates) or slows down (decelerates). **Acceleration (*a*)** is correctly defined as the change in velocity divided by time and it is measured in SI units of m $s^{-2}$. Just as velocity provides directional information, acceleration provides directional information too.

Consider a **stationary** bus at a traffic light; we would say that it has an initial speed of 0 km $h^{-1}$. Imagine that when the light turns green the bus 'speeds up' to 40 km $h^{-1}$ in the next five seconds. This change in velocity means that the bus has an acceleration. Similarly, if the bus was moving and put on the brakes to 'slow down', this is known as **deceleration** or negative acceleration. If the bus is travelling at a **constant velocity**, that is it is not speeding up or slowing down, its acceleration is zero. That is, there is zero change in its velocity over that time.

Acceleration can be calculated as follows:

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken}} = \frac{\text{final velocity} - \text{initial velocity}}{\text{time taken}}$$

$$a = \frac{v_2 - v_1}{t}$$

Using the acceleration triangle in Figure 6.14 is another helpful way to remember the formula for acceleration.

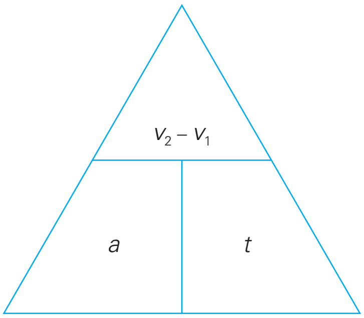



**Figure 6.14** To use the acceleration triangle, cover the variable you want to calculate. If the other variables are on the same row, multiply them together. If they are on different rows, divide the top variable by the bottom variable.

Using this acceleration triangle, you can derive formulas for:

- acceleration $a = \frac{v_2 - v_1}{t}$
- time taken $t = \frac{v_2 - v_1}{a}$
- change in velocity $v_2 - v_1 = a \times t$.

**acceleration (*a*)**
the change in velocity of an object over time

**stationary**
not moving

**deceleration**
when an object is slowing down

**constant velocity**
when an object is travelling at the same speed and is not accelerating or decelerating

EXTENSION WORKSHEET
Scalar and vector quantities

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## Worked example 6.4

**Acceleration**

Consider the motion of a dirt bike.

1. If it speeds up from rest to 54 km h$^{-1}$ in a straight line in 3.0 seconds, calculate the acceleration.
2. If that same bike travelling at 54 km h$^{-1}$ comes to a stop in a straight line within 5.0 seconds, what is the acceleration?
3. If better brakes were installed on the bike, it could decelerate at a quicker rate of 10 m s$^{-2}$. Calculate how long it would take to stop if it was initially travelling at a speed of 72 km h$^{-1}$.

**Figure 6.15** A dirt bike in motion

| Working | Explanation |
|---|---|
| **1** Acceleration | |
| $v_1 = 0$ m s$^{-1}$<br>$v_2 = 54$ km h$^{-1}$ = 15 m s$^{-1}$<br>$t = 3.0$ s<br>$a = ?$ | List the information you have.<br>Since the bike begins at rest, the initial speed is zero.<br>Recall that to convert from km h$^{-1}$ to m s$^{-1}$ we divide by 3.6. |
| $a = \frac{v_2 - v_1}{t} = \frac{(15 - 0)}{3.0} = 5.0$ m s$^{-2}$ | Calculate using the acceleration formula by substituting in all the known values. |
| The bike accelerates (speeds up) at a rate of 5 m s$^{-2}$ (5 metres per second, every second). | Interpret the answer. |
| **2** Negative acceleration | |
| $v_1 = 54$ km h$^{-1}$ = 15 m s$^{-1}$<br>$v_2 = 0$ m s$^{-1}$<br>$t = 5.0$ s<br>$a = ?$ | List the information you have. In this example, the bike has an initial speed of 54 km h$^{-1}$ and a final velocity of 0 km h$^{-1}$. |
| $a = \frac{v_2 - v_1}{t} = \frac{(0 - 15)}{5.0} = -3.0$ m s$^{-2}$ | Substitute the known values. |
| Since there is a negative acceleration, the bike is decelerating at a rate of 3.0 m s$^{-2}$. | Interpret the solution and remember to include correct units. |
| **3** Faster stopping | |
| $a = -10$ m s$^{-2}$<br>$v_1 = 72$ km h$^{-1}$ = 20 m s$^{-1}$<br>$v_2 = 0$ m s$^{-1}$<br>$t = ?$ | List the known information. |
| $-10 = \frac{(0 - 20)}{t}$ | Substitute the values into the acceleration formula. |
| $t = \frac{-20}{-10} = 2.0$ s | Rearrange so that the unknown is the subject of the equation. |
| It takes the bike 2.0 seconds to decelerate from 72 km h$^{-1}$ to rest. | Interpret the solution. |

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## Try this 6.2

**Car acceleration**

Next time you are in a car and travelling in a straight line, use the stopwatch on your phone to time the change in speed. Get the driver to read the speedometer to capture the instantaneous speed. Calculate the acceleration of the car under different circumstances using the formula for average acceleration in the following table. Remember not to distract the driver when doing this.

| Test | Initial velocity | Final velocity | Time taken | Acceleration |
|---|---|---|---|---|
| Example: | 0 km $h^{-1}$ = 0 m $s^{-1}$ | 10 km $h^{-1}$ = 2.8 m $s^{-1}$ (divide by 3.6 to convert) | 5 s | $a = \frac{(2.8 - 0)\text{ m s}^{-1}}{5\ s} = 0.56\text{ m s}^{-2}$ |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

## Quick check 6.4

1 Define the terms 'acceleration', 'deceleration' and 'constant velocity'.

2 An object increases its speed from 5.2 m $s^{-1}$ to 7.7 m $s^{-1}$ in 4 seconds.

 a Calculate the acceleration of the object.

 b Assume that the object could decelerate at a rate of 1.5 m $s^{-2}$. Calculate the time it would take for the object to stop if it was initially travelling at a speed of 10 m $s^{-1}$. Round your answer to two decimal places.

## Explore! 6.1

**Speed limits in Australia**

It might be surprising to learn that prior to 1967 some roads in Australia had no speed limit at all! Over the decades since, road speed limits have been installed and updated to improve the road safety of drivers and pedestrians. In the 1980s, the maximum speed limit in some built-up areas such as school zones was decreased to 40 km $h^{-1}$, and there are proposals to decrease this further to 30 km $h^{-1}$, as is common in some other countries in the world.


**Figure 6.16** Speed limits in school zones in Australia are typically 40 km $h^{-1}$ at set times on school days.

Explore the National Road Safety Week website as a starting point to gather some data. Construct an argument, supported by data, for a campaign to reduce speed limits in school zones from 40 km $h^{-1}$ to 30 km $h^{-1}$.

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## Investigation 6.1

### Ramps and cars

**Aim**

To investigate the effect of ramp height on the average speed of a crash trolley or model car.

**Materials**

- ramp at least 90 cm long
- stopwatch
- metre ruler
- books or blocks that can be used to make a ramp
- crash trolley or model car

**Planning**

1 Develop a hypothesis by predicting how a change to the height of the ramp will affect the average speed of a model car.
2 Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.

**Method**

**Part 1: Prepare the results table**

1 Copy the results table into your science journal.
2 Identify the independent variable and state it in the table.
3 Identify the dependent variable and state in the table.

| Independent variable: ____________ | Dependent variable: ____________ | | | |
|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Mean |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Part 2: Collect the data**

1 Set up the ramp as shown in Figure 6.17.

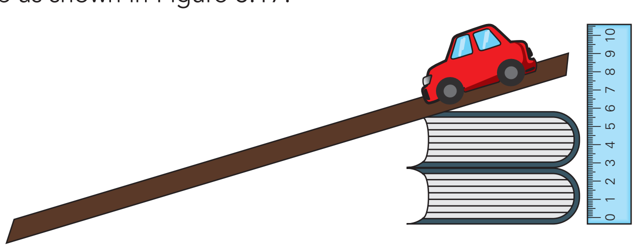


**Figure 6.17** Experimental set-up

2 Measure the height of the ramp.
3 Use the stopwatch to measure how long it takes for a crash trolley or model car to roll down the ramp. Record the results in the results table.
4 Repeat steps **2** and **3** three times so you can calculate the mean of the results.
5 Repeat steps **3–4** using some different heights and record your results in the table.

*continued …*

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*continued …*

**Results**

1 Calculate the average time taken for the car to roll down the ramp.
2 Draw a scatterplot to analyse the relationship between the height and the speed.
3 Insert a copy of your graph below the results table in your science journal.

**Analysis**

Describe the effect of different ramp heights on the mean speed of a model car.

**Evaluation**

**Limitations**

1 Describe any limitations of your investigation and how these may have affected your results.

**Improvements**

2 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

**Conclusion**

1 State a conclusion about how increasing the height of the ramp can affect speed.
2 Justify this conclusion using data from your results.

**Figure 6.18** How would the incline and height of this hill affect the speed of the mountain biker?

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QUIZ

## Section 6.1 questions

**Retrieval**

1 **Recall** a unit used for distance.

2 **Recall** a unit used for speed.

3 **Recall** the formula and unit for average acceleration in a straight line.

4 The average top speed of an e-scooter is 40 km $h^{-1}$. If the e-scooter is already travelling at that speed, **calculate** how far will it travel in 3 minutes.

5 If a person walks at an average speed of 4 km $h^{-1}$, **calculate** how long it will take them to travel 50 metres, to the nearest second. HINT: First convert 4 km $h^{-1}$ into m $s^{-1}$.

**Comprehension**

6 **Determine** the acceleration of a car travelling at a constant speed of 50 km $h^{-1}$.

7 A sprinter starts from rest. In the first 3 seconds they reach a velocity of 2 m $s^{-1}$. After the next 10 seconds they reach a velocity of 6.5 m $s^{-1}$.

- a **Calculate** the average acceleration in the first 3 seconds, and round to two decimal places.
- b **Calculate** the average acceleration in the last 10 seconds.
- c **Identify** whether the sprinter's acceleration is greater in the first 3 seconds or the last 10 seconds.

8 A car starts from rest and accelerates at a constant rate of 5 m $s^{-2}$ for 3 seconds.

- a **Calculate** the final velocity.
- b **Calculate** the average velocity. Because the velocity increases at a constant rate, you can do this by using $\frac{v_1 + v_2}{2}$ to find the average velocity.
- c **Calculate** the displacement of the car after 3 seconds.

9 **Describe** displacement.

**Analysis**

10 **Distinguish** between speed and velocity.

11 **Contrast** average speed and instantaneous speed.

12 **Categorise** the following motions as either acceleration, deceleration or constant.

| | Motion | Acceleration/deceleration/constant |
|---|---|---|
| a | A bike rider slowing down | |
| b | A textbook sitting on a desk | |
| c | A sprinter taking off at the start of a race | |
| d | A dog running at 5 m $s^{-1}$ forwards | |
| e | A car crashing into a brick wall | |
| f | A car rolling down a hill and gaining speed | |

**Knowledge utilisation**

13 Imagine you were trying to determine how efficiently your car uses petrol. **Discuss** if you would use distance travelled or displacement covered with one tank full.

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# 6.2 Graphing motion

**Learning goals**

1. To interpret distance vs. time and displacement vs. time graphs.
2. To be able to calculate the velocity from a displacement vs. time graph.
3. To be able to calculate acceleration and displacement from a velocity vs. time graph.

WORKSHEET Graphing motion

Quantities that describe motion, such as distance, displacement, speed, velocity and acceleration, can be calculated using mathematical equations. However, they can also be illustrated on journey graphs, which represent the information visually.

## Distance–time graphs

Distance–time graphs display the total distance an object travels over time. The **gradient** of the line indicates the speed of the object. Recall that:

$$\text{speed} = \frac{d}{t} = \frac{\text{rise}}{\text{run}}$$

Table 6.1 shows some shapes you may see on a distance–time graph. Note that distance–time graphs are always horizontal or increasing; they cannot be decreasing.

**gradient**
in physics, how quickly something changes, or the rate of change. The gradient of a graph is calculated as the rise over the run

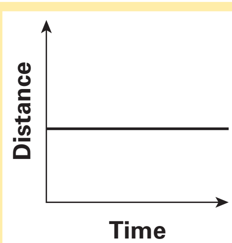
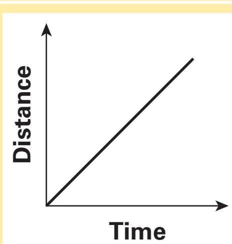
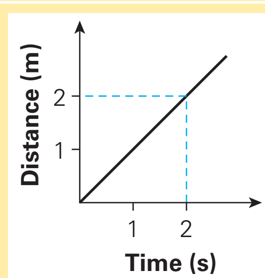
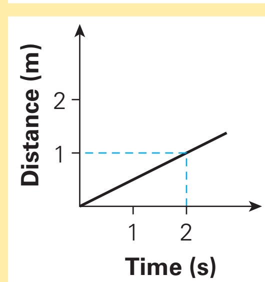
| Shape | Explanation | Example |
|---|---|---|
|   | Horizontal lines indicate that an object is stationary. | The $\frac{\text{rise}}{\text{run}}$ of horizontal lines is zero because the rise is 0 m. So the speed is 0 m s$^{-1}$. |
|   | A straight line with a gradient indicates that the object is moving at a constant speed. |   $v = \frac{\text{rise}}{\text{run}} = \frac{2\text{ m}}{2\text{ s}} = 1\text{ m s}^{-1}$   $v = \frac{\text{rise}}{\text{run}} = \frac{1\text{ m}}{2\text{ s}} = 0.5\text{ m s}^{-1}$ The gradient of the first graph is steeper, which shows that object has a greater speed. |

**Table 6.1** Two shapes of distance–time graphs

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## Worked example 6.5

**Distance–time graph**

Take a look at the distance–time graph that shows Elliott's walk in a straight line for 6 seconds.

1 Calculate his speed at the following time intervals: from 0 to 2 seconds, 2 to 5 seconds and 5 to 6 seconds.

2 When is Elliott travelling fastest?

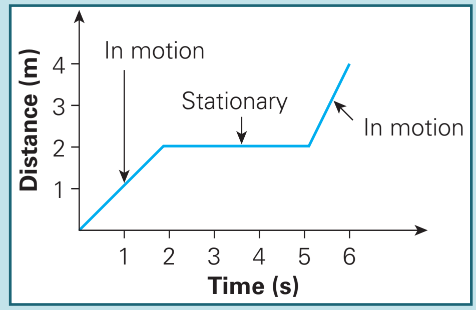


**Figure 6.19** Distance–time graph of Elliott's walk

| Working | Explanation |
|---|---|
| **1** Speed | |
| 0 to 2 seconds: $\text{speed} = \frac{\text{rise}}{\text{run}} = \frac{(2-0)\text{ m}}{(2-0)\text{ s}} = \frac{2\text{ m}}{2\text{ s}} = 1$<br>2 to 5 seconds:<br>A horizontal line indicates he is stationary.<br>5 to 6 seconds:<br>$\text{speed} = \frac{\text{rise}}{\text{run}} = \frac{(4-2)\text{ m}}{(6-5)\text{ s}} = \frac{2\text{ m}}{1\text{ s}} = 2\text{ m s}^{-1}$ | Select two points from each time interval and use $\frac{\text{rise}}{\text{run}}$ to calculate the speed. |
| **2** Fastest interval | |
| He travels the fastest from the 5th to the 6th second. | The steeper line indicates a faster speed. |

## Quick check 6.5

1 Analyse the distance–time graph of a moving object in Figure 6.20.

a Calculate the average speed for each of the sections A, B and C.

b Describe the motion of the object in the graph.

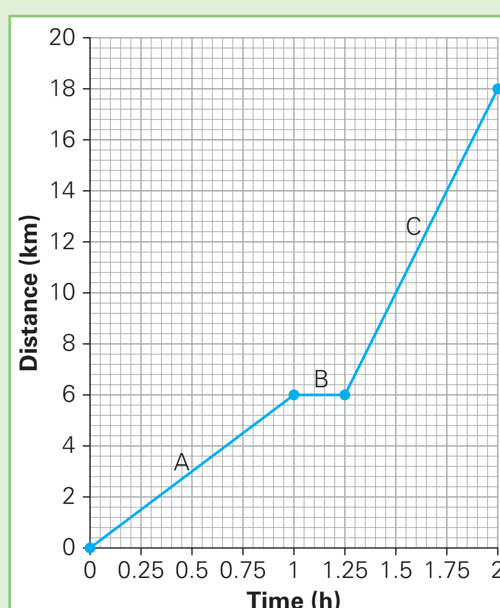


**Figure 6.20** Distance–time graph of a moving object

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## Displacement–time graphs

Displacement–time graphs display an object's movement with respect to a starting point. The starting position is always located on the graph at the coordinate (0, 0), and is referred to as the **origin**. When displacement returns to 0 on the $y$-axis, the object has returned to the point of origin at a particular time. This type of graph shows the displacement that the object travels away from and towards the origin over time. The gradient of a displacement–time graph is the velocity as it includes information of direction.

**origin**
the 0 point on the $y$-axis of a displacement–time graph

### Worked example 6.6

**Displacement–time graph**

Remember the distance–time graph for Elliott's walk. Here is his displacement–time graph for the same motion.

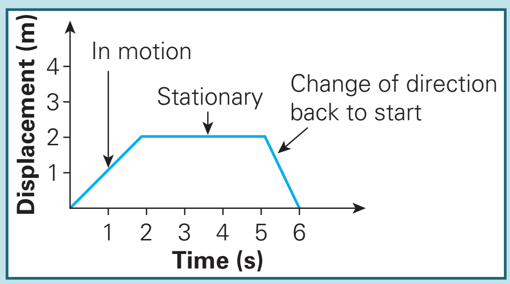


Figure 6.21 Displacement–time graph of Elliott's walk

1 Describe his movements in relation to his starting point.
2 Calculate his velocity at the following time intervals: from 0 to 2 seconds, 2 to 5 seconds and 5 to 6 seconds.

| Working | Explanation |
|---|---|
| **1** Describing movements | |
| For the first 2 seconds, Elliott moves away from his starting position by 2 metres. For the next 3 seconds, he is stationary. In the final second, he increases his velocity moving back to the origin (his starting position). | The displacement $y$-axis indicates how far from the start he is. In the distance–time graph, you could not tell which direction he was travelling, only that he was moving. |
| **2** Velocity | |
| 0 to 2 seconds: $v = \frac{\text{rise}}{\text{run}} = \frac{(2-0)\ \text{m}}{(2-0)\ \text{s}} = \frac{2\ \text{m}}{2\ \text{s}} = 1\ \text{m s}^{-1}$ <br> 2 to 5 seconds: <br> A horizontal line indicates he is stationary, in other words, $v = 0\ \text{m s}^{-1}$. <br> 5 to 6 seconds: $v = \frac{\text{rise}}{\text{run}} = \frac{(2-4)\ \text{m}}{(2-6)\ \text{s}} = \frac{-2\ \text{m}}{1\ \text{s}} = -2\ \text{m s}^{-1}$ | Select two points from each interval and use $\frac{\text{rise}}{\text{run}}$ to calculate the velocity. <br> A negative velocity means that he has changed directions and is travelling the opposite direction, in this case, back to the start. <br> He is travelling faster towards his original position (5 to 6 seconds) than he was when travelling away from it (0 to 2 seconds). |

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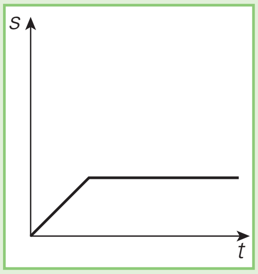
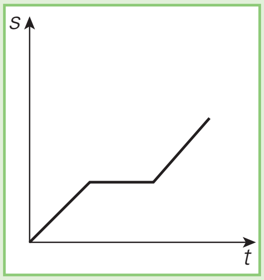
## Quick check 6.6

1 Describe the motion of an object according to the following displacement–time graph shapes.

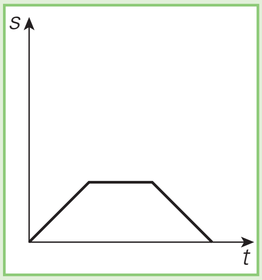
a




b




c




## Making thinking visible 6.2

**Elaboration game: Displacement–time graphs**

As a group of four, observe the displacement–time graph in Figure 6.22.

1 One person starts a plausible story by describing the first motion in the graph.

2 When the motion changes, a second person in the group continues the plausible story until the motion changes again.

3 Continue to take turns creating the motion story until each group member has had two turns.

4 Bring together your creative story that accurately describes what is occurring in the displacement–time graph.

Hold off on giving your ideas unless it is your turn to continue the story. Remember to include words from this chapter such as constant velocity, stationary, acceleration and at rest. And be creative!

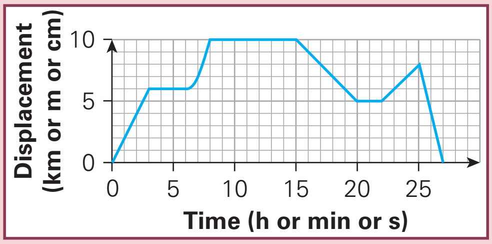
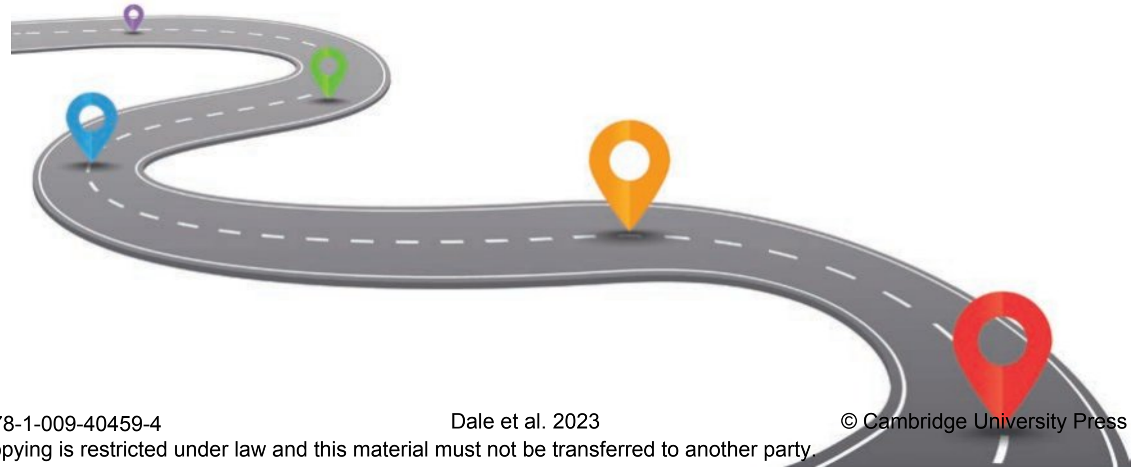



**Figure 6.22** Displacement–time graph

Challenge: If you have finished your story, calculate the velocity at certain points along the path.

The *Elaboration game* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education



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## Velocity–time graphs

Velocity–time graphs show the velocity of an object over time. This is a very versatile graph as it can be used to calculate other quantities such as displacement, instantaneous velocity and acceleration:

- Instantaneous velocity can be read directly from the line at any point in time.
- The gradient between two points on a velocity–time graph represents the acceleration over that time period.
- The area under a velocity–time graph calculates displacement of an object in that time period.

WORKSHEET Speed-time and velocity-time graphs

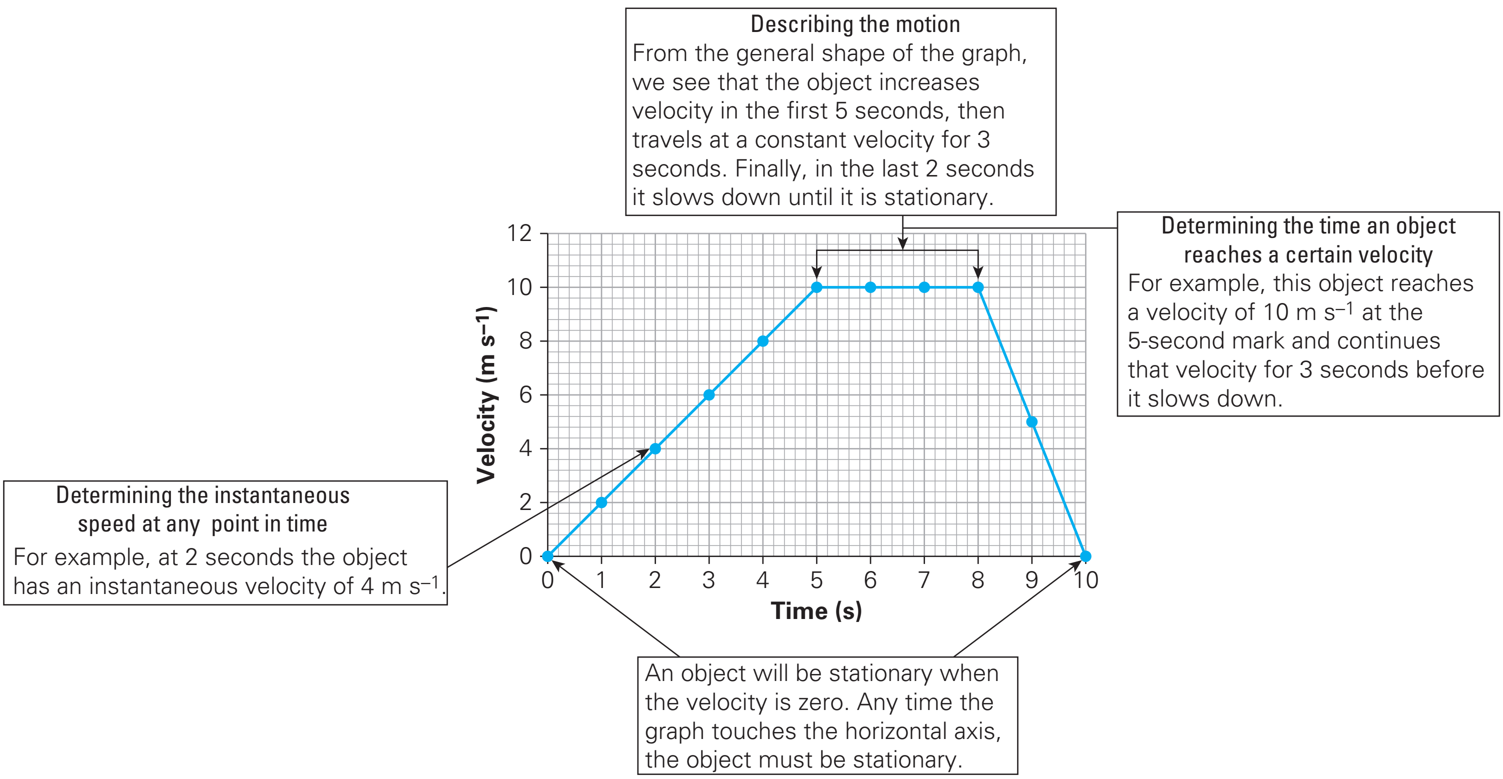


**Figure 6.23** A velocity–time graph tells you a lot about an object's motion.

### Reading instantaneous velocity

Imagine that a detector is used to capture the instantaneous velocity of an object moving in a straight line away from the detector. It records at every second for a period of 10 seconds. The following table is created and then the data can be represented on a velocity–time graph.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Velocity (m s$^{-1}$)** | 0 | 2 | 4 | 6 | 8 | 10 | 10 | 10 | 10 | 5 | 0 |
| **Time (s)** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

### Finding acceleration from the gradient

The three velocity–time graphs in Table 6.2 help to identify when an object in motion is accelerating, decelerating or travelling at a constant velocity.

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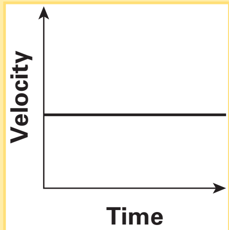
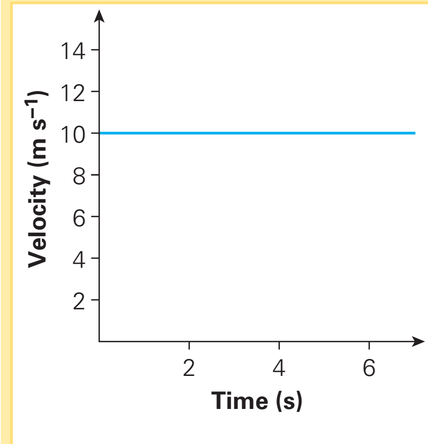
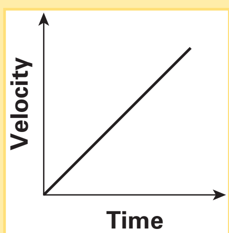
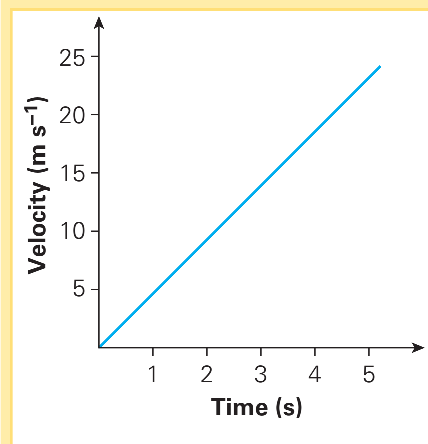
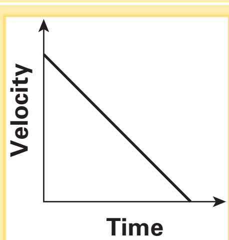
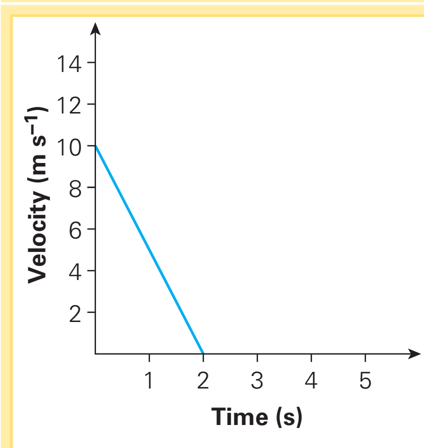
<table>
<tr><th>Shape</th><th>Explanation</th><th>Example</th></tr>
<tr><td>
</td><td>Horizontal lines indicate that an object is travelling at a constant velocity.</td><td>

$a = \frac{\text{rise}}{\text{run}} = \frac{0\ \text{m s}^{-1}}{10\ \text{s}} = 0\ \text{m s}^{-2}$</td></tr>
<tr><td>
</td><td>Positive gradient means positive acceleration (speeding up). The steeper the gradient, the more the object accelerates.</td><td>

$a = \frac{\text{rise}}{\text{run}} = \frac{25\ \text{m s}^{-1}}{5\ \text{s}} = 5\ \text{m s}^{-2}$</td></tr>
<tr><td>
</td><td>Negative gradient means negative acceleration (deceleration). The steeper the gradient, the quicker the object decelerates.</td><td>

$a = \frac{\text{rise}}{\text{run}} = \frac{-10\ \text{m s}^{-1}}{2\ \text{s}} = -5\ \text{m s}^{-2}$</td></tr>
</table>

**Table 6.2** Three types of velocity–time graphs

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## Calculating displacement

Displacement can be calculated from a velocity–time graph by calculating the area under the graph. In some cases, it is easier to split the graph into smaller sections.

### Worked example 6.7

**Calculating the displacement**

Consider the following graph of an object in motion.

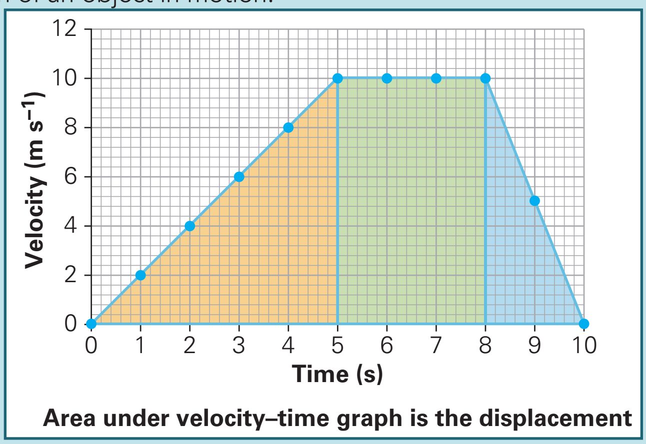
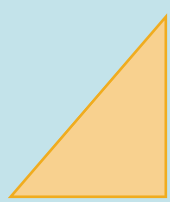
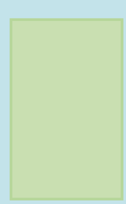



**Figure 6.24** Velocity–time graph

1. Calculate the displacement in the first 5 seconds.
2. Calculate the displacement from $t = 5$ to $t = 8$.
3. Calculate the displacement in the final 2 seconds.
4. What is the total displacement covered by the object over the entire 10 seconds?

| Working | Explanation |
|---|---|
| **1** Displacement in first 5 seconds | |
| The area in the first 5 seconds can be described by the triangle shown. $A_1 = \frac{1}{2}(5)(10) = 25$ This means that in the first 5 seconds the object displaces 25 metres.   | Redraw the shape and label the known sides. Calculate the area of the triangle which is given by the formula $A_1 = \frac{1}{2}bh$. Interpret the area, and check that units are correct. |
| **2** Displacement from $t = 5$ to $t = 8$ | |
| The area under the graph between $t = 5$ and $t = 8$ can be described by the rectangle shown. $A_2 = 3 \times 10 = 30$ This means that the displacement over this period is 30 metres.   | Redraw the shape and label the known sides. Calculate the area of the rectangle which is given by the formula $A_2 = l \times w$. Interpret the solution with correct units. |

*continued ...*

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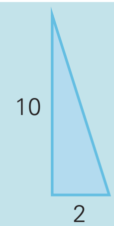
*continued …*

**3** Displacement in final 2 seconds

The area under the graph in the final 2 seconds is represented by the triangle shown.

$$A_3 = \frac{1}{2}(2)(10) = 10$$

In the final 2 seconds the object displaces 10 metres.




Redraw and label the shape.
Calculate the area.
Interpret solution with correct units.

**4** Total displacement

Sum each of the areas for the total distance covered.

$A_T = A_1 + A_2 + A_3$
$= 25 + 30 + 10$
$= 65$

Therefore, the total displacement by the object over the 10 seconds is 65 metres.

Add up all of the area sections under the graph to get the total displacement.

## Try this 6.3

**Plotting the motion of students over 100 metres**

**Instructions**

1 Copy the results tables into your science journal.
2 As a class, choose two students to run a 100-metre sprint.
3 All other students should line up at the 0, 20, 40, 60, 80 and 100 metre marks with a stopwatch.
4 Use stopwatches to capture the time from when a sprinter begins to when they pass each 20-metre mark. Ideally, there will be at least two classmates at each point so that an average of the times can be calculated. Record these results in the table.

**Results**

1 Calculate the difference in elapsed time for each 20-metre interval.

| Sprint times (s) at each 20 m mark | | | | | |
|---|---|---|---|---|---|
| Student name | 20 m | 40 m | 60 m | 80 m | 100 m |
| | | | | | |
| | | | | | |

2 Calculate the average velocity for each interval and complete the table of average velocity for each distance.

| Average velocity (m $s^{-1}$) | | | | | |
|---|---|---|---|---|---|
| Student name | 0–20 m | 20–40 m | 40–60 m | 60–80 m | 80–100 m |
| | | | | | |
| | | | | | |

3 Plot the displacement–time graph by drawing smooth trend lines.

**Analysis**

1 Describe the shapes of each interval in each graph.
3 Propose why it was important to gather data from more than one classmate.
4 Identify some potential sources of error in the data.

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## Quick check 6.7

Analyse the velocity–time graph in Figure 6.25.

1 Describe the motion of the object shown in the graph.
2 Calculate the acceleration over the first two seconds.
3 Calculate the acceleration between $t = 2$ and $t = 4$.
4 Calculate the displacement after the first two seconds.
5 Determine the total displacement over four seconds.

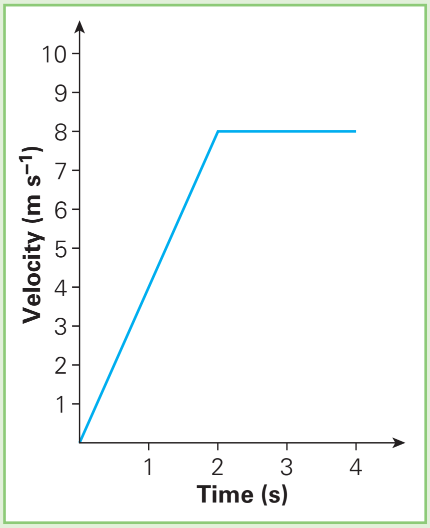
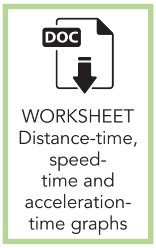
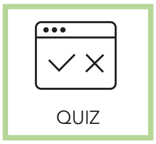



**Figure 6.25** Velocity–time graph




## Section 6.2 questions




**Retrieval**

1 **Recall** what the gradient of a displacement–time graph indicates.
2 **Recall** what the gradient of a velocity–time graph indicates.
3 **Recall** what the area under a velocity–time graph indicates.
4 Consider the velocity–time graph in Figure 6.26.
   a **Calculate** the acceleration in the first three seconds.
   b **Calculate** the acceleration for the next two seconds.
   c **Calculate** the displacement of the object after five seconds.

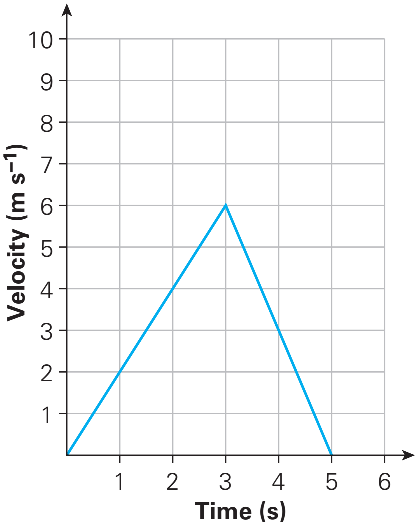



**Figure 6.26** Velocity–time graph

**Comprehension**

5 **Describe** what the shape of a displacement–time graph can reveal about an object's movements.
6 **Describe** what the shape of a velocity–time graph can reveal about an object's movements.

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**Analysis**

**7** The path of a hiker in the Wooroonooran National Park from the parking lot to a lookout is described in the displacement–time graph in Figure 6.27.

- **a** **Determine** the distance to the lookout, where the walker sat to take a break.
- **b** **Determine** the average velocity of the hiker in the first two hours.
- **c** **Determine** how long the hiker sits at the lookout.
- **d** **Determine** the velocity of the hiker on their way back to the parking lot.

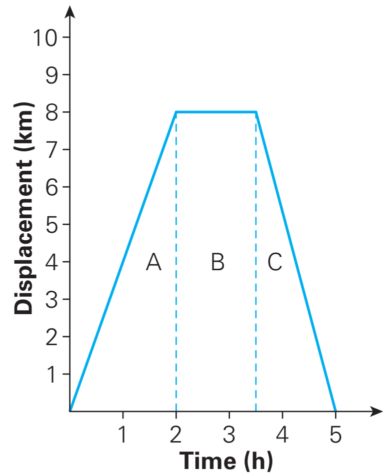


Figure 6.27 Displacement–time graph of a hiker's walk

**Knowledge utilisation**

**8** Hundreds of thousands of animals in Australia are killed every year by vehicles. Consider the velocity–time graph in Figure 6.28.

- **a** If a driver travelling at 90 km $h^{-1}$ takes 0.5 seconds to react, and they come to a stop according to the following velocity–time graph, **determine** the total stopping distance.

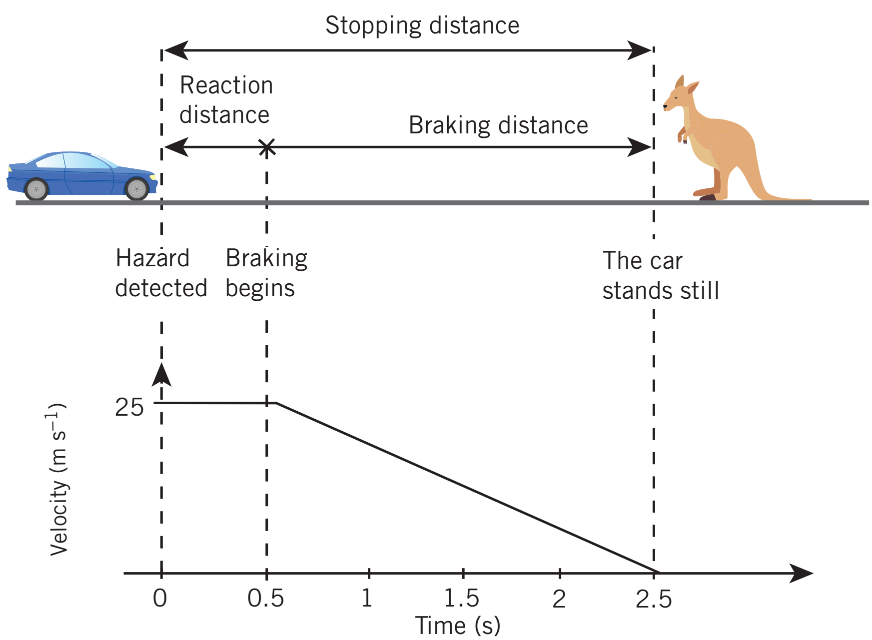


Figure 6.28 Velocity–time graph

- **b** If the reaction time was increased to one second, **determine** what the stopping distance would be.

**9** **a** Use the following table to **construct** a displacement–time graph of a koala.

| Time (s) | Displacement (m) |
|---|---|
| 0 | 0 |
| 2 | 2 |
| 5 | 3 |
| 7 | 3 |
| 9 | 4 |
| 10 | 5 |

- **b** Using the graph, **decide** what conclusions can be made about its movements, including whether we can tell the direction it went.

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# 6.3 Newton's laws of motion

WORKSHEET
Forces and Newton's laws of motion

VIDEO
Newton's first law

**Learning goals**

1. To be able to recall Newton's first law of motion.
2. To be able to use the equation $F = ma$, Newton's second law of motion.
3. To be able to recall Newton's third law of motion.
4. To investigate how First Nations Australians used tools to increase impact force.
5. To apply Newton's laws of motion in sports and transportation.

## Sir Isaac Newton's three laws of motion

### Newton's first law of motion

**Newton's first law of motion**, is the law of **inertia**, and states:

> An object will remain at rest or travel at a constant speed in a straight line unless it is acted upon by an external force.

A **force** is a push or a pull, and when unopposed, a net force causes an object to speed up, slow down or change direction. This means a force could accelerate or decelerate a moving object, or even cause a moving object to become stationary. A force can also change the direction of a moving object. In the real world, an object will often have multiple forces acting on it, all contributing to that object's motion.

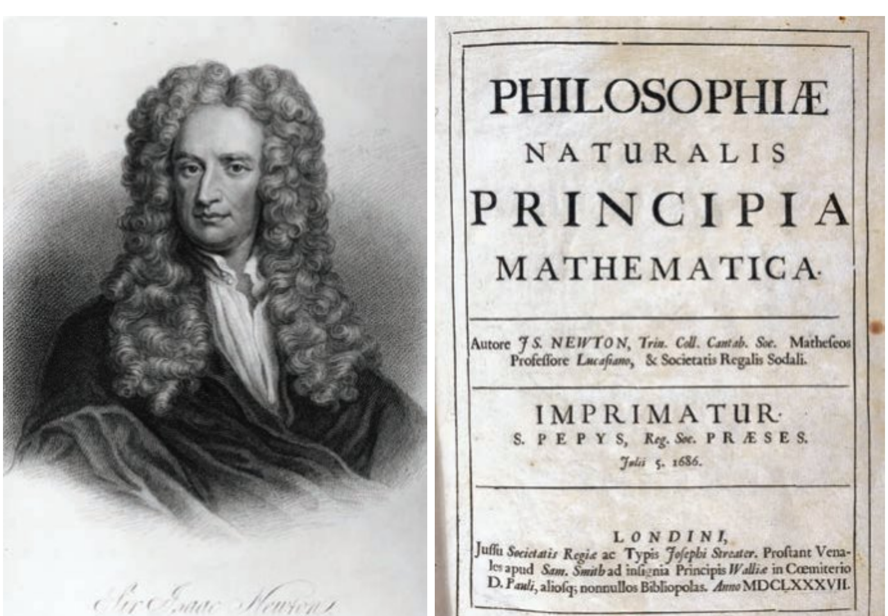
If the multiple forces acting on an object are balanced – the forces are equal in magnitude and occurring in opposite directions – the object's motion will not change. A stationary object will remain stationary, and a moving object will continue to move in the same direction at constant velocity. The term **net force** is used to describe the sum of all forces acting on an object. When the net force is zero ($F_{net} = 0$), the forces are balanced and will not change the motion of the object. However, if the forces applied to an object are unbalanced ($F_{net} \neq 0$), the object will either accelerate, decelerate or change direction.

**Newton's first law of motion**
an object will remain at rest or moving at a constant speed in a straight line unless acted upon by an external force

**inertia**
the tendency of an object to remain in its state of motion in the same direction unless acted upon by an external force

**force**
any interaction that, when unopposed, will change the motion of an object

**net force**
the sum of all the forces acting on an object


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore J S. NEWTON, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Jussu Societatis Regiæ ac Typis Josephi Streater. Prostant Venales apud Sam. Smith ad insignia Principis Walliæ in Cœmiterio D. Pauli, aliosq; nonnullos Bibliopolas. Anno MDCLXXXVII.

**Figure 6.29** Newton's *Philosophiae Naturalis Principia Mathematica* (The Mathematical Principles of Natural Philosophy) was published in 1687. It revolutionised the scientific thinking of the time by formulating the laws of motion.

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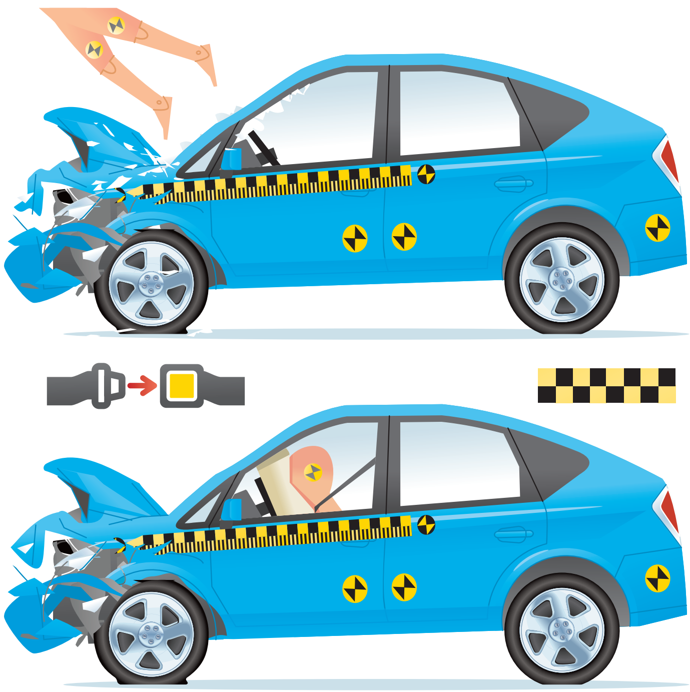
| $F_{net} = 0$ | $F_{net} \neq 0$ |
|---|---|
| The forces acting on an object are balanced and sum to zero. The motion of the object is not changed in speed or direction. | The forces on the object are unbalanced and sum to either a positive or negative number. The motion of the object changes. It either speeds up or slows down or changes direction, depending on the direction of the net force. |

**Table 6.3** The effect of balanced and unbalanced forces



Inertia is responsible for the feeling that you get when you suddenly change motion in a car, train or aeroplane or on a bike. At times when we travel at a constant speed we hardly even recognise that we are moving. But when the vehicle that we are travelling in suddenly stops, turns a sharp corner or accelerates, we notice that our body moves unexpectedly. This is inertia! It is the tendency for objects to either stay at rest or continue travelling at a constant speed, in the same direction.

**Figure 6.30** Consider travelling in a car at a constant speed. When the brakes are suddenly pressed, the car quickly slows down but our body continues to move forwards at the original speed. If it were not for seatbelts, we would continue our motion through the front window of the car.

## Try this 6.4

**Inertia at a roundabout**

Imagine you are sitting in the back seat of a car and the driver drives around a roundabout rather quickly. How does your body move? You might have experienced a force pulling you to the side. Remembering that inertia is an object's tendency to resist a change in motion, consider how your body moves in a car when it:

- travels at a constant speed
- brakes suddenly
- takes a roundabout turn quickly
- takes off at a green light.

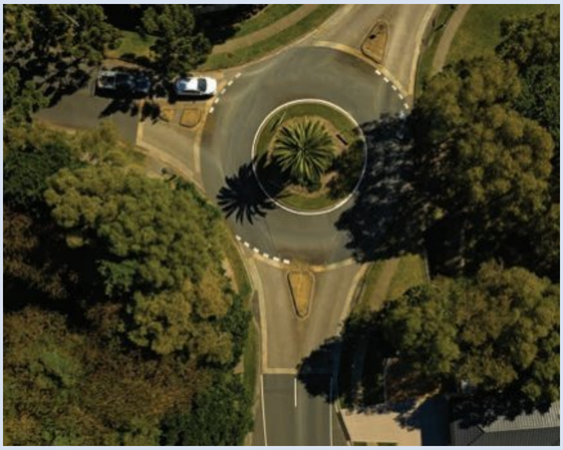


**Figure 6.31** You can feel the effect of inertia when you're going around a roundabout.

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## Newton's second law of motion

**Newton's second law of motion** is a mathematical formula that describes the relationship between net force, **mass** and acceleration. Newton's second law states:

> The net force acting on an object equals the mass of the object multiplied by its acceleration.

It can also be written as:

$$\text{net force (N)} = \text{mass (kg)} \times \text{acceleration (m s}^{-2}\text{)}$$

$$F_{net} = ma$$

NOTE: The units for force are newtons, N, in which 1 N is equal to 1 kg m $s^{-2}$.

From this equation, the following relationships can be noted:

- The greater the mass of the object, the greater the force needed to accelerate it.
- The greater the force applied to an object, the greater its acceleration.
- If an object is accelerating, then there must be a net force.

Figure 6.32 shows a cricket bat hitting a cricket ball of mass $m$. When a net force $f$ is applied to the cricket ball, it will experience an acceleration $a$. If a cricket ball of larger mass $2m$ was hit with the same net force $f$, its acceleration ($1/2a$) will be less than that of the original ball. Finally, if the cricket ball is hit harder with a net force of $2f$, its acceleration will also increase to $2a$, in proportion to the force.

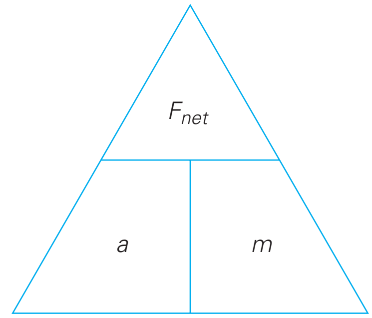


Figure 6.33 To use the force triangle, cover the variable you want to calculate. If the other variables are on the same row, multiply them together. If they are on different rows, divide the top variable by the bottom variable.

VIDEO Newton's second law

WIDGET Newton's second law

**Newton's second law of motion** an object acted upon by a force experiences acceleration in the same direction proportional to the magnitude of the net force and inversely proportional to the mass of the object

**mass** the quantity of matter

Using the force triangle (Figure 6.33), we have:

$$F_{net} = ma, \quad a = \frac{F_{net}}{m}, \quad m = \frac{F_{net}}{a}.$$

Newton's first law of motion describes how a net force on an object is required to overcome its inertia and change its motion. Newton's second law of motion allows this change in motion to be quantified.

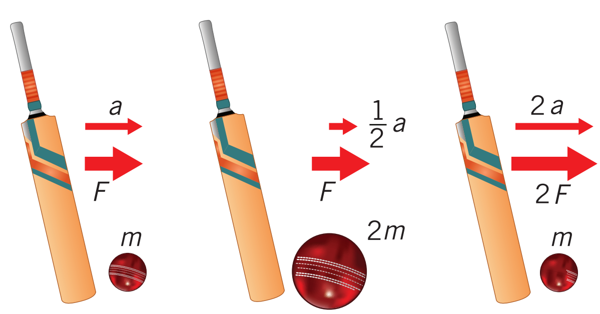


Figure 6.32 A cricket ball hit by a bat follows Newton's second law of motion.

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### Worked example 6.8

Consider two students moving a table of mass 13 kilograms. One student pushes horizontally with a force of 30 N while the other pulls horizontally with a force of 80 N. Ignore all vertical forces and ignore frictional forces between the table and the floor.

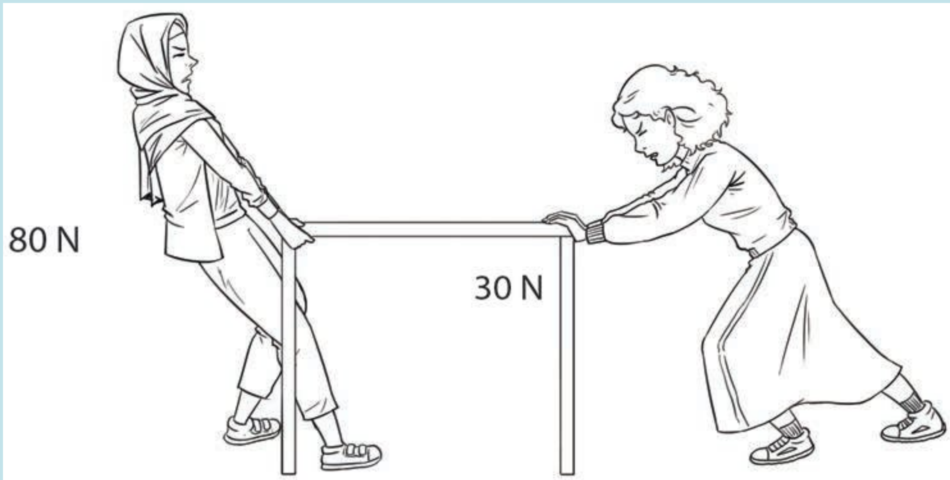


**Figure 6.34** Two students trying to move a table

1 What is the net force and direction of the table?
2 What is the acceleration of the table?

| Working | Explanation |
|---|---|
| **1** Net force | |
| $F_{net}$ = 30 + 80 = 110 N to the left<br>There is effectively 110 N of force acting on the table towards the left direction. | Calculate the net force by adding all of the forces acting on the object, i.e. the table. Since the surface of the floor pushes up on the table with the same force as the table pushes back on the floor, you can ignore the vertical forces. The only relevant forces acting on the table are the two in the horizontal direction. The net force is the sum of the two forces that the students exert on the table. |
| **2** Acceleration | |
| $a = \frac{F_{net}}{m}$<br>$a = \frac{110\text{ N}}{13\text{ kg}} = 8.46\text{ m s}^{-2}$ to the left | Newton's second law allows you to calculate how quickly the table will accelerate if you know what the mass of the table is. (In real life there would be a frictional force between the table and the floor acting against the motion. If in this example, the frictional force was 50 N, then the net force would be 110 N – 50 N = 60 N and the acceleration 60 N/13 kg = 4.62 m s$^{-2}$ to the left.) |

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## Newton's discovery of gravity

The story goes that an apple falling from a tree onto Newton's head led him to wonder why the Moon does not also fall towards Earth. His question led him to the discovery of gravity, which is an attractive non-contact force felt by all objects that have a mass. The greater the mass of an object, such as a planet, the greater the gravitational force it will exert. This discovery answered Newton's question about the Moon: he was able to identify that the Moon is attracted to Earth's gravity, just as the apple is, but the Moon's attraction and speed causes it to orbit Earth.

Mass is the quantity of matter in an object and does not change regardless of the gravitational force acting on it. Mass is measured in kilograms when using SI units. **Weight** is different to mass, as it is actually a force, measured in newtons. In physics, weight is often called the 'force due to gravity', or the 'weight force'. It is calculated by multiplying the mass of the object by the acceleration due to gravity acting on it. For example, Earth's gravitational field pulls objects to its centre at a rate of 9.8 m $s^{-2}$, so a person with a mass of 70 kilograms will have a weight of 70 kg × 9.8 m $s^{-2}$ = 686 N (where N is the unit used to describe kg m $s^{-2}$).

In general, you can use the following equation to calculate the weight force

$$F_g = mg$$

where $F_g$ is the force due to gravity, also known as the weight force measured in newtons (N), $m$ is the mass of the object measured in kilograms and $g$ is the strength of the gravitational field measured in m $s^{-2}$. Note that $g$ can be given as 9.8 m $s^{-2}$ or 9.8 N $kg^{-1}$; the two units are equivalent. The unit N $kg^{-1}$ is convenient when working out the weight of an object.

**weight**
the force of gravity on the mass of an object

Remember the mass of an object is the same regardless of the strength of the gravitational field.

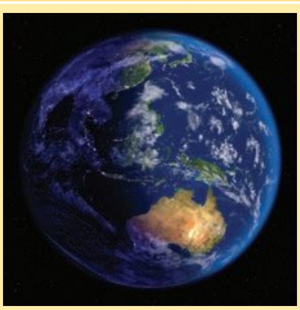
| Earth | Moon | Mars | Venus |
|---|---|---|---|
|  |  |  |  |
| $g$ = 9.8 N $kg^{-1}$ | $g$ = 1.6 N $kg^{-1}$ | $g$ = 3.7 N $kg^{-1}$ | $g$ = 8.9 N $kg^{-1}$ |

**Table 6.4** The strength of the gravitational field is different on Earth, the Moon, Mars and Venus.

### Quick check 6.8

1. Calculate the force that is required to accelerate an object of mass 6 kilograms at 2.3 m $s^{-2}$.
2. Calculate the mass of an object that accelerates at 0.2 m $s^{-2}$ when it is pushed with a force of 20 N.
3. If a car of mass 1000 kilograms is travelling at a constant velocity, calculate the deceleration when the brakes are applied with a force of 1500 N.
4. Calculate the weight of a 60 kg person on Earth, the Moon, Mars and Venus.

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## Practical skills 6.1: Self-design

### Acceleration due to gravity

**Aim**

To accurately calculate acceleration due to gravity.

**Useful equation**

$$\text{Acceleration due to gravity (m s}^{-2}\text{)} = \frac{2 \times \text{distance travelled during vertical descent (m)}}{\text{time}^2\ (\text{s}^2)}$$

**Materials**

- a number of objects to drop (e.g. marble, steel ball bearing, tennis ball)
- 3-metre measuring tape
- smartphone with high-speed slow-motion capabilities

**Method**

Use the formula given as a guide to design a method of accurately calculating acceleration due to gravity. For example, tape the 3-metre measuring tape to a wall and drop different objects a number of times. Try a few different dropping heights. Analyse the high-speed videos.

**Results**

1 Create a table for your results.
2 Record all the collected data.
3 Process the data to produce an estimate of the magnitude of the acceleration due to gravity.

**Analysis**

1 Discuss if the different objects accelerate at the same rate. Why or why not?
2 State how many trials there were of the same object and why that number was selected.
3 Determine if air resistance affected your results. Explain your reasoning.
4 Explain why you did not measure the mass of the various objects that you were dropping.
5 Compare your results with the accepted value of the magnitude of the acceleration due to gravity.

## Explore! 6.2

### Protecting drivers and passengers

Car crashes can result in extreme forces acting on humans within the crashed vehicle. Engineers are constantly investigating ways to reduce the possible impact forces on drivers and passengers, of all body types and age. They might do this by conducting test car crashes with human-like crash-test dummies or even by engineering driverless cars, whose reaction times are far superior than those of humans, to reduce the occurrence of crashes. Use the internet to gather some answers to the following questions.

1 In 2022, the first female crash-test dummy was produced. Why was this important in the future of car safety?
2 What are some causes of car crashes, even if the driver is following the road rules?
3 Driverless cars will have a 360-degree view of their surroundings, and a faster reaction time and better braking performance than a human driver. Research your preferred car brand and describe the time frame for the future of any driverless vehicles in production.

**Figure 6.35** Female and child crash-test dummies in a car (left). A woman sitting in a driverless car (right).

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## Practical skills 6.2: Self-design

### Force and mass

**Aim**

To investigate the effects of force or mass on acceleration.

**Hypothesis**

Write a hypothesis regarding the effect of changing force or mass on the velocity or acceleration of a trolley.

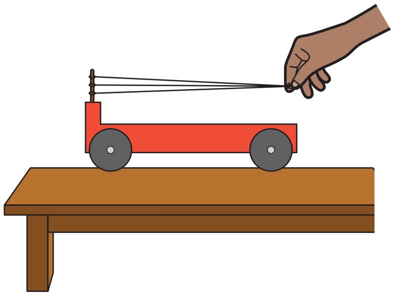
**Materials**

- crash trolley
- elastic bands
- weights
- tape
- stopwatch
- data logger (if available)

**Method**

1. Design an experiment that investigates the effects of either force or mass on acceleration.
2. Team up with another group, who should investigate the effect of the other factor (force or mass).

NOTE: You can use increasing numbers of elastic bands to demonstrate increased force applied on the trolley, and increased masses on the trolley to investigate mass.



**Results**

1. Record your mass, force, velocity or acceleration data in an appropriate table.
2. Plot an appropriate graph or graphs of force or mass vs. velocity and/or acceleration.

**Analysis**

1. As force increases, what happens to velocity and acceleration?
2. As mass increases, what happens to velocity and acceleration?

**Evaluation**

1. How can your experimental design be improved?
2. Identify any sources of error (experimental uncertainty or experimental faults).

**Conclusion**

1. Make a claim about force, mass, velocity and acceleration based on this experiment.
2. Does the claim support or not support your hypothesis?
3. Use the data that you gathered to explain whether the hypothesis is or is not supported.

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**Newton's third law of motion**
for every action, there is an equal and opposite reaction

## Newton's third law of motion

**Newton's third law of motion** describes that a force exerted from an object on another object will also have a reactive force exerting back in the opposite direction. These are called action and reaction forces. For example, if you were to push on a wall, the wall pushes back just as hard (Figure 6.36) – if it did not, you would fall through! Newton's third law formally states:

> For every action, there is an equal and opposite reaction.

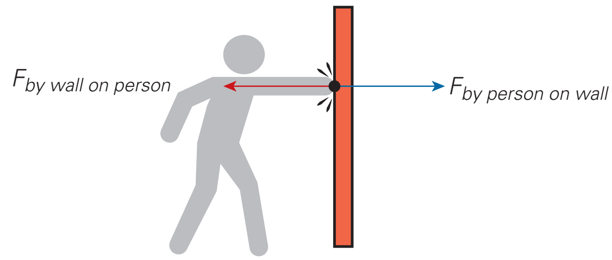


**Figure 6.36** The action of pushing against a wall has a reaction force that pushes back on the person with the same magnitude.

Action and reaction pairs always act on different objects exerting a force. For example, when you walk on the ground, you exert a force on the ground, but you don't fall through the ground as an equal and opposite force is acting back on you. Similarly, if you were to exert a force to throw a ball, the ball would also exert a force back onto your hand. For every action force, there is a reaction force.


**Figure 6.37** As a person lands on a trampoline, they exert a force downwards on the mat when in contact with the mat. The mat then pushes them back up with an equal but opposite force. This causes the person to slow down and stop, then bounce back into the air.

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## Explore! 6.3

### Foot scooters and e-scooters

In Queensland it is legal to ride a foot scooter without a helmet, but a strap-fastened helmet is required to ride an electric-powered e-scooter. Helmets are capable of reducing the impact force of the head on another hard object such as the ground in a crash or fall. They also increase the visibility of riders, potentially reducing the risk of collisions on footpaths or roads.

Use the internet to investigate the statistic that helmets can reduce the risk of head and brain injury for e-scooter riders by at least 80%. Examine the information that you collect in your research and make a statement on the effectiveness of helmets to the safety of e-scooter riders.

**Figure 6.38** An e-scooter rider with a helmet (left) and a foot scooter rider (right).

## Try this 6.5

### Newton's third law in sport

Action and reaction forces are at play in all sports, and some of those forces can impact the safety of players. Consider some of the safety gear or precautions in the rules of the following sports that might protect players from dangerous action and reaction forces.


**Figure 6.39** Jordan Mailata, an Australian professional American football player, wears protective gear when playing for the Philadelphia Eagles.

| Sport | Protective gear or rules |
|---|---|
| Rugby | |
| Australian rules football | |
| Netball | |
| Cricket | |
| Horse riding | |
| American football | |
| Ice hockey | |

**Table 6.5** Action and reaction forces

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## Explore! 6.4

**Projectiles and throwing devices**

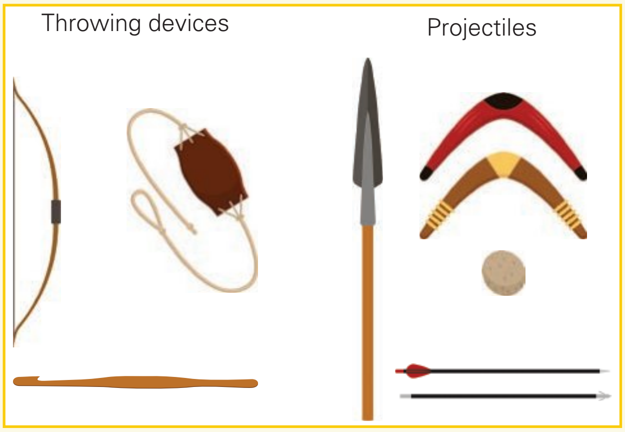


**Figure 6.40** What type of throwing device is the boomerang?

Different groups of First Nations Australians have used spears and spear-throwers, and bows and arrows, for thousands of years. They learned from experience what works best and have an understanding of the relationship between the mass of the projectile (spear or arrow), the throwing device (spear-thrower or bow), the force applied to it, and the effect on its velocity, range and impact force. The types of devices used varies widely among different Peoples throughout Australia. Use your preferred search engine to investigate how First Nations Australians achieved an increase in velocity and subsequent impact force by using spear-throwers and bows.

## Practical skills 6.3: Self-design

### Crash-test eggs

**Aim**

To design and build a car with safety features that will protect an egg from breaking during a collision.

**Hypothesis**

Write a hypothesis investigating how the crash impact force and speed will affect whether the egg in the car will break.

**Materials**

As chosen by students but may include:

- rubber bands
- wheels
- icy-pole craft sticks
- dowels
- plastic cups
- straws
- rubber bands
- string
- springs
- balloons
- toilet paper or paper towel rolls
- cardboard boxes (varying sizes)
- plastic bottles
- flat cardboard
- sticky tape

*continued …*

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*continued …*

**Method**

1 Research vehicle collisions, safety features of cars and the forces involved during a collision.
2 Based on your research, design and build a vehicle or device that has safety features to protect an egg during a collision.
3 Test your design by competing as a class to see whose crash-test egg survives.

**Results**

Take a high-speed video of your collision and slow it down to see the forces in effect.

**Analysis**

1 Compare your safety device to a safety feature in a car.
2 Draw the forces acting on the egg during the collision.
3 Describe how seatbelts, airbags and crumple zones in a car reduce the force on a passenger in a car crash. How have you modelled these aspects in your model?

**Evaluation**

What difficulties or errors did you encounter during this experiment? How could you improve the experiment to avoid these in the future?

**Conclusion**

1 Make a claim about safety based on this activity.
2 Support the statement by using your observations and include potential sources of error.
3 Explain how your observations support the statement.

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QUIZ

## Section 6.3 questions

### Retrieval

1 An object is travelling at a constant speed and zero net force is applied to it.
   a **Recall** what happens to the object.
   b **Identify** the Newton's law that applies in this situation

2 **Calculate** the mass of an object, to two decimal places, that accelerates at 0.63 m $s^{-2}$ when it is pushed with a force of 20 N.

3 If a car of mass 1500 kilograms is travelling at a constant velocity, **calculate** the deceleration when the brakes are applied with a force of 1200 N.

**Figure 6.41** A 1500 kg car driving at constant velocity.

### Comprehension

4 **Define** the term 'inertia'.

5 **Describe** the term 'net force'.

6 **Describe** the term 'weight'.

### Analysis

7 **Contrast** the quantities 'weight' and 'mass'.

### Knowledge utilisation

8 A 50-kilogram person sits on a chair with feet dangling above the ground. **Construct** a diagram to represent the action–reaction pair of forces acting on the scenario and include labels to indicate the force quantities. (Note that acceleration due to gravity $g$ = 9.8 m $s^{-2}$.)

9 Two students are trying to push a mass towards each other. Student 1 on the left exerts a force of 155 N on the mass to the right and student 2 on the right exerts a force of 220 N to the left. Ignore frictional forces.
   a **Determine** the net force acting on the mass.
   b **Deduce** the direction in which the mass will move.
   c Using Newton's second law, if the mass is 216 kilograms, **determine** the acceleration of the mass.
   d **Elaborate** on whether there are action–reaction pairs in the system. Quantify the forces where possible.

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# Chapter review

## Chapter checklist

You can download this checklist from the Interactive Textbook to complete it.

| Success criteria | | Linked questions | Check |
|---|---|---|---|
| 6.1 | I can distinguish between distance and displacement. | 1 | |
| 6.1 | I can calculate the speed of an object in units of m $s^{-1}$ and km $h^{-1}$. | 8, 10a | |
| 6.1 | I can describe and distinguish between speed and velocity. | 1, 4 | |
| 6.1 | I can calculate the acceleration of an object. | 10b | |
| 6.2 | I can use velocity–time, distance–time and displacement–time graphs to analyse and communicate an object's motion. | 2, 9, 10c | |
| 6.3 | I can explain Newton's three laws of motion. | 3, 5 | |
| 6.3 | I can explain how knowledge of Newton's laws of motion can be applied, e.g. in sports, safety or transport issues. | 6 | |
| 6.3 | I can describe how First Nations Australians achieve an increased impact force through the use of spear-throwers and bows. | 7 | |

## Review questions

SCORCHER

### Retrieval

1 **Distinguish** between distance and displacement, and between speed and velocity, using an example.

2 **Recall** what the gradient of a displacement–time graph indicates.

3 **Describe** Newton's three laws of motion.

4 **Provide** one example that demonstrates average speed and one example that demonstrates instantaneous speed.

### Comprehension

5 **Identify** three action–reaction pairs in Figure 6.42.

6 **Describe**, using your knowledge of Newton's third law of motion, how a cricket helmet can protect a player's head from the impact force of a cricket ball.

7 Use of a spear-thrower increases the spear's speed. **Describe**, using your knowledge of Newton's second law of motion, how the use of a First Nations Australian spear-thrower can increase the impact force of a spear.

**Figure 6.42** Action–reaction pairs on rugby players

### Analysis

8 Consider the hypothetical times of Cathy Freeman's personal best 400-metre sprint.

| Distance (m) | 0 | 50 | 100 | 200 | 300 | 400 |
|---|---|---|---|---|---|---|
| Time (s) | 0 | 5.98 | 11.54 | 23.65 | 35.22 | 48.63 |

a **Calculate** the average speed of Cathy Freeman for the entire 400 metres. That is, from $t = 0$ to $t = 48.63$.

b **Determine** if she travels quicker in the first 200 metres or the last 200 metres.

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**Knowledge utilisation**

9 Consider the path of a bungee jumper. For simplicity, assume that the path of motion is straight up and down. As a person jumps from the platform, they accelerate towards the ground. They decelerate when the rope tightens, then accelerate back up and so on. The first ten seconds of the jump are plotted in Figures 6.44 and 6.45, where the origin represents the position of the jumper just before they leap from the platform.

a **Determine** the distance that the jumper travels in the first four seconds.

b **Determine** the displacement of the jumper after four seconds.

c **Determine** the distance covered by the jumper in the first ten seconds.

d **Determine** how far the jumper is from the platform after ten seconds (i.e. the displacement).

e **Calculate** the average speed in the first four seconds.

f **Determine** the speed at the six-second mark.

Figure 6.43 A bungee jumper in Cairns

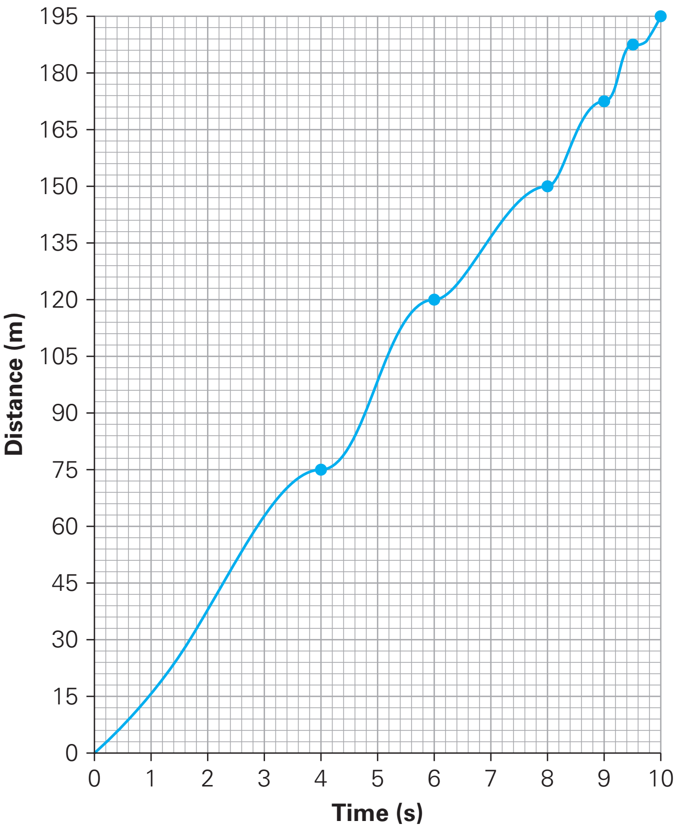


Figure 6.44 A distance–time graph of the bungee jumper

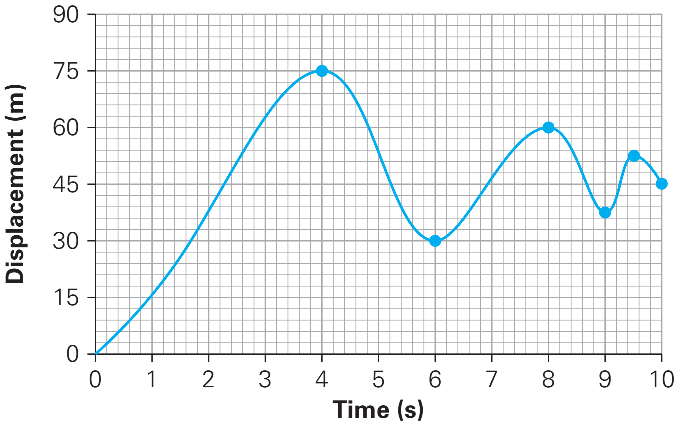


Figure 6.45 A displacement–time graph of the bungee jumper

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10 A car starts from rest and accelerates at a constant rate in a straight line for five seconds to a final velocity of 54 km $h^{-1}$.

a **Calculate** the final velocity in m $s^{-1}$.

b **Calculate** the acceleration, in m $s^{-2}$, over the five seconds.

c Construct the velocity–time graph for this scenario and use it to **calculate** the distance the car had moved using the area under the graph.

## Data questions

### Apply

1 Using the velocity–time graph in Figure 6.46, **identify** the velocity of the object at the 10, 40, 90 and 140 second marks.

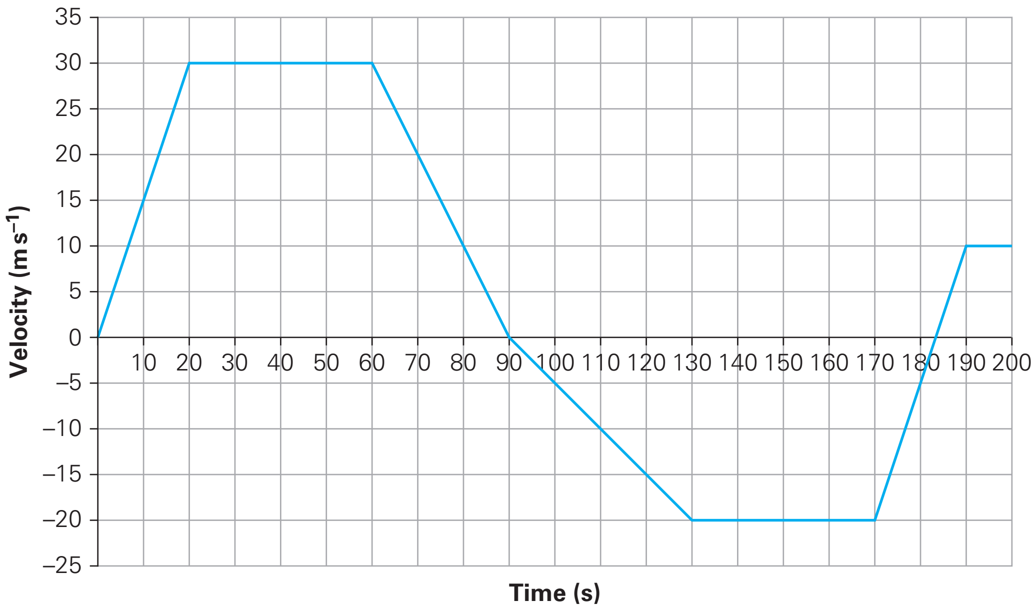


**Figure 6.46** Velocity–time graph of unknown object

2 **Calculate** the acceleration of the object at the 10, 40, 80 and 110 second marks.

3 **Calculate** the displacement of the object from its origin after 170 seconds.

### Analyse

4 **Interpret** the velocity–time graph to describe the motion of the object in words.

### Interpret

5 **Deduce** a potential identity of the object.

6 **Propose** why the object is unlikely to be a bicycle.

# STEM activity: Transportation and energy usage

## Background information

Transportation is a major part of everyday life, and whether it's a car, train, bus, plane or even a boat, energy is used in some form. While there has been a considerable push towards replacing fossil-fuel-burning engines with rechargeable batteries in the 2020s, many vehicles still use petroleum-based fuels as their source of energy. This makes it really important to be efficient in transportation design, including considering how energy is being transferred and transformed in the vehicle.

In petroleum engines, some energy is lost as heat going into the surrounding environment rather than directly into moving the wheels. Kinetic energy, which comes from the transformation of mechanical energy, is also lost as heat energy within the tyres and the road. It is estimated that approximately 75% of the energy input into a petrol-powered car engine is lost. Of this, the majority is engine losses, but there are also losses in the drivetrain and tyres. The aerodynamics of the vehicle shape also contributes to the energy efficiency issues.

**Design brief:** Decide on a mode of transportation and design improvements that will increase the efficiency of energy usage of a model.

**Figure 6.47** A car being charged with electricity

## Activity instructions

In groups of three, decide on a mode of transportation that you are interested in and research the ways in which energy is lost due to inefficiencies in design. Then, design and test improvements that could be made to improve efficiency of energy.

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## Suggested materials

- cardboard boxes
- cardboard
- tape
- various types of materials
- glue
- force meter
- measuring tape

## Research and feasibility

1 Discuss and decide with your group which type of transportation you would like to learn about.
2 List all the ways energy goes in and then is used or lost.
3 Research ways to increase efficiency of energy as it goes in and is used or lost. This can be done in a table – an example is shown below.

| Energy | Possible issues | Ideas for design |
|---|---|---|
| e.g. Car<br>Energy in – petrol | Engine can be dirty and incomplete combustion occurs. | Recommend engine regularly serviced. |
| e.g. Car<br>Energy out – axle turning | Axle can have friction. | Lubricate axle |
| e.g. Car<br>Energy out – car shape | Air resistance | Make car bonnet smooth to allow less friction from air resistance. |
| | | |
| | | |

## Design and sustainability

4 Discuss available materials in your group and decide how you will design your initial prototype for preliminary testing.
5 Design your prototype without any efficiency ideas in place and decide how you will test this prototype.
6 Design a prototype, or changes to your initial prototype, that includes all efficiency ideas. You may choose to test them one by one or all together, depending on time and materials.
7 Discuss and justify why efficient design components are important for sustainability and how they contribute on a global energy scale.

## Create

8 Construct your prototype and then complete testing.

## Evaluate and modify

9 Using your energy equations, perform calculations on energy you supplied to your prototype and consider how effectively this energy was used.
10 Explain to the class your prototype improvements and justify why your changes resulted in improved efficiency of energy transformation, or why they did not.

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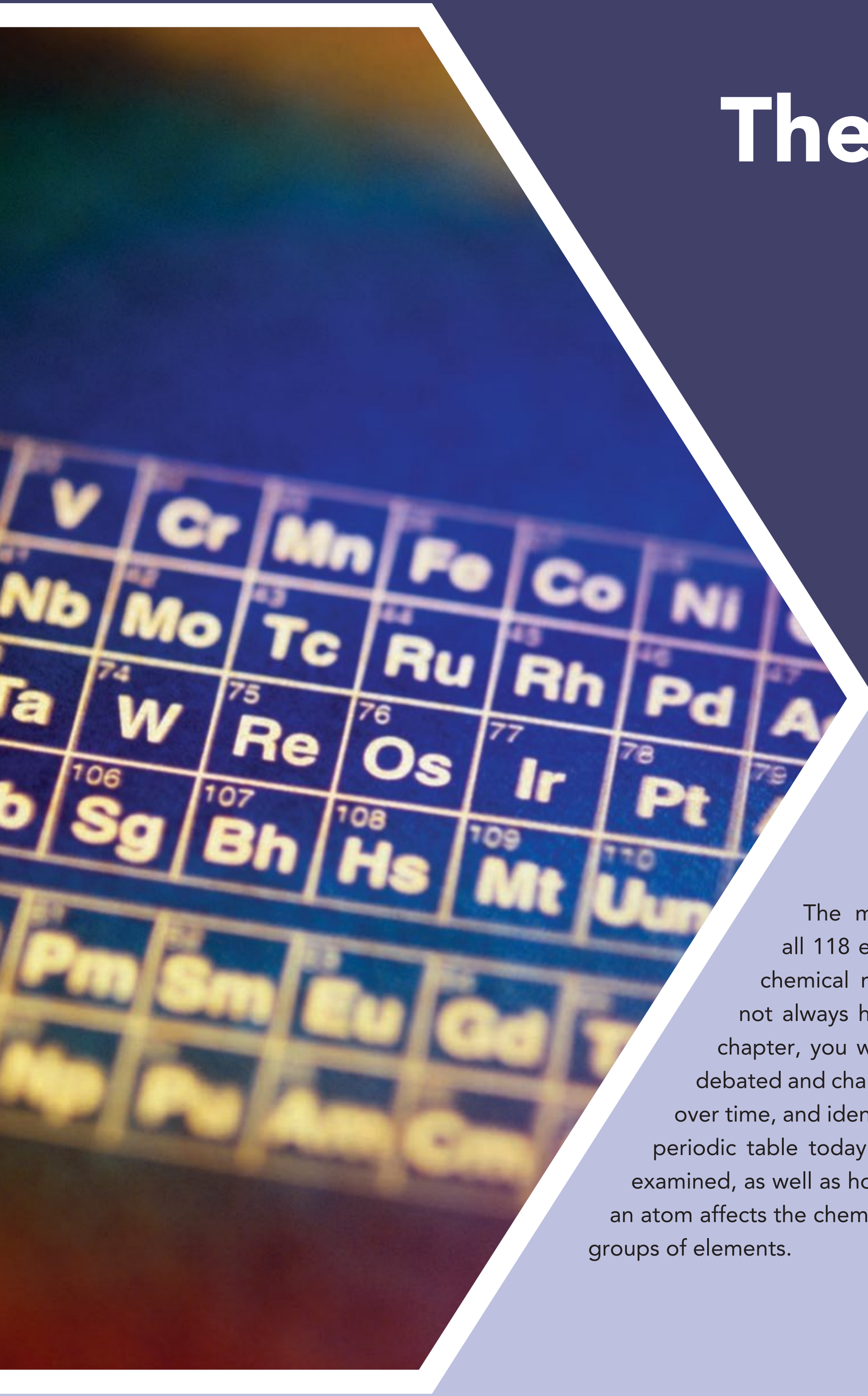
# Chapter 7
# The periodic table




## Chapter introduction

The modern-day periodic table organises all 118 elements based on properties such as chemical reactivity, but the periodic table has not always had the structure it has today. In this chapter, you will explore the scientists whose work debated and changed the organisation of the elements over time, and identify the helpful trends observed in the periodic table today. The electron shell structure will be examined, as well as how the number of valence electrons in an atom affects the chemical reactivity and properties of whole groups of elements.

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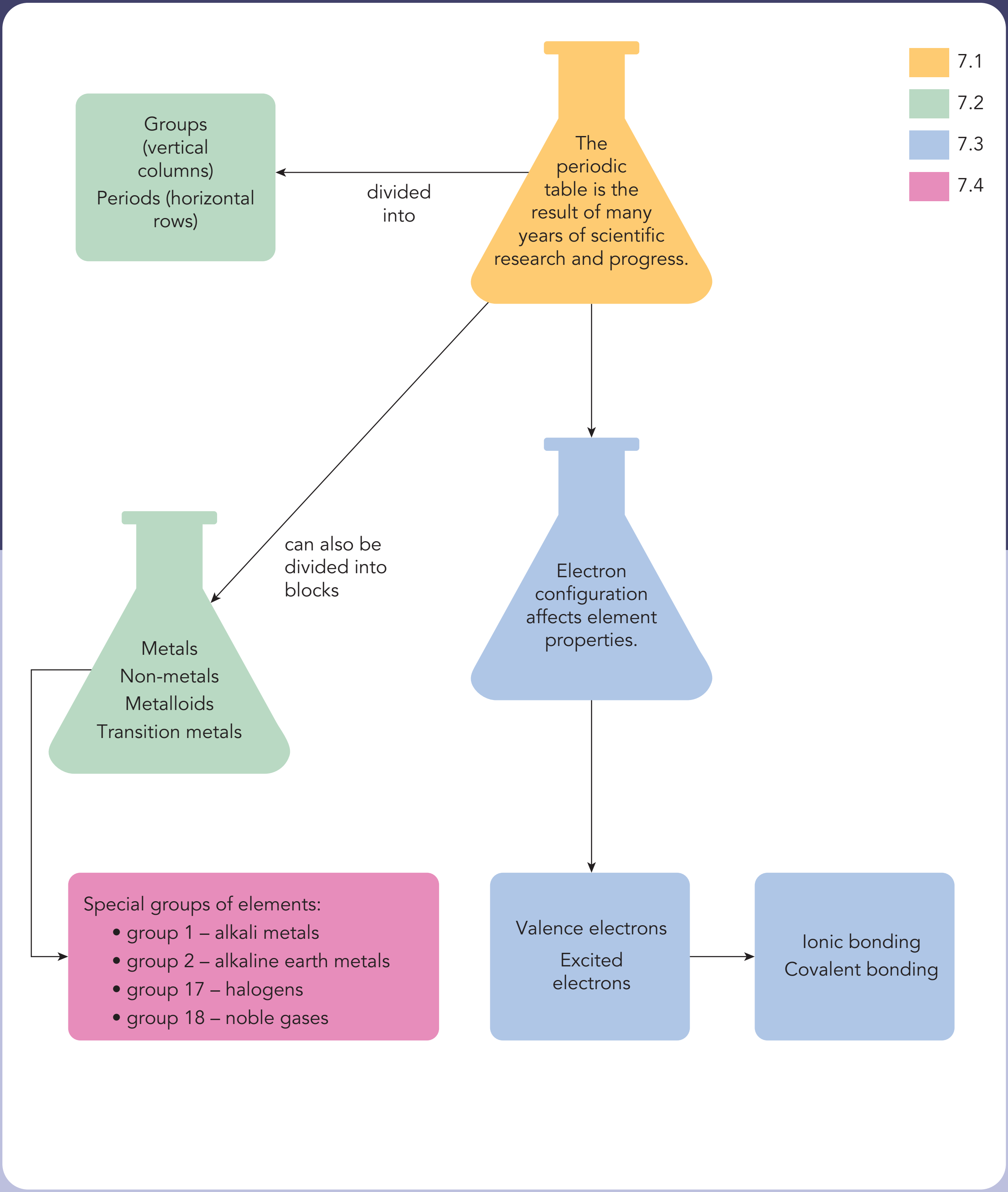
# Concept map

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## Curriculum

| | |
|---|---|
| Explain how the structure and properties of atoms relate to organisation of the elements in the periodic table (AC9S10U06) | |
| examining how elements are organised in the periodic table and analysing patterns to discern that elements in the same group of the periodic table have similar properties | 7.1, 7.2, 7.4 |
| deducing that repeating patterns of the periodic table reflect patterns of electrons in outer electron shells | 7.2, 7.4 |
| conducting flame tests for a selection of elements and examining emission spectra | 7.3 |
| examining how the development of the spectroscope led to further development of the model of the atom | 7.3 |
| using the Bohr model of the atom to describe the structure of atoms in terms of electron shells and relating this to their properties and position in the periodic table | 7.3, 7.4 |
| investigating the physical properties of some metals and non-metals | 7.4 |



## Glossary terms

Alkali metals
Alkaline earth metals
Anion
Cation
Covalent bond
Electron
Electron configuration
Electron shell
Element
Ground state
Group
Halogens
Ion
Ionic bond
Lustrous
Metalloids
Noble gases
Octet rule
Period
Transition metals
Valence electrons
Valence shell

# 7.1 Development of the periodic table

**Learning goals**
1. To be able to recall the scientists in the timeline of the periodic table.
2. To be able to describe the structure and property trends in Mendeleev's periodic table.

WORKSHEET
Periodic table timeline

How to best organise the known **elements** has been a topic of scientific debate since the late 1700s. In this section, we will follow the work of six scientists who influenced the shape and structure of the periodic table.

**element**
chemical substance made up of only one type of atom

## Timeline of the periodic table

**1789**

**Antoine Lavoisier**
- Lavoisier discovered and named the elements oxygen and hydrogen.
- In 1789, there were thought to be 33 elements (including light!). Lavoisier sorted these elements into gases, metals, non-metals and earths, constructing the first list of the known elements.
- His table of elements quickly became outdated as new elements were discovered.

**1808**

**John Dalton**
- Dalton was a chemist, physicist and meteorologist. He was responsible for developing early atomic theory and publishing a table of relative atomic masses.
- Dalton allocated symbols to the 36 known elements, which were later replaced by the notation devised by Jöns Jacob Berzelius that is still used today.


**Figure 7.1** Dalton's element symbols

**1817**

**Johann Wolfgang Döbereiner**
- Döbereiner noticed that known elements could be arranged into groups of three by their similarities in appearance and reactions. He called these groups triads (for example, lithium, sodium, potassium). He found that, when the elements in a triad were placed in order of their atomic mass the middle element had a mass which was the average of the other two.
- Döbereiner's work encouraged others to look for patterns in chemical properties and atomic weights.

| Alkali formers | |
|---|---|
| Li | 7 |
| Na | 23 |
| K | 39 |

((39 + 7) ÷ 2 = 23)

| Salt formers | |
|---|---|
| Cl | 35.5 |
| Br | 80 |
| I | 127 |

((127 + 35.5) ÷ 2 = 81)

**Figure 7.2** Two Döbereiner triads

*(continued)*

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VIDEO Properties of elements

## 1863

(continued)

### Alexandre-Émile Béguyer de Chancourtois

- de Chancourtois arranged known elements by increasing atomic mass.
- The atomic mass of oxygen was set at 16 and used as a standard for all the other elements. He wrapped his list around a cylinder which allowed sets of similar elements to line up. As tellurium was situated in the middle of the cylinder, he named his system the telluric screw.
- The first geometric representation of periodic law was created, meaning that de Chancourtois's system showed repetition in the properties of elements at certain, regular intervals.

**Figure 7.3** The telluric screw set-up at the ParisTech School of Mines

## 1864

### John Newlands

- Newlands listed the known elements in order of their atomic masses into horizontal rows, seven elements long.
- He stated that the eighth element would have similar properties to the first element in the series, known at the time as the law of octaves.
- His work was the first time anyone had used the sequence of atomic masses to organise the elements.

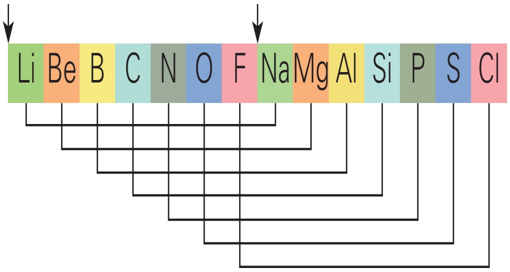


**Figure 7.4** Newlands's law of octaves. Every eighth element in the row has similar properties. Track the lines and investigate what is similar about each element.

## 1869

### Dmitri Mendeleev

- By 1869, 56 elements were known and a new element was being discovered approximately once every year.
- Mendeleev organised the elements into a table with rows and columns, organising elements by properties and in order of their atomic mass.
- Mendeleev left space in his table for elements he thought would later be discovered.

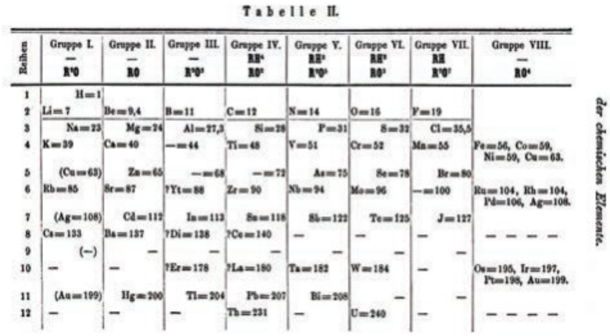

Tabelle II.

| Reihen | Gruppe I. — $R^2O$ | Gruppe II. — $RO$ | Gruppe III. — $R^2O^3$ | Gruppe IV. $RH^4$ $RO^2$ | Gruppe V. $RH^3$ $R^2O^5$ | Gruppe VI. $RH^2$ $RO^3$ | Gruppe VII. $RH$ $R^2O^7$ | Gruppe VIII. — $RO^4$ |
|---|---|---|---|---|---|---|---|---|
| 1 | H=1 | | | | | | | |
| 2 | Li=7 | Be=9,4 | B=11 | C=12 | N=14 | O=16 | F=19 | |
| 3 | Na=23 | Mg=24 | Al=27,3 | Si=28 | P=31 | S=32 | Cl=35,5 | |
| 4 | K=39 | Ca=40 | —=44 | Ti=48 | V=51 | Cr=52 | Mn=55 | Fe=56, Co=59, Ni=59, Cu=63. |
| 5 | (Cu=63) | Zn=65 | —=68 | —=72 | As=75 | Se=78 | Br=80 | |
| 6 | Rb=85 | Sr=87 | ?Yt=88 | Zr=90 | Nb=94 | Mo=96 | —=100 | Ru=104, Rh=104, Pd=106, Ag=108. |
| 7 | (Ag=108) | Cd=112 | In=113 | Sn=118 | Sb=122 | Te=125 | J=127 | |
| 8 | Cs=133 | Ba=137 | ?Di=138 | ?Ce=140 | — | — | — | — — — — |
| 9 | (—) | — | — | — | — | — | — | |
| 10 | — | — | ?Er=178 | ?La=180 | Ta=182 | W=184 | — | Os=195, Ir=197, Pt=198, Au=199. |
| 11 | (Au=199) | Hg=200 | Tl=204 | Pb=207 | Bi=208 | — | — | |
| 12 | — | — | — | Th=231 | — | U=240 | — | — — — — |

der chemischen Elemente.

**Figure 7.5** Mendeleev's early attempt at arranging the known elements into a table

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### Quick check 7.1

1 Determine the atomic mass of element Y using Döbereiner's method if X, Y and Z form a triad.

| Element | Atomic mass |
|---|---|
| X | 24 |
| Y | |
| Z | 58 |

2 Describe how Mendeleev's attempt was similar and different to those made by other scientists.

## Predicting future elements

WORKSHEET
Predicting properties

Mendeleev's approach differed from other scientists in that he left space for elements that had not yet been discovered; he knew that new elements were being discovered regularly in the 1800s. Figure 7.5 shows that he drew lines to denote a missing piece in his arrangement.

Mendeleev left calculated spaces in his periodic table where he thought the elements would have similar properties to those above and below. Take his prediction of the element between silicon (Si) and tin (Sn), shown in Figure 7.6.

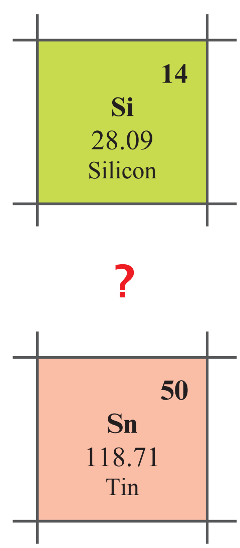


**Figure 7.6** Mendeleev predicted that there would be an element between silicon and tin.

He named this element eka-silicon and made the predictions shown in Table 7.1 based on the known properties of the elements above and below it in the periodic table. He was close! In 1886, the element germanium (Ge) was discovered with the properties described in Table 7.2. The discovery of germanium occurred within Mendeleev's lifetime and confirmed his arrangement.

| Element | Mass | Density (g $cm^{-3}$) | Density of its chloride (g $cm^{-3}$) | Boiling point of its chloride (°C) |
|---|---|---|---|---|
| Eka-silicon | 72 | 5.5 | 1.9 | 100 |

**Table 7.1** Mendeleev's predictions for the chemical properties of eka-silicon

| Element | Mass | Density (g $cm^{-3}$) | Density of its chloride (g $cm^{-3}$) | Boiling point of its chloride (°C) |
|---|---|---|---|---|
| Germanium | 73 | 5.3 | 1.88 | 86 |

**Table 7.2** The chemical properties of germanium

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While Mendeleev's work had a great influence on the work of all chemists attempting to organise the elements in the periodic table, his work did not earn him a Nobel Prize. However, in 1955, scientist Albert Ghiorso and colleagues discovered element 101 and named it Mendelevium (Md) after the 'father of chemistry'.

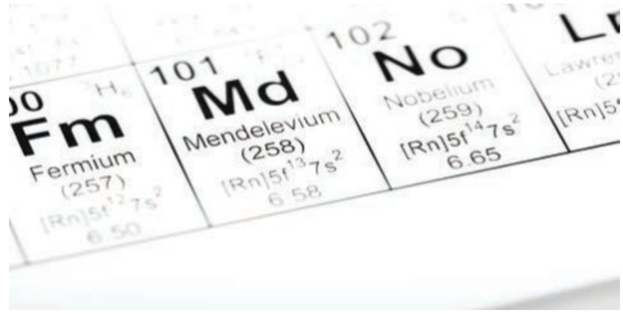


**Figure 7.7** Mendelevium has the atomic number 101.

## Making thinking visible 7.1

**What can be: The periodic table**

The periodic table organises the known elements based on various properties, but has it reached its final form? Consider the following exercise:

1. Review: How did the periodic table get to be the way it is now?
2. Predict: How else might it change in the future?
3. Imagine and create: Future changes might come with challenges. How do you think the scientific community could turn these challenges into opportunities?

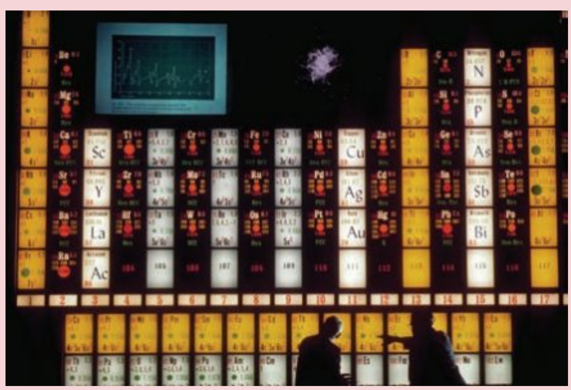

**Figure 7.8** The periodic table has been debated and changed a lot since the late 1700s.

The *What can be* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

## Investigation 7.1

### Predicting properties of elements

**Aim**

To investigate the relationship between the position of an element in the periodic table and its density.

**Useful formulas**

$$\text{Density (g cm}^{-3}) = \frac{\text{mass (g)}}{\text{volume (cm}^3)}$$

$$\text{Percentage difference} = \frac{(\text{actual value} - \text{predicted value})}{\text{actual value}} \times 100$$

*continued ...*

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*continued …*

**Materials**

- sample elements (carbon rod, silicon, tin)
- 50 mL measuring cylinder
- graph paper
- balance
- ruler
- weigh boats (small containers to hold sample elements)

**Method**

**Part 1: Prepare the results table**

1. Copy the results table into your science journal.
2. For each element used in this experiment, state in the results table their position on the periodic table.
3. Identify the dependent variable in the table. HINT: Which property are you investigating?

| Element sample | Position in periodic table (group, period) | Mass (g) | Initial volume in measuring cylinder ($cm^3$) | Final volume in measuring cylinder ($cm^3$) | Volume of element ($cm^3$) | Calculated density ($g\ cm^{-3}$) | Actual density ($g\ cm^{-3}$) (secondary data source) | Percentage difference (%) |
|---|---|---|---|---|---|---|---|---|
| Carbon | | | | | | | | |
| Silicon | | | | | | | | |
| Tin | | | | | | | | |

**Part 2: Measure the mass of each sample element**

1. Place a weigh boat onto the balance and zero the balance by pressing ‘tare’.
2. Place the first sample element on the empty weigh boat and record the mass in the table.
3. Remove the sample element.
4. Repeat steps **1–3** with the other sample elements.

**Part 3: Measure the volume of each sample element**

1. Half fill a 50 mL measuring cylinder with water and record the initial volume in cubic centimetres (1 mL = 1 $cm^3$).
2. Place the first sample element into the measuring cylinder gently and record the new volume in the table.
3. Remove the sample element by tipping the water out of the measuring cylinder.
4. Repeat steps **1–3** with the other sample elements.

*continued …*

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*continued …*

**Results**

**Calculate and graph the densities**

1 Calculate the volume of each sample element in cubic centimetres and record it in the results table.

2 Calculate the density of each sample element using the formula above and record it in the results table.

3 Draw a scatterplot to analyse the relationship between the period numbers and densities of different elements.

4 Add a line of best fit to the graph, if possible. Note the type of line that fits best to reflect the relationship between the two variables.

**Analysis**

1 Describe the trend or pattern that was found when the line of best fit was applied to the graph. What type of relationship was found?

2 Predict the densities of germanium (row 4) and lead (row 6) using your graph. Record the predictions in your science journal.

**Evaluation**

**Reliability**

1 Compare the actual densities for each element (obtained from secondary data sources; the 'properties' tab at the website ptable.com is a good resource to use) with their calculated densities.

2 Compare the actual densities for carbon, silicon and tin to the densities calculated mathematically by calculating the percentage difference using the formula above.

3 Was the calculated density data reliable enough to base predictions on? Justify your response with data.

4 Research online to find the actual densities of germanium and lead. Record the actual densities for each in your science journal.

5 Compare the actual densities for germanium and lead to the densities predicted mathematically by calculating the percentage difference using the formula above.

6 Can reliable conclusions and predictions be drawn from the results? Justify your response with data.

**Limitations**

7 Can you identify possible limitations of this method? Justify your answer using data if possible.

**Improvements**

8 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

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## Section 7.1 questions

QUIZ

### Retrieval

1 **Recall** the names of three scientists who attempted to organise elements.
2 **Recall** who created the first version of the modern periodic table.
3 **Recall** the method that most scientists used to arrange chemical elements.
4 **State** the modern-day arrangement of elements for which Döbereiner's triads were the forerunner.
5 Using Döbereiner's law of triads, **calculate** the mass of the element B.

| Element | Mass |
|---|---|
| A | 12 |
| B | |
| C | 34 |

### Comprehension

6 **Explain** why de Chancourtois's arrangement was superior to Döbereiner's.
7 **Summarise** how Mendeleev made his predictions about the properties of elements which had yet to be discovered.

### Analysis

8 **Compare** Newlands's and Mendeleev's arrangements.
9 **Critique** de Chancourtois's arrangement of the elements.

### Knowledge utilisation

10 **Propose** the reasons why Mendeleev's periodic table was accepted.
11 **Discuss** the reasons why multiple ways were proposed throughout history to arrange chemical elements.
12 **Determine** the properties of the middle element in the tables below.

a

| | Lithium | Sodium | Potassium |
|---|---|---|---|
| Atomic mass | 7 | | 39 |
| Melting point (°C) | 180 | | 63 |

b

| | Silicon | Germanium | Tin |
|---|---|---|---|
| Atomic mass | 28 | | 119 |
| Melting point (°C) | 1414 | | 232 |

c

| | Chlorine | Bromine | Iodine |
|---|---|---|---|
| Atomic mass | 35.5 | | 127 |
| Melting point (°C) | −101 | | 114 |

13 **Determine** why the modern periodic table has remained relatively unchanged since it was reordered by atomic number instead of atomic mass.

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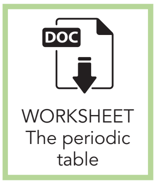
# 7.2 Structure of the periodic table




## Learning goals

1. To be able to distinguish the groups and periods in the periodic table.
2. To be able to differentiate between metals, non-metals and metalloids by their position on the periodic table.
3. To be able to identify the transition metals, lanthanoids and actinoids on the periodic table.


The modern periodic table is a list of all the known elements in order of their atomic number. The atomic number of an element is the number of protons it has. This makes hydrogen (H) the first element in the periodic table as it has one proton and therefore an atomic number of 1. Oganesson (Og), a synthetic element discovered by Russian scientists in 2002 and officially named in 2016, is currently the last element. It has an atomic number of 118, which means it has 118 protons.

Oganesson is nicely placed in the last place of the noble metals in group 18, but that does not mean that the periodic table is now finished! Elements with atomic numbers greater than 118 are possible, and scientists are currently working to discover these new elements. Where might they go on the modern periodic table?

**group**
a vertical column in the periodic table

### Explore! 7.1

**Naming the elements**

You may have noticed that many elements have symbols that don't match their English names. Some of them have interesting backstories.

Research the source of the symbol for the following elements:

- Sodium (Na)
- Iron (Fe)
- Lead (Pb)
- Gold (Au)
- Silver (Ag).

## Groups of the periodic table

The periodic table is arranged into vertical columns called **groups**. There are 18 groups in total.

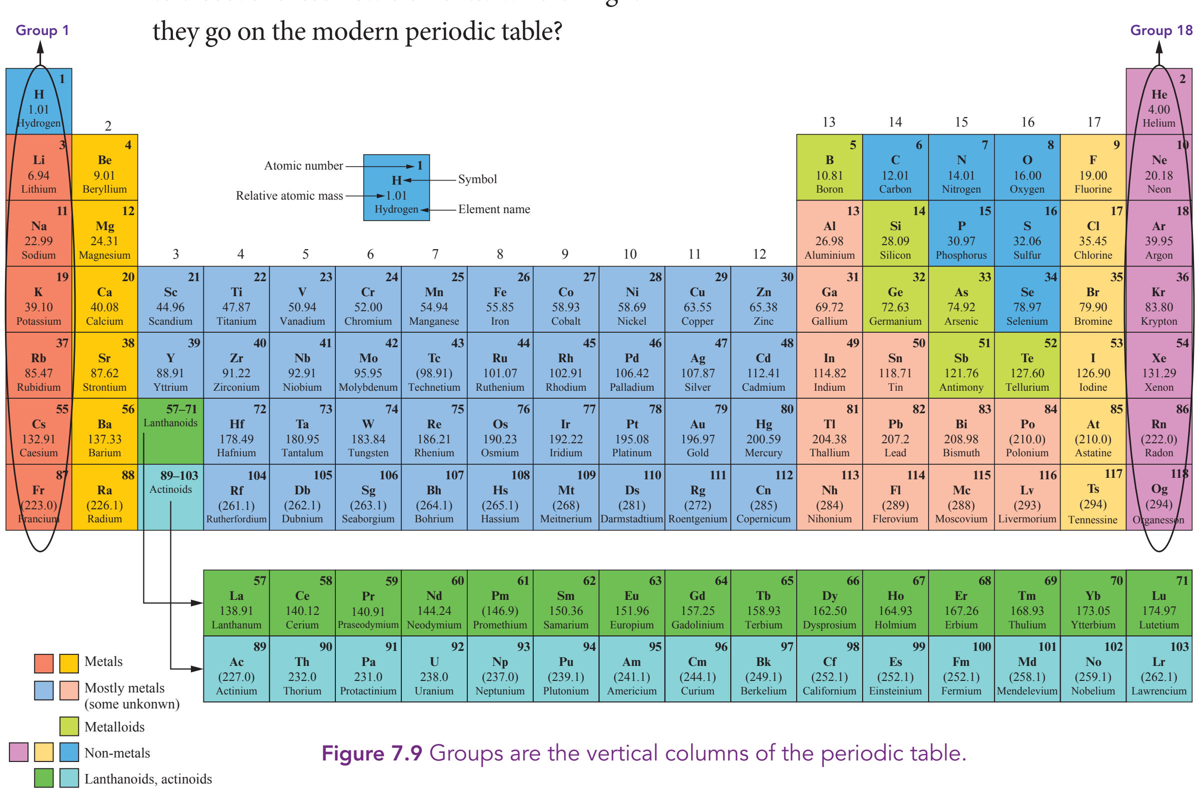



**Figure 7.9** Groups are the vertical columns of the periodic table.

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Elements in the same group generally have similar properties; for example, they react with the same chemicals in similar ways. This lets us predict the properties of elements by looking at others in the same group. For example, sodium, an element in group 1, reacts violently when placed in water. Therefore, we can expect that potassium, also in group 1, will react in a similar way.

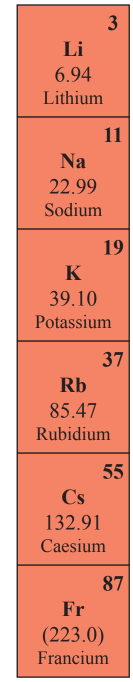


**Figure 7.10** The group 1 metals all have similar properties so behave in similar ways.

## Quick check 7.2

1. Decide whether the following statements are true or false.
   a. Groups are the vertical columns in the periodic table.
   b. Oxygen (O) is in group 5.
   c. As strontium (Sr) is in the same group as silicon (Si), it will have similar properties.
2. Barium (Ba) in group 2 reacts with oxygen (O) to form barium oxide, a metal oxide with the formula BaO. Potassium (K) in group 1 reacts with oxygen (O) to form potassium oxide with the formula $K_2O$. An unknown element was reacted with oxygen. The product was a metal oxide with the formula XO (X being the unknown element). Explain in which group you would place the unknown element.

## Periods of the periodic table

Groups are the vertical columns and **periods** are the horizontal rows in the periodic table. There are seven periods in total.

It is often easy to skip over hydrogen (H) and helium (He), but these two elements make up the first period of the periodic table. As you move across a period, the atomic number increases (that is, the number of protons increases), as does the number of **electrons**.

**period**
a horizontal row in the periodic table

**electron**
smallest subatomic particle in an atom arranged around the nucleus in shells

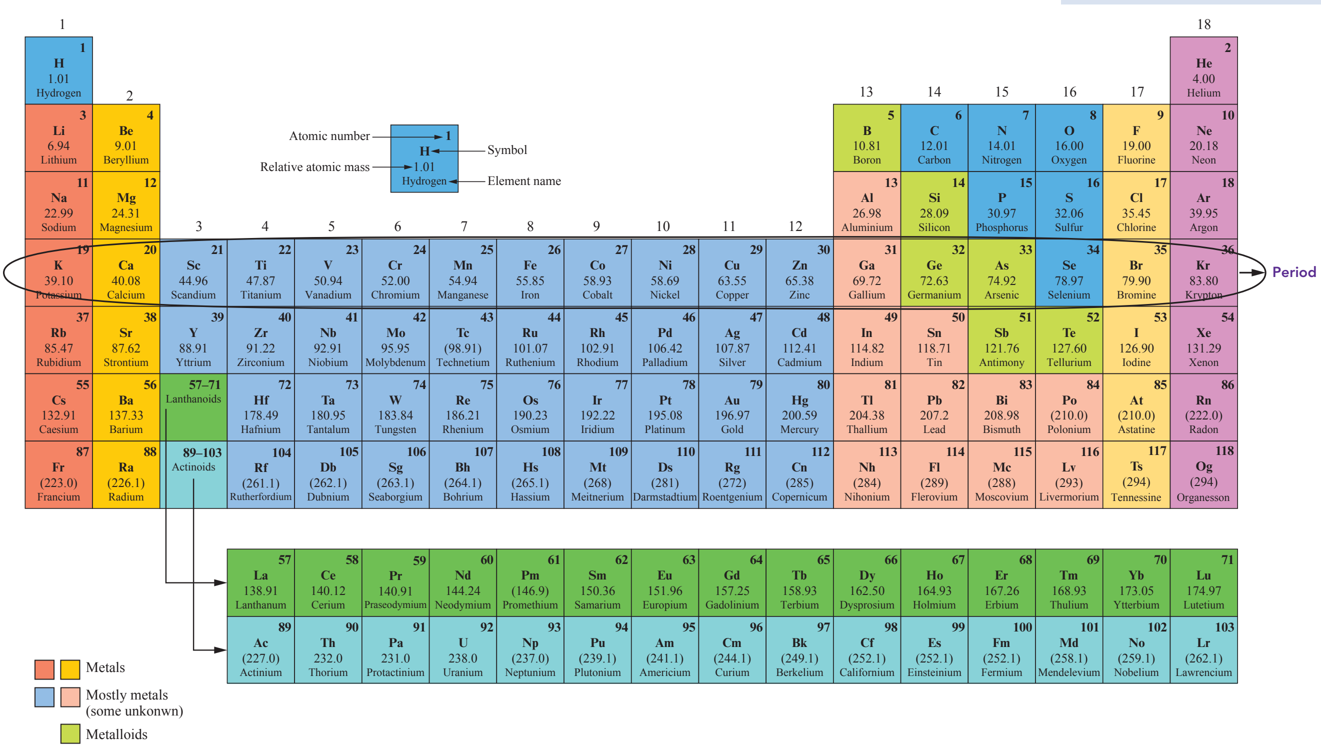


**Figure 7.11** Periods are the horizontal rows in the periodic table.

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This arrangement into groups and periods causes elements to have a specific position on the periodic table. For example, carbon (C) is placed in group 14, period 2, and helium (He) is in group 18, period 1. You might wonder why helium is not placed next to hydrogen, in group 2. Helium has a full outer shell of electrons and behaves like all the other group 18 'noble gases', being very unreactive.

## Quick check 7.3

1 Decide whether the following statements are true or false.
   a Periods are the horizontal rows in the periodic table.
   b Lithium is in period 1.
2 State the position (group and period) of the following elements in the periodic table.
   a Copper (Cu)
   b Calcium (Ca)
   c Neon (Ne)
   d Aluminium (Al)

## Explore! 7.2

### Melting points in the periodic table

While chemical reactivity shows a trend in the periodic table, a trend in a property such as melting point of elements is more challenging to identify.

Analyse Figure 7.12 below.

1 What trends can be identified in the melting point?
2 Are there any anomalies to your observed trend?
3 What can you deduce about the elements in the periodic table from your answer to Questions 1 and 2?

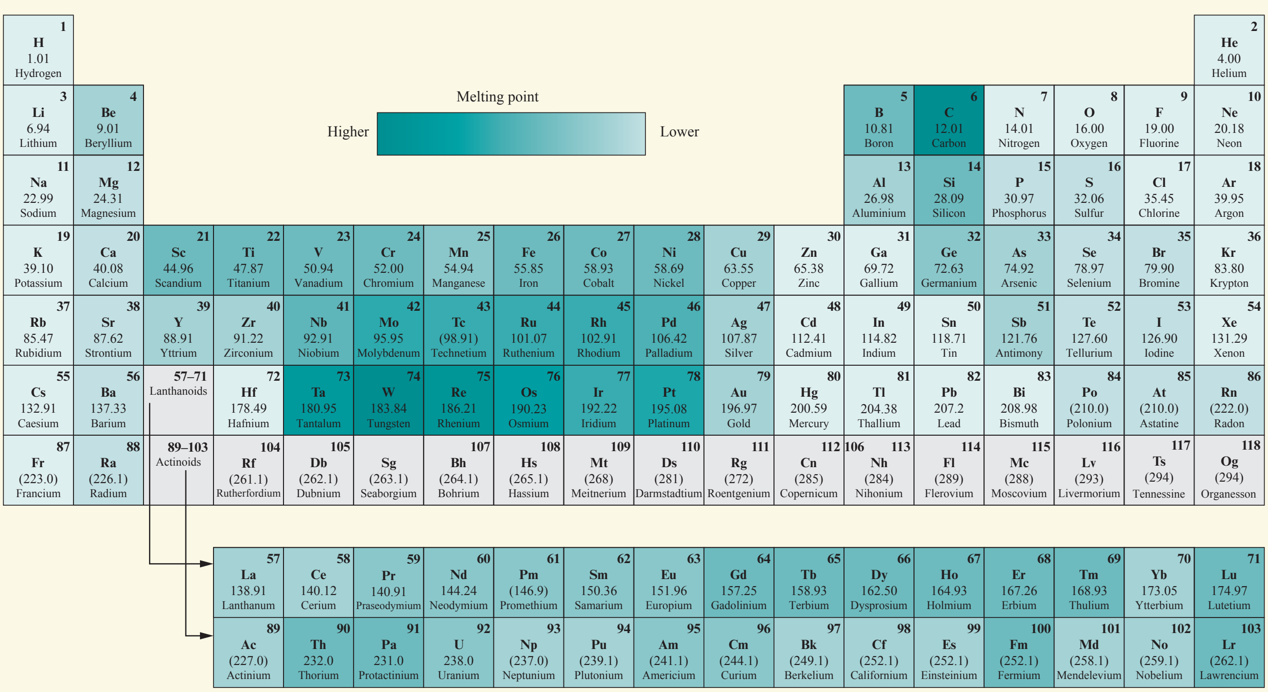


**Figure 7.12** Is there a trend in melting points in the periodic table?

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## Blocks of the periodic table: metals, non-metals and metalloids

The periodic table can be further split up into different blocks.

Elements can be classified as metals, non-metals or metalloids.

### Metals

Metals make up most of the elements in the periodic table. In fact, 93 of the 118 known elements are metals, and they sit on the left-hand side of the table. Almost all metals in the periodic table are solids at room temperature; the exception is mercury (Hg), which is a liquid.

Metals have particular properties; they:

- are **lustrous**
- have high melting and boiling points
- are malleable, meaning they can be beaten into shapes
- are ductile, meaning they can be drawn out into long, thin wires
- are good conductors of heat and electricity.

VIDEO
Reactive metals

Figure 7.14 Mercury is the only liquid metal at room temperature.

**lustrous**
in metals, having a shiny surface

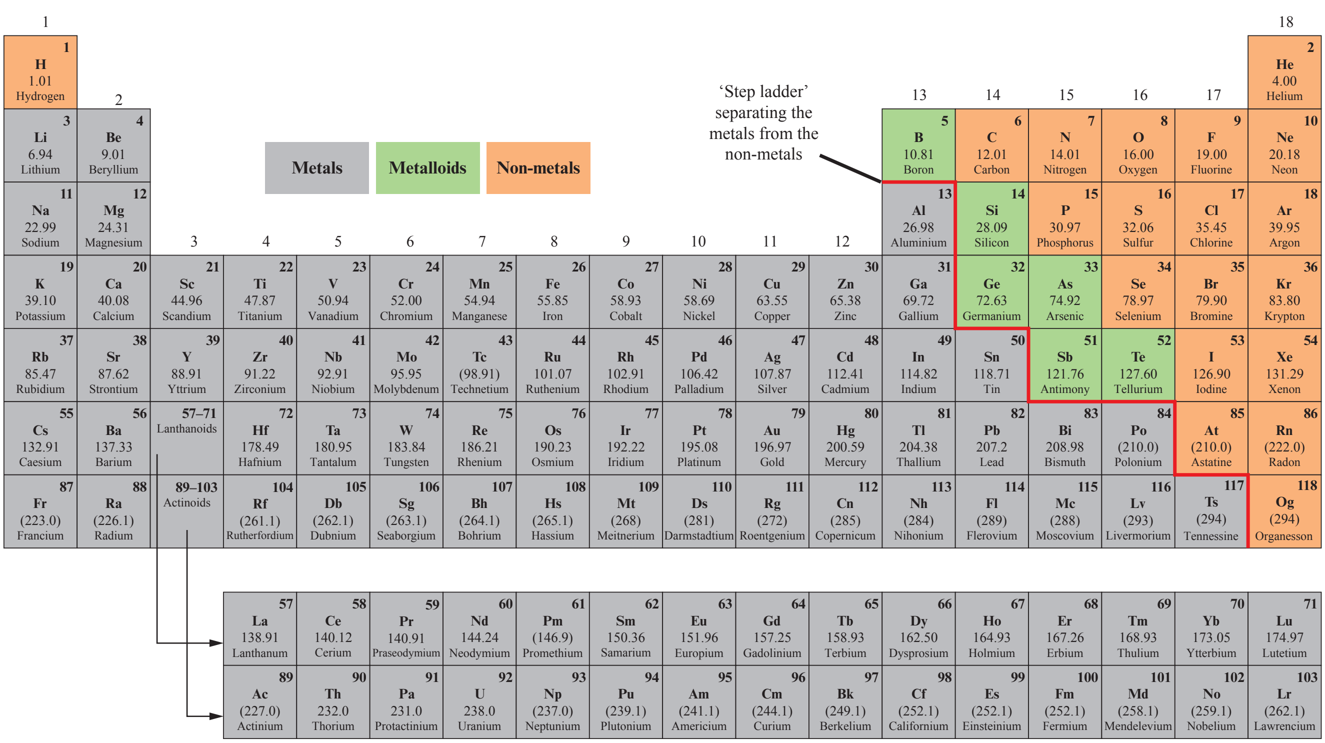


Figure 7.13 Three colours show the elements classified as metals, non-metals and metalloids.

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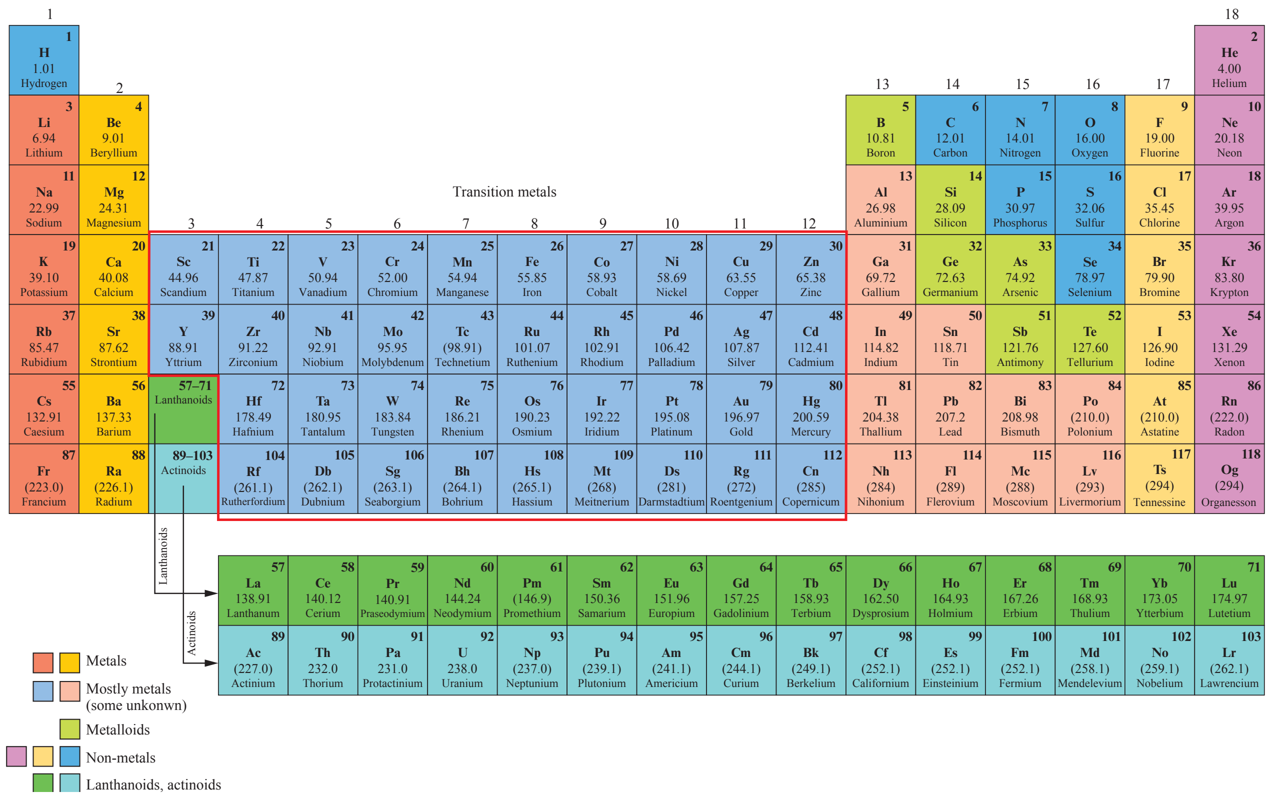


**Figure 7.15** Location of the transition metals

**transition metals** the block of metals containing the elements in groups 3 to 12 and in periods 4 to 7 in the periodic table

### Transition metals

The **transition metals** are a large block of metals containing the elements from groups 3 to 12 in periods 4 to 7 (see Figure 7.15). These metals are generally hard and dense, but chemical reactivity does vary among the transition metals. Iron (Fe), silver (Ag), chromium (Cr) and zinc (Zn) are all transition metals but differ vastly in reactivity.

### Lanthanoids and actinoids

The lanthanoids and actinoids are elements that sit between the group 2 metals and the transition metals. They are placed at the bottom of the periodic table so that the table is easier to work with. If they were not placed below the periodic table, it would be extended horizontally and wouldn't fit nicely on a page!

The lanthanoids include elements with atomic numbers from 57 to 71 (in period 6) and are sometimes called the 'rare earth elements' along with scandium (Sc) and yttrium (Y), two other elements commonly found in ores containing the lanthanoid elements. The lanthanoids are lustrous grey metals.

The actinoids contain elements with atomic numbers from 89 to 103 (in period 7). They are primarily synthetic elements with a few exceptions, such as uranium. The instability of these elements, including uranium, can be manipulated to produce radioactive atoms that can release energy in nuclear reactors.

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## Science as a human endeavour 7.1

### Luminescent lanthanoids

The lanthanoids are fascinating elements; each has unique luminescent properties. The light emission of the lanthanoid elements displays sharp line-like emission bands of very specific wavelengths. This gives the lanthanoids rather pure colours of visible light emission, which makes them useful for applications such as the LED pixels in mobile phones and televisions. For example, europium (Eu) emits red light, terbium (Tb) green light and thulium (Tm) blue light.

**Figure 7.16** Lanthanoids are responsible for light emission in smart phones (left) and torches for night-vision goggles (right).

The efficiency and long lifetime of their emissions make the lanthanoids ideal candidates for use in new light-emitting materials.

An example is the use of lanthanoids such as ytterbium that emit near-infrared (NIR) light. These wavelengths of light are not in the visible spectrum and so cannot be seen by humans with the naked eye, but they can be seen by some nocturnal animals. This is the type of light that night-vision goggles detect and translate to green visible light on a screen for humans to view, making vision on a dark night possible. On some nights there is not even enough NIR light to brighten the surroundings for night-vision goggles. On those occasions, NIR torches, based on NIR-emitting lanthanoids, can make it possible to use night-vision goggles.

Researchers are continuing to make even brighter emissions and to use these cutting-edge materials for devices such as mobile phones that use visible light and night-vision goggles that use NIR radiation.

## Quick check 7.4

1. The block of elements in the middle of the periodic table, containing groups 3 to 12, is called the ___________.
2. Identify which of the following is a transition metal: sodium (Na), tungsten (W), europium (Eu), aluminium (Al).
3. State if the following statement is true or false.
   Lanthanoids are part of the sixth period on the periodic table.

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## Non-metals

Non-metals (except hydrogen) are located on the right-hand side of the periodic table.

**metalloids**
elements in the periodic table that are situated close to the border between metals and non-metals; they share properties and appearance characteristics with both metals and non-metals

There are fewer non-metals than metals, but their properties are much more varied. The naturally occurring non-metals consist of one liquid – bromine (Br) – five solids and 11 gases at room temperature.

In general, non-metals:

- are dull
- are brittle, meaning they will shatter when bent or struck with something hard
- have low melting and boiling points
- are poor conductors of heat and electricity.

**Figure 7.17** A bottle of liquid bromine, the only liquid non-metal at room temperature

## Metalloids

The elements located between the metals and non-metals, are called **metalloids**. Six elements are typically classified as metalloids: boron (B), silicon (Si), germanium (Ge), arsenic (As), antimony (Sb) and tellurium (Te). The metalloids share some properties of metals and non-metals. For example, germanium has a lustrous grey appearance, like a metal, but is a non-conductor of electricity and is brittle like the non-metals.

**Figure 7.18** Germanium is a lustrous metalloid.

### Quick check 7.5

1 Recall the side of the periodic table where metals are located.

2 Select the correct word to complete this sentence:
The name given to elements which behave like metals and non-metals is ____________.

3 Decide whether the following statements are true or false. If false, provide reasons why.
   a Metals have high melting points.
   b Almost all metals are liquids at room temperature.
   c There are more non-metals than metals on the periodic table.
   d There are only two liquid elements on the periodic table at room temperature.

Table 7.3 summarises the properties of metals and non-metals.

| Metals | Non-metals |
|---|---|
| Lustrous | Dull |
| High density | Low density |
| Good conductors of heat and electricity | Poor conductors of heat and electricity |
| Malleable and ductile | Brittle |
| High melting and boiling points | Low melting and boiling points |

**Table 7.3** Properties of metallic and non-metallic elements

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## Section 7.2 questions

QUIZ

### Retrieval

1 **State** the number of groups on the periodic table.
2 **Name** one of the following.
  a An element in period 4
  b An element in group 18
  c A transition metal
  d An actinoid
3 **State** helium's period on the periodic table.
4 **Identify** the element that is in the following positions.
  a Period 4, group 6
  b Period 2, group 13
  c Period 5, group 18
  d Period 7, group 1
  e Period 6, group 15

### Comprehension

5 **Explain** the properties of metalloids.

### Analysis

6 **Classify** the following elements as either metals or non-metals.

| Element | Metal or non-metal |
|---|---|
| Oxygen (O) | |
| Boron (B) | |
| Aluminium (Al) | |
| Iodine (I) | |
| Nickel (Ni) | |

7 **Compare** metals and non-metals.
8 **Categorise** the following elements as a transition metal, lanthanoid, actinoid or metalloid.

| Element | Category |
|---|---|
| Promethium (Pm) | |
| Zinc (Zn) | |
| Arsenic (As) | |
| Thorium (Th) | |
| Ytterbium (Yb) | |

### Knowledge utilisation

9 **Decide** what happens to the number of protons as you move to the right across a period.
10 A new element is discovered that:
- is shiny
- conducts electricity
- is malleable
- sinks when placed in water.

**Determine** from these properties whether it will be categorised as a metal or a non-metal.

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# 7.3 Electronic configuration

WORKSHEET
Electronic configurations

**Learning goals**

1. To be able to write an electron configuration for the first 20 elements.
2. To be able to describe how electrons are responsible for light emission from some elements.
3. To differentiate between sharing electrons in an ionic bond and in a covalent bond.

## Where are the electrons?

An atom is made up of a nucleus of positively charged protons and neutral neutrons surrounded by orbiting negatively charged electrons. In this chapter, electrons will be shown orbiting the nucleus in different energy levels, called 'shells'. This shell configuration is shown in Figure 7.19 for the element lithium (Li) with three electrons.

**electron shell**
the energy level in which the electrons orbit the nucleus of an atom

**octet rule**
atoms tend to lose, gain or share outer shell electrons to achieve eight electrons in their outer shell

As electrons are negatively charged, they repel each other while moving around the nucleus. Therefore, electrons organise themselves in spaces around the nucleus to minimise the possible repulsion from other electrons. This results in **electron shells**, which are shown as different distances from the nucleus and can hold different maximum numbers of electrons. Electrons situated in shells furthest away from the nucleus are at higher energy levels than electrons in closer shells.

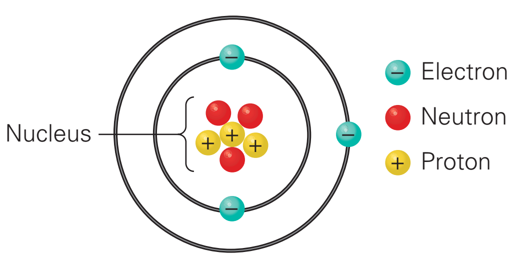


Figure 7.19 An atomic model for lithium

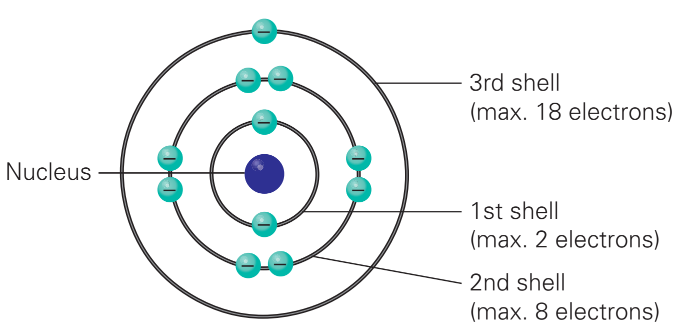


Figure 7.20 Arrangement of electrons in shells around the nucleus

The first electron shell can hold a maximum of two electrons in its small area before the repulsion becomes so much that electrons must move to a second shell. The second shell can hold a maximum of eight electrons, the third shell up to 18 electrons and the fourth shell up to 32 electrons.

However, electrons do not fill shells completely before moving to a higher energy shell; in fact, the order of filling is 2,8,8,2 for the first 20 elements. This occurs because electrons repel each other and it requires less energy to place them in a space with less repulsion, even if it is a higher energy level. This phenomenon, in which electrons tend to fill electron shells to a stable number of eight electrons first (or two electrons in the first shell), is referred to as the **octet rule**. Note that further electron shells exist but are not covered here.

Table 7.4 summarises the maximum number of electrons in each electron shell and the actual order of filling.

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| Electron shell | Maximum number of electrons | Order of filling (from top down) |
|---|---|---|
| First (lowest energy level) | 2 | 2 |
| Second | 8 | 8 |
| Third | 18 | 8 |
| Fourth (higher energy level) | 32 | 2 |

**Table** 7.4 The maximum number of electrons in each electron shell

**Quick check 7.6**

1 How do electrons arrange themselves in an atom?
2 Complete the sentence by circling the correct italicised words:
The electron shell *closest to/furthest from* the nucleus is the *first/last* to be filled.
3 What is the maximum number of electrons in the following shells?
  a First shell
  b Second shell
  c Third shell
  d Fourth shell

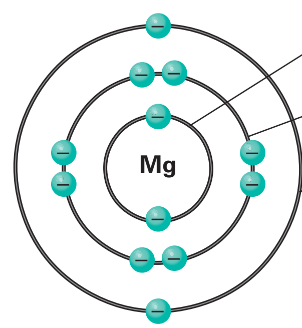


**Figure 7.21** The electron configuration of magnesium (2,8,2)

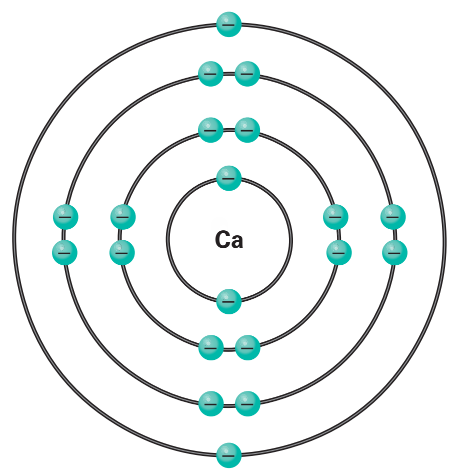


**Figure 7.22** The electron configuration of calcium (2,8,8,2)

**electron configuration** the arrangement of an atom's electrons in the shells around the nucleus

**ground state** the lowest energy level of an atom

## Electron configurations of the elements

The **electron configuration** shows how the electrons for a particular element are arranged. When electrons fill shells, they always start from the lowest energy level (the electron shell closest to the nucleus). This means that atoms are always at their lowest energy level or **ground state**.

Magnesium (Mg) has an atomic number of 12, so it has 12 electrons. It has an electron configuration of 2,8,2. This shows that there are two electrons in the first shell, eight in the second and two in the third. Figure 7.21 shows the electron arrangement of a magnesium atom. The sum of all the numbers in the electron configuration should add up to the total number of electrons in that atom. Calcium fills its shells with 20 electrons in the order 2,8,8,2 (see Figure 7.22). Element 21, scandium (Sc) with 21 electrons will actually begin filling its third shell again, that is, 2,8,9,2. Electron configurations with more than 20 electrons are beyond the scope of this course as the order of electron shell filling becomes quite complicated.

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**Quick check 7.7**

1. State the name given to atoms when they are at their lowest energy level.
2. State the number of electrons in an element with an electron configuration of 2,8,5.
3. State the atomic number of an element which has 18 electrons.
4. State the electron configuration of an oxygen atom.

## Electron configuration and element properties

The way atoms react is largely determined by the arrangement of their electrons. Protons and neutrons are situated in the centre of the atom and therefore are not affected when particles collide during chemical reactions. It is the electrons, and mainly the outermost electrons, which are the most affected.

The outermost electrons in an atom are called **valence electrons** and exist in the **valence shell**. It is these electrons in the outer shell that are most affected when atoms collide with one another during chemical reactions.

**valence electrons**
the electrons in the outer shell of an element

**valence shell**
the outermost shell of the atom that contains electrons

The biggest influence on an element's chemical and physical properties is the number of electrons in the valence shell. This means that elements with the same number of valence electrons are grouped together in the periodic table with similar chemical properties. For example, all elements in group 1 have one valence electron. Their electron configurations all end in the number 1.

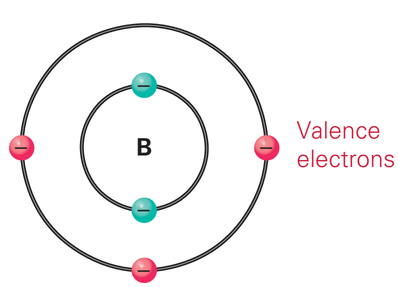


**Figure 7.23** Boron (B) has an electron configuration of 2,3. It therefore has three valence electrons (shown in red).

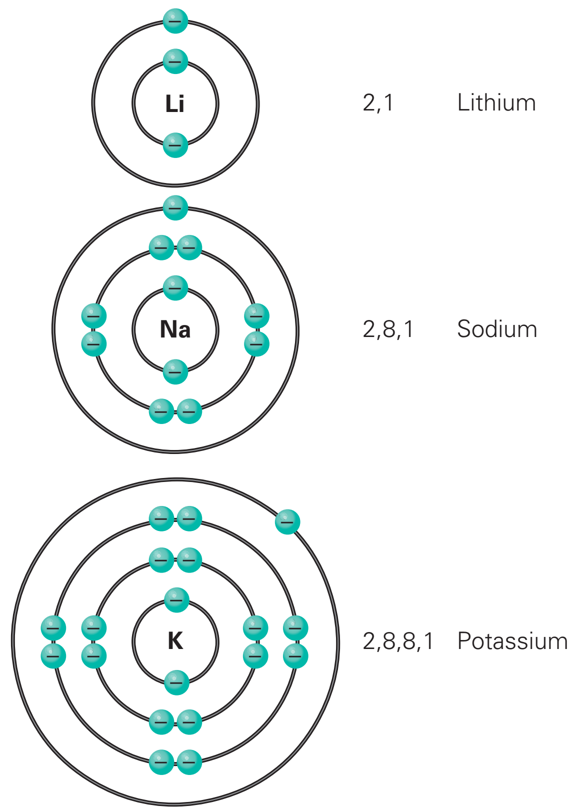


**Figure 7.24** These elements in group 1 have one valence electron.

We can also determine the period an element is in using its electron configuration. For example, if an electron configuration contains two numbers (as for lithium, 2,1), then it is in period 2.

**Quick check 7.8**

1. Recall the definition of valence electrons.
2. Recall how reactivity of an element is determined.
3. State the group that the element with the electron configuration 2,8 belongs to, and why.
4. State the period on the periodic table where the element with the electron configuration 2,8,4 is found.

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## Excited electrons

WORKSHEET Excited electrons

When atoms absorb energy, with light or heat for example, the valence electrons gain energy to move to higher energy electron shells. An electron that has jumped to a higher energy shell is said to be in an 'excited state', and when it releases energy to return to its 'ground state' that energy is released as a specific wavelength (colour) of light.

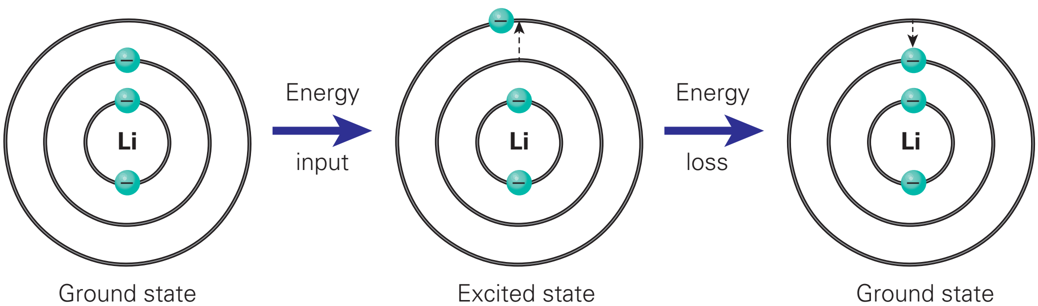


**Figure 7.25** What happens to atoms when electrons gain energy?

VIDEO The emission spectrum

The difference in energy between electron shells is unique for every element, so each different element emits a unique wavelength of light. This allows for a qualitative observation and inference of a particular element based on the colour of the light emission when excited with light or heat. An example of this is a flame test, in which an element is placed in a flame. Often the atomic emission can be clearly visible, such as the green copper (Cu) and red lithium (Li) flames shown in Figure 7.26.

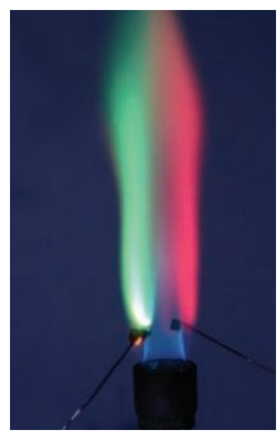

**Figure 7.26** A copper compound burning with a green flame and a lithium compound burning with a red flame

### Explore! 7.3

**Niels Bohr and the atomic emission of hydrogen**

A spectroscope is an instrument capable of separating white light into a continuous spectrum of visible wavelengths that resembles a rainbow. In 1913, the Danish scientist Niels Bohr used a spectroscope to view the continuous spectrum of light that had been absorbed and emitted by hydrogen. He observed that hydrogen absorbed very specific wavelengths of light (shown in its absorption spectrum) and emitted these exact wavelengths of light (emission spectrum).

**Figure 7.27** White light passes through a prism and is split into a continuous (visible) spectrum.

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Hydrogen is an atom with one electron, and Bohr theorised that the absorbed light energy was transferred to the electron, which moved to a higher energy state. As the electron released this amount of energy, as light, it returned to its original energy level. This is the same explanation used to describe the colours observed in a flame test above. In 1922, Niels Bohr was awarded Nobel Prize for this work, which led him to propose an atomic model in which electrons orbited the nucleus in shells.

The pattern of lines on an emission spectrum correspond to a particular element. They are exactly like barcodes!

1 What are the main differences between an emission spectrum and an absorption spectrum, such as those shown in Figure 7.28?
2 Research which colour of light has the highest energy.
3 Deduce what element is present in the unknown emission spectrum shown in Figure 7.29.

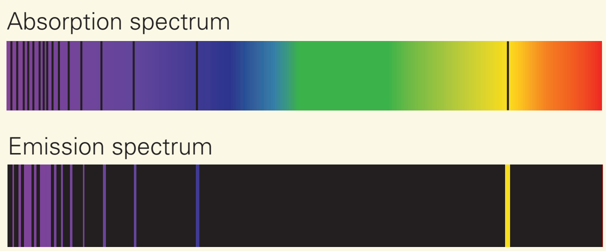


**Figure 7.28** The absorption spectrum (top) and emission spectrum (bottom) of a particular element

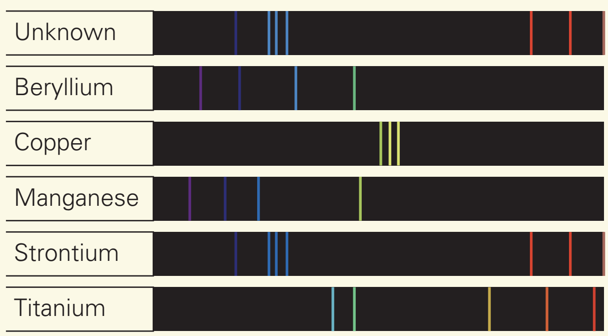


**Figure 7.29** We can compare emission spectra to find out the identity of an unknown element.

## Did you know? 7.1

**Fireworks**

Fireworks are an example of multiple flame tests occurring all at once in explosions in the sky! The colours observed are due to the absorption of energy and emission of light from various elements including calcium (yellow), strontium (red) and potassium (lilac).

**Figure 7.30** Fireworks rely on the energy emitted from excited electrons returning to ground state.

## Quick check 7.9

1 Recall what causes electrons to become excited and move to higher energy levels.
2 State the type of energy that is emitted when electrons return to ground state.
3 Recall how we can identify the type of element present when electrons are excited.

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## Practical skills 7.1

### Flame tests using metal salts

**Be careful**
Wear appropriate personal protective equipment.

**Aim**
To observe the flame colours of different salt solutions.

**Materials**

- solutions of copper (II) chloride, potassium chloride, sodium chloride, lithium chloride and strontium chloride
- beakers
- boiling tubes
- distilled water
- wooden splints
- Bunsen burner
- bench mat
- matches

**Method**

1. Copy the results table into your science journal.
2. Prior to the lesson, thoroughly soak a supply of wooden splints in a beaker of distilled water.
3. Fill sets of boiling tubes up to half full with the salt solutions and immerse one splint in each of the tubes.
4. Hold a soaked splint in a blue Bunsen flame to reveal the flame colour, being careful not to let the splint burn too vigorously.
5. Dispose of used splints in another beaker filled with water.

**Results**

| Metal compound | Colour in flame |
|---|---|
| Copper (II) chloride | |
| Lithium chloride | |
| Strontium chloride | |
| Sodium chloride | |
| Potassium chloride | |

**Analysis**

1. What provides the energy in this experiment for electrons to be excited to the next energy level?
2. Why is it better to use a blue flame than a yellow safety flame to observe the colour of light emitted?
3. Explain why different colours of light were observed for compounds containing different metallic elements.

## Valence electrons and bonding

The number of valence electrons in an atom influences how it will react and bond with other atoms. Metals generally have fewer than four electrons in their outermost shell. Thus, metals tend to lose electrons to obtain a full stable valence shell. When they lose electrons, they form positively charged **ions** (known as **cations**) represented like this:

$$Na^+ \text{ or } Mg^{2+}$$

A single + sign indicates the atom has lost one electron, while a number before the + sign indicates how many electrons were lost.

**ion**
a charged version of an atom, formed from the loss or gain of electrons

**cation**
a positively charged ion formed from the loss of electrons

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Non-metals, located on the right-hand side of the periodic table, have valence shells that are almost full. To achieve stability, they tend to gain electrons, forming negatively charged ions (known as **anions**) represented like this:

**anion**
a negatively charged ion formed from the gain of electrons

$$S^{2-} \text{ and } F^{-}$$

A single – sign indicates the atom has gained one electron, while a number before the – sign indicates how many electrons were gained.

Cations and anions are collectively known as ions; that is, charged versions of an atom.

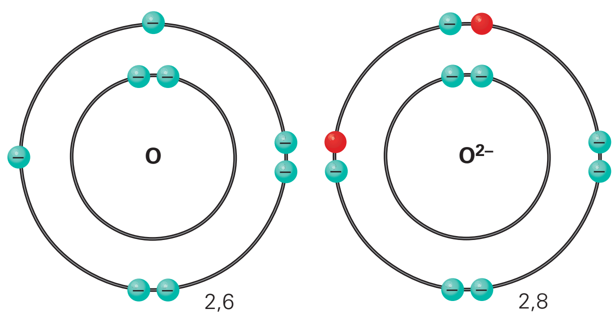


Figure 7.31 An oxygen atom has an electron configuration of 2,6. It tends to gain two electrons to achieve a stable outer shell, giving it an electron configuration of 2,8. It now has a net negative charge and is represented as $O^{2-}$.

## Explore! 7.4

### The Large Hadron Collider

The Large Hadron Collider (LHC) is used for international scientific research and is based at the laboratory operated by CERN on the border of Switzerland and France. The LHC is a particle accelerator that can make particles, like protons and ions, collide at close to the speed of light! Use your preferred search engine to find the Large Hadron Collider page on the CERN website. Explore the facts and figures for answers to the following questions.

1. How long is the ring that particles are accelerated at the LHC?
2. What is a hadron?
3. What is one of the main goals of the LHC?

## Ionic bonding

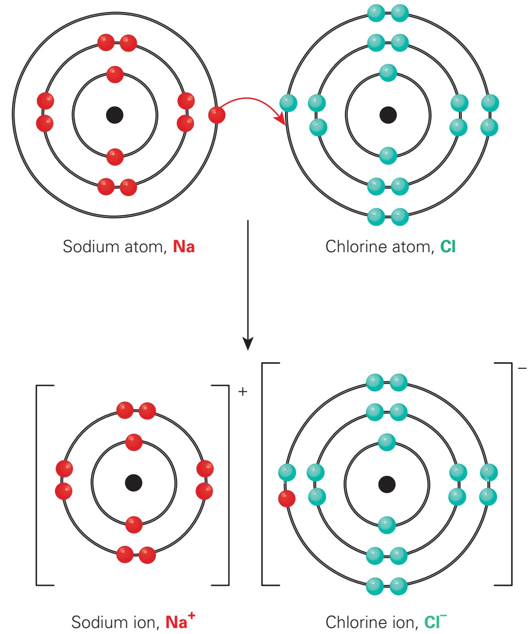


Figure 7.32 Ionic bonding in sodium chloride

Positively charged cations are electrostatically attracted to negatively charged anions, and this attraction is known as an **ionic bond**. Strong electrostatic forces bond the ions together into an ionic compound, which tend to take on a lattice structure. The structure of a sodium chloride lattice is shown in Figure 7.33. Because the ionic bond is strong, ionic compounds tend to have high melting temperatures. For example, table salt (NaCl) has a melting point of 801°C.

**ionic bond**
a strong bond between an anion and a cation, formed via electron donation

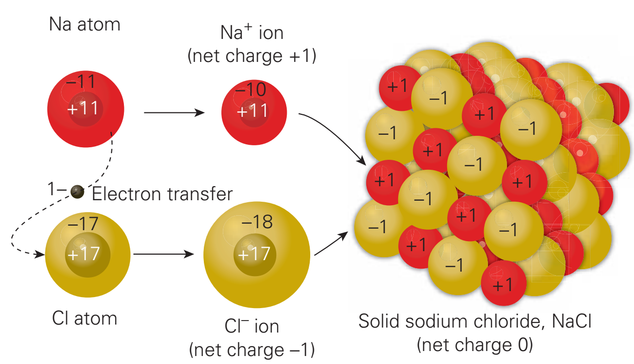


Figure 7.33 A sodium atom donates an electron to a chlorine atom (left). The sodium atom now forms a positively charged cation and the chlorine atom forms a negatively charged anion. These ions are attracted and bond into an ionic compound (right). A crystal lattice configuration is a common structure of ionic compounds.

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## Covalent bonding

Covalent bonding is the sharing of valence electrons, typically between two non-metal atoms. Both atoms have almost full valence shells and, rather than donate and gain electrons in an ionic bond, they formally share some of their valence electrons. Covalently bonding atoms form elements and compounds in the form of molecules held together by strong **covalent bonds**.

For example, an oxygen (O) atom has an electron configuration of 2,6. Oxygen is certainly capable of accepting electrons to form the oxide ion ($O^{2-}$) and contribute to ionic bonding. However, it can also share two electrons with another non-metal to complete its valence shell. An oxygen atom could share two electrons with two hydrogen atoms, which each require one electron to complete their valence shells. Look at the molecule in Figure 7.34: each hydrogen atom has a full outer shell (two electrons), and the oxygen atom has a full outer shell (eight electrons). Each bond in a covalent molecule is a shared pair of electrons.

**covalent bond**
a strong bond almost always between two non-metals which share electrons, forming a molecule

VIDEO
Ionic versus covalent bonding

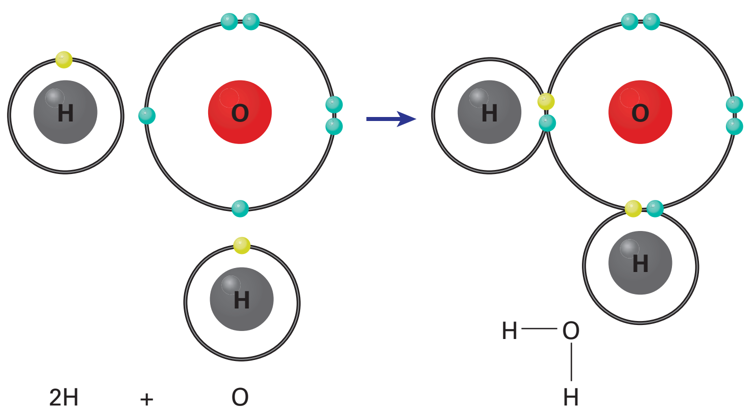


**Figure 7.34** Two hydrogen atoms and an oxygen molecule showing only their valence electrons. These electrons covalently bond to form a water molecule. The lines between the atoms represent covalent bonds.

### Quick check 7.10

1 Define these terms.
 a Ion
 b Cation
 c Anion
2 Explain why certain elements are likely to form cations while others tend to form anions.
3 Describe a covalent bond.

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QUIZ

## Section 7.3 questions

### Retrieval

1 **Select** the correct numbers to complete the following table:

| Electron shell | Maximum number of electrons |
|---|---|
| First | |
| Second | |
| Third | |
| Fourth | |

2 **Recall** why the shell closest to the nucleus fills with electrons first.

3 For each of the following electron configurations, **state** the:
- name of the element
- number of valence electrons
- period the element is in
- group the element is in.

   a 2,8,2
   b 1
   c 2,5
   d 2,8,8,2

4 **State** the electron configurations for the following elements.

   a Helium (He)
   b Beryllium (Be)
   c Phosphorus (P)
   d Potassium (K)

### Comprehension

5 The electron configuration of carbon is 2,4. **Draw** a diagram of a carbon atom with this electron configuration.

6 **Describe** the order in which electrons fill shells around the nucleus.

7 **Explain** why elements in the same group have similar properties.

8 Chlorine has the electron configuration 2,8,7. **Represent** the arrangement of the electrons within a chlorine atom in a diagram.

9 Use your knowledge of electron arrangement to **explain** what is significant about the electron configurations of group 18 elements.

### Analysis

10 **Compare** the number of protons and electrons in an uncharged atom with those in an ion.

11 **Distinguish** between valence electrons and other electrons of an atom.

12 **Compare** how an oxygen atom would participate in an ionic bond versus a covalent bond.

### Knowledge utilisation

13 Helium, a group 18 element, has the electron configuration 2, meaning that it has two valence electrons. **Discuss** why helium is not located next to hydrogen with the other group 2 elements, which also have two valence electrons.

14 **Construct** a diagram which shows an example of what happens when electrons are excited from ground state.

15 A student was instructed to conduct a flame test using copper chloride and strontium chloride. **Discuss** the results they would obtain.

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# 7.4 Special groups of elements

**Learning goals**

1. To be able to recall the physical properties and reactivity trends in group 1 and 2 metals.
2. To be able to recall the physical properties and reactivity trends in group 17 and 18 non-metals.

WORKSHEET
Group 1 and group 17

Generally, the periodic table groups elements based on similar chemical properties such as reactivity. This is more true in some groups of the periodic table than others. Groups 1, 2, 17 and 18 are examples of groups having consistent chemical properties down the periodic table and will be explored in this section. Elements in a group tend to have the same number of valence electrons, which is the primary factor that influences chemical reactivity.

## The alkali metals (group 1)

The **alkali metals** (group 1) make up the first group of the periodic table. The elements lithium (Li), sodium (Na), potassium (K), rubidium (Rb), caesium (Cs) and francium (Fr) all belong to the alkali metals. Note that hydrogen is also in group 1, but is not considered an alkali metal as it is a non-metal.

| |
|---|
| 3 **Li** 6.94 Lithium |
| 11 **Na** 22.99 Sodium |
| 19 **K** 39.10 Potassium |
| 37 **Rb** 85.47 Rubidium |
| 55 **Cs** 132.91 Caesium |
| 87 **Fr** 223.0 Francium |

### Physical properties

The alkali metals, including those you might observe in the classroom (sodium (Na) and potassium (K)), are soft and can be cut with a knife. When they are cut open, they have a shiny appearance on the inside compared to their dull outer surface. This is because their outer surfaces readily react with oxygen in the air, forming dull metal oxides.

**Figure 7.35** The elements in group 1 are also known as the alkali metals.

This reaction can be written as the following word and balanced chemical equations.

$$\text{sodium} + \text{oxygen} \rightarrow \text{sodium oxide}$$
$$4\ Na + O_2 \rightarrow 2\ Na_2O$$

When placed in water, lithium, sodium and potassium will float as they are less dense than water. Again, this is unlike most other metals you may have encountered.

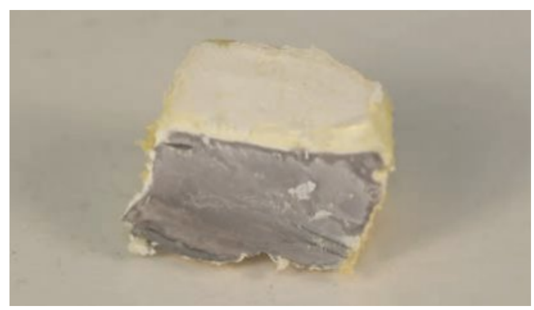

**Figure 7.36** A piece of sodium metal which has been cut by a knife. It is shiny on the inside and dull on the outside.

### Reactivity

All group 1 metals are highly reactive due to their one valence electron. Elements are stable when they have a full outer shell of electrons, so group 1 metals readily react with other atoms and donate the one valence electron. When they do this, they all form ions with a +1 charge.

**alkali metals**
group 1 metals

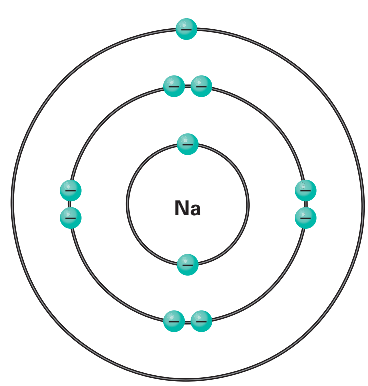


**Figure 7.37** The one valence electron makes group 1 elements highly reactive.

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Elements become more reactive down a group. This is because the one valence electron becomes further from the attraction of the nucleus as the atom gets larger. The weaker attraction to the nucleus makes the electron easier to lose when colliding with other atoms. In fact, caesium can be quite explosive when reacting with substances such as water.

Group 1 elements readily react with group 17 elements, forming white salts – one of these salts being table salt that you put on your chips!

**Figure 7.38** Table salt is formed when sodium reacts with chlorine to form sodium chloride.

The following word and balanced chemical equations show how sodium (Na) reacts with chlorine (Cl) to form table salt (sodium chloride, NaCl).

sodium + chlorine → sodium chloride

$$2\ Na + Cl_2 \rightarrow 2\ NaCl$$

To show how other alkali metals and group 17 elements react with each other, all you need to do is substitute their chemical names and symbols into the equations above.

Alkali metals are most famous for their reaction with water, and this is where they get their name. All group 1 metals react violently with water, producing hydrogen gas and an alkaline solution.

The word and balanced chemical equations show what happens when sodium reacts with water.

sodium + water → sodium hydroxide + hydrogen

$$2\ Na + 2\ H_2O \rightarrow 2\ NaOH + H_2$$

You can use these equations to predict what will happen when other alkali metals react with water.

## Did you know? 7.2

**Explosive group 1!**

Group 1 metals, such as sodium and potassium, are stored in jars of oils. When they come into contact with oxygen or water, these metals react, producing a lot of heat, an alkaline solution and hydrogen gas. This can often cause the metals to burst into flames. Due to this fire risk, group 1 metals are stored in oil, to be protected from oxygen and water vapours. The reactivity of group 1 metals increases down the group, so don't add caesium or francium to water!

**Figure 7.39** What happens when sodium reacts with water? Here, the hydrogen gas produced has ignited.

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## Quick check 7.11

1 Why are group 1 metals also known as alkali metals?
2 Why do alkali metals form +1 ions when they react with other substances?
3 Write a word equation for lithium reacting with fluorine.
4 Why are alkali metals shiny on the inside and dull on the outside?
5 Identify whether the following statements are true or false. If false, give a reason why.
   a Alkali metals are denser than water so they float.
   b Alkali metals react with oxygen to form metal oxides.
   c Alkali metals are hard.
6 Other than an alkali, what other product is formed when alkali metals react with water?
7 Which metal is the most reactive in group 1?

## Practical skills 7.2: Teacher demonstration

**Investigating the reactivity of group 1 metals**

### Aim

To determine the order of reactivity of two group 1 metals.

### Materials

- lithium and sodium metals
- universal indicator
- large, thick-walled glass bowl
- scalpel
- white tile
- blotting paper
- tweezers
- safety screen
- disposable gloves

### Method

1 Students should write a prediction in their books stating which they think will be the most reactive metal out of lithium and sodium.
2 Students should copy the results table into their science journal.
3 Half fill the large glass bowl with water and add a few drops of universal indicator until the colour can be seen throughout the liquid.
4 Using the tweezers, take a piece of lithium from its bottle and place it on the white tile.
5 Use the scalpel to cut off a small piece of the metal and observe the appearance of the metal on the inner and outer surfaces.
6 Making sure that all students are behind the safety screen, add the small piece of metal to the water and record your observations.
7 Repeat steps **4–6** with sodium.

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**Results**

| | Hard or soft | Appearance when cut | More or less dense than water | Observations during reaction |
|---|---|---|---|---|
| Lithium | | | | |
| Sodium | | | | |

**Risk assessment**

1 Explain the decision to use tweezers rather than hands to pick up the metals.
2 Why was a safety screen necessary when conducting this experiment?

**Analysis**

1 Describe the purpose of the universal indicator.
2 Describe any patterns, trends or relationships in your results.
3 Describe how you determined the reactivity of each of the metals investigated.
4 How did you determine whether the metals were more or less dense than water?
5 Explain how the reactivity of the metals changes as you go down group 1.

**Conclusion**

1 Propose a conclusion regarding the varying levels of reactivity of group 1 metals based on this experiment.
2 Support your statement by using the data you gathered.

## The alkaline earth metals (group 2)

Group 2 metals are also known as the **alkaline earth metals**. This group contains the elements beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba) and radium (Ra).

**alkaline earth metals** group 2 metals

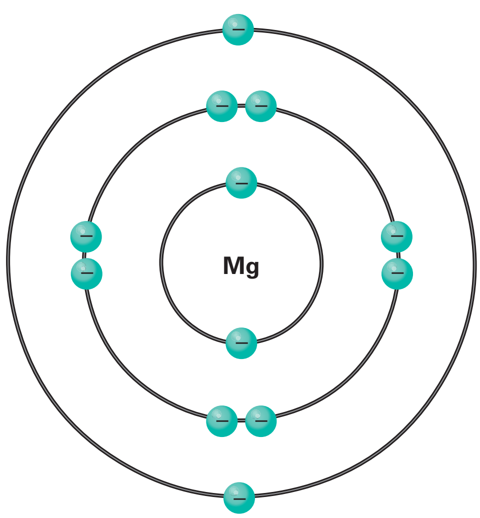


**Figure 7.40** Group 2 elements have two valence electrons.

### Physical properties

The naturally occurring alkaline earth metals tend to be shiny and silvery-white in colour. Magnesium and calcium are abundant in Earth's crust and are considered essential to all living organisms.

### Reactivity

All group 2 elements are reactive, but not as reactive as group 1 elements. This is because they have two valence electrons compared to one in group 1 elements. Group 2 elements form ions with a charge of +2 as they lose two electrons when they react.

Just like group 1 metals, alkaline earth metals react with oxygen to form metal oxides and with group 17 elements to form metal salts. Table 7.5 shows the names and formulas of the products formed.

**Quick check 7.12**

1 List four of the alkaline earth metals.
2 State the charge that alkaline earth metals tend to form when they react.

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| Element | Product formed when reacting with oxygen | Product formed from reacting with chlorine |
|---|---|---|
| Beryllium (Be) | Beryllium oxide<br>$BeO$ | Beryllium chloride<br>$BeCl_2$ |
| Magnesium (Mg) | Magnesium oxide<br>$MgO$ | Magnesium chloride<br>$MgCl_2$ |
| Calcium (Ca) | Calcium oxide<br>$CaO$ | Calcium chloride<br>$CaCl_2$ |

**Table 7.5** The products formed when group 2 metals react with oxygen and chlorine

## Investigation 7.2

### Investigating the reactivity of group 2 metals

**Be careful**

To reduce risk of skin burn from acid:

- wear appropriate personal protective equipment
- wear safety glasses at all times
- wash your hands after the practical.

#### Aim

To investigate the relationship between the position of a group 2 element in the periodic table and its reactivity with acid.

#### Prior understanding

Metals in group 2 of the periodic table are less reactive than those in group 1. This investigation will determine the order of reactivity within group 2.

**Recommended:** Use a spreadsheet to analyse the data for this experiment and calculate uncertainty.

#### Useful formula

Change in volume (mL) = final volume (mL) − initial volume (mL)

$$\text{Rate of gas produced } (\text{mL min}^{-1}) = \frac{\text{mean change in volume (mL)}}{\text{mean reaction time (min)}}$$

#### Materials

- 3 similarly sized samples of calcium (approximately 5 mm in diameter)
- 3 similarly sized samples of magnesium (approximately 5 mm in diameter)
- 30 mL hydrochloric acid (1 mol $L^{-1}$)
- 6 test tubes
- 10 mL measuring cylinder
- 100 mL measuring cylinder
- test-tube holder
- rubber stopper with glass tubing inserted through to fit the test tube
- rubber stopper to fit the 100 mL measuring cylinder
- 4 mm plastic tubing (minimum 30 cm)
- large bowl
- retort stand, bosshead and clamp
- stopwatch
- tweezers

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**Planning**

1. Develop a hypothesis by predicting how a change in the periodic position of the group 2 metal will affect its reactivity.
2. Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.
3. Complete a risk assessment for this investigation, describing how any risks will be controlled.

**Method**

**Part 1: Prepare the results table**

Copy the results table into your science journal.

**Part 2: Measure the reactivity of the first metal sample**

1. Fill the large bowl with tap water.
2. Fill the 100 mL measuring cylinder with tap water.
3. Stopper the measuring cylinder using the rubber stopper (a complete seal will not be possible).
4. Invert the measuring cylinder into the large bowl (your teacher will show you how to do this if you are not sure) and clamp it in place with the stopper below the water line, as shown in Figure 7.41.
5. Remove the stopper from the measuring cylinder.
6. Attach the plastic tubing to the glass tubing on the rubber stopper. Place beside the measuring cylinder for easy access later.
7. Measure 5 mL of 1 mol $L^{-1}$ hydrochloric acid and pour into a test tube.
8. Using tweezers, add a piece of the first metal sample into the acid in the test tube. Be careful not to splash the acid.
9. Attach the rubber stopper with the plastic tubing to the test tube and position the end of the plastic tubing underneath the measuring cylinder so the gas can be collected.
10. Measure the initial volume of the gas in the inverted measuring cylinder and record in your table. Start the stopwatch.

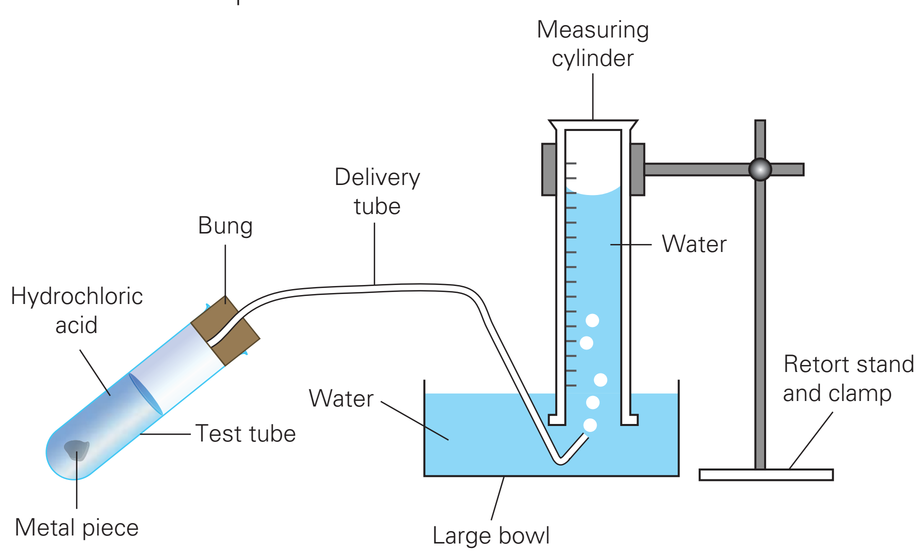


Figure 7.41 Diagram of experimental set-up

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11 After 5 minutes, record the final volume of the gas in the inverted measuring cylinder in your table.
12 Remove the rubber stopper and tubing from the test tube. Store the test tube and contents in the test-tube holder.
13 Repeat steps **7–12** with the other two samples of the first metal.
14 Remove the measuring cylinder and refill with tap water.
15 Stopper the measuring cylinder using the rubber stopper.
16 Invert the measuring cylinder into the large bowl and clamp it in place with the stopper below the water line.
17 Remove the stopper from the measuring cylinder.

**Part 3: Measure the reactivity of second metal sample**

Repeat steps **7–12** from Part 2 with the samples of the second metal.

**Results**

**Calculate the mean reaction rate for each metal sample**

1 Calculate the change in gas volume for each trial and record it in the results table.
2 Calculate the rate of gas production in mL $min^{-1}$ for each metal and record it in the results table.
3 Draw a scatterplot to analyse the relationship between the period number of each metal and its reaction rate.
4 Calculate the uncertainty for each metal.
5 Optional: Format the graph and insert a copy below the results table in your science journal.

| | Measurements | Trial 1 | Trial 2 | Trial 3 | Mean rate of gas production (mL $min^{-1}$) | Uncertainty of rate of gas production: $\frac{max - min}{2}$ |
|---|---|---|---|---|---|---|
| Period 2 Magnesium | Initial volume (mL) | | | | | |
| | Final volume (mL) | | | | | |
| | Change in volume (mL) | | | | | |
| | Rate of gas production (mL $min^{-1}$) | | | | | |
| Period 3 Calcium | Initial volume (mL) | | | | | |
| | Final volume (mL) | | | | | |
| | Change in volume (mL) | | | | | |
| | Rate of gas production (mL $min^{-1}$) | | | | | |

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**Analysis**

1. Compare the mean rate of gas production for the different elements.
2. Predict the trend in reactivity for group 2 elements that are positioned lower on the periodic table.
3. Draw a conclusion as to how using different elements going down group 2 might affect the rate of gas production in reactions with acids.

**Evaluation**

**Reliability**

1. Compare the uncertainties for each element. Which were the best results? Justify your answer with data.
2. Critique your management of the controlled variables. Were they managed properly to ensure they did not change and affect the measurements?

**Limitations**

3. Could these results be used to predict reactivity trends in other groups on the periodic table? Explain your reasoning.

**Improvements**

4. Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

**Conclusion**

1. Propose a valid conclusion that can be drawn from these results.
2. Justify this conclusion using data from your results.
3. Explain your conclusion using your own knowledge and research about group 2 metals.
4. State whether or not your hypothesis is supported.

## The halogens (group 17)

Group 17 elements are known as the **halogens**. This group contains the elements fluorine (F), chlorine (Cl), bromine (Br) and iodine (I). Astatine (At) is also a halogen, but it is a rare radioactive element and will not be considered here.

**halogens** group 17 elements

### Physical properties

The halogens form diatomic molecules, and their states and colours vary at room temperature. For example, fluorine and chlorine are gases, bromine is a liquid and iodine is a solid. Table 7.6 lists some of the properties of these elements.

### Reactivity

All group 17 elements have seven valence electrons. When they react with other substances, they gain an electron to make a full outer shell of eight electrons.

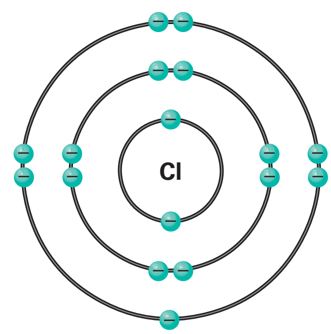


**Figure 7.42** Group 17 elements have seven valence electrons.

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| Halogen | Formula | State | Colour | Melting point (°C) | Boiling point (°C) | Reactivity |
|---|---|---|---|---|---|---|
| Fluorine | $F_2$ | Gas | Yellow | −220 | −188 | Reactivity increases up the group |
| Chlorine | $Cl_2$ | Gas | Greenish-yellow | −101 | −35 | |
| Bromine | $Br_2$ | Liquid | Red | −7.2 | 58.8 | |
| Iodine | $I_2$ | Solid | Grey (purple in gas state) | 114 | 184 | |

**Table 7.6** Some properties of the halogens

This means that they form ions with a charge of −1, or they covalently bond with non-metal atoms capable of sharing one electron.

As shown in Table 7.6, the reactivity of group 17 elements decreases as you move down the group. As the atom gets larger, the valence electrons are further from the attraction of the nucleus. This makes it more difficult for the elements to attract valence electrons to fill the valence shell.

**Quick check 7.13**

1. Name three elements in group 17.
2. State the charge of a group 17 ion.
3. State one physical or chemical trend that can be observed going down group 17.

## The noble gases (group 18)

Group 18 elements are also known as the **noble gases**. This group contains the elements helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn).

### Physical properties

The noble gases tend to be colourless, odourless and non-flammable. They have a full valence shell of electrons, which makes them very unreactive. Their applications include neon signs, medical imaging and radiotherapy to treat cancer.


**Figure 7.43** The first neon signs used neon, which produces an orange colour. Different elements, such as hydrogen and helium, are used to get different colours in modern neon signs.

### Reactivity

Unlike the other groups we have discussed, noble gases are extremely unreactive and are sometimes called the inert gases to reflect this.

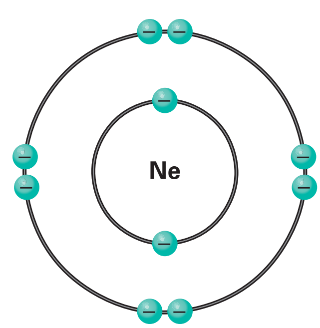


**Figure 7.44** Group 18 elements all have eight valence electrons and therefore a full outer shell.

**noble gases** group 18 elements

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**Quick check 7.14**

1 Name three elements in group 18.
2 State why group 18 elements don't form ions.

QUIZ

## Section 7.4 questions

**Retrieval**

1 **State** the group number of the following.
  a Alkaline earth metals  b Halogens
  c Noble gases  d Alkali metals
2 **Recall** what happens to the reactivity as you move down group 1.
3 **Identify** if the following statements are true or false. If false, give a reason why.
  a All halogens are gases.
  b All alkali metals form hydrogen when they react with water.
  c Noble gases do not form ions.
  d Alkaline earth metals form ions with a +2 charge.
  e The general formula of a halogen molecule is $X_2$.
4 **State** how many valence electrons each of the following groups has.
  a Alkali metals  b Alkaline earth metals
  c Halogens  d Noble gases
5 A new element is discovered. It is shown to form an ion with a charge of +2. **Identify** which group it could belong to.

**Comprehension**

6 **Explain** why group 2 elements are less reactive than group 1 elements.
7 Helium does not have eight valence electrons. **Explain** why it is still classified as a noble gas.
8 **Explain** why alkali metals are stored in oil or even sealed in inert gases.

**Analysis**

9 **Classify** the following elements as alkali metals, alkaline earth metals, halogens or noble gases.
  a Magnesium  b Argon  c Sodium
  d Potassium  e Iodine
10 **Compare** the properties and reactions of group 1 and 2 elements.

**Knowledge utilisation**

11 Use examples provided in the text to **construct** a balanced chemical equation for the reaction between the following.
  a Rubidium and water  b Lithium and oxygen
12 Use Table 7.6 to **predict** some properties of astatine.
13 **Predict** the products of the following reactions.
  a Potassium and water  b Magnesium and chlorine
  c Calcium and oxygen  d Sodium and fluorine
14 **Decide** why group 18 was not present in Mendeleev's periodic table.
15 **Decide** if you would expect strontium to be chemically more similar to calcium or rubidium, giving reasons for your choice.

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# Chapter review

## Chapter checklist

You can download this checklist from the Interactive Textbook to complete it.

| Success criteria | | Linked questions | Check |
|---|---|---|---|
| **7.1** | I can describe how Mendeleev arranged elements in his early periodic table. | 9, 16 | |
| **7.2** | I can describe the structure of the periodic table in terms of groups and periods, and blocks of metals, metalloids and non-metals. | 1, 2 | |
| **7.2** | I can identify the transition metals, lanthanoids and actinoids on the periodic table. | 3, 5 | |
| **7.3** | I can determine the electron configuration of different elements. | 8, 11 | |
| **7.3** | I can describe how electron configuration is linked to the emission of light from an element, as observed using a spectroscope. | 19 | |
| **7.3** | I can describe how valence electrons are shared in ionic bonding and covalent bonding. | 12 | |
| **7.4** | I can recall the physical properties and chemical reactivity of elements in groups 1, 2, 17 and 18 in the periodic table. | 10, 15, 17 | |

## Review questions

SCORCHER

### Retrieval

1 **State** the group and period of the following elements.
  - **a** Boron (B)
  - **b** Titanium (Ti)
  - **c** Platinum (Pt)
  - **d** Strontium (Sr)

2 **State** the group number of the following elements.
  - **a** An element with the electronic configuration 2,8,1
  - **b** An element with 18 electrons
  - **c** A halogen
  - **d** A noble gas

3 **Identify** each of the following elements as a transition metal, lanthanoid or actinoid.
  - **a** Europium (Eu)
  - **b** Rhenium (Re)
  - **c** Uranium (U)

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4 Magnesium and beryllium are in group 2. **Recall** the other name given to elements in group 2.
5 **Identify** the names and positions of three elements that are transition metals.
6 **State** why elements are placed together in the same group.

### Comprehension

7 **Describe** the position of metals and non-metals on the periodic table.
8 **Write** the electron configuration for a sulfur atom.
9 **Explain** why Mendeleev left gaps in his periodic table.
10 **Describe** the change in properties of the halogens as you move down group 17.
11 **Represent** the electron arrangement of an atom of carbon in a diagram.

### Analysis

12 **Compare** ionic and covalent bonding by completing this table:

| | Ionic bonding | Covalent bonding |
|---|---|---|
| Strength of bond | | |
| Bond is between ___ and ___ | | |
| How is the bond formed? | | |

13 **Compare** the properties of iron and chlorine gas.
14 Observe the ammonia molecule shown in Figure 7.45. It is a gas at room temperature and has a chemical formula of $NH_3$. **Infer** what sort of bond exists between the nitrogen and hydrogen atoms.
15 **Distinguish** between elements in group 1 and elements in group 2.
16 **Critique** Mendeleev's method of predicting the properties of unknown elements.

**Figure 7.45** Ammonia molecule

### Knowledge utilisation

17 A unknown element is found to:

- react violently with water
- feel soft
- have an electron configuration of 2,8,8,1.

Given those properties, **determine** the group in which it belongs. Give reasons for your choice.
18 **Determine** the relationship of an element's atomic number, number of electrons and its position in the periodic table.
19 **Explore** how Niels Bohr used the absorption and emission spectra of hydrogen to suggest a new model of the atom.
20 Use the melting point data below to **predict** the physical states (solid, liquid or gas) of the unknown elements at room temperature. Note that room temperature is around 25°C.

| Element | Melting point (°C) | Physical state |
|---|---|---|
| X | −240 | |
| Y | 17 | |
| Z | 57 | |

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## Data questions

Magnesium and calcium are group 2 alkaline earth metals and can be taken as general health supplements to aid regulation of bodily functions including muscle functions and bone development. A scientist is testing the claim from eight different supplement brands that their magnesium and calcium tablets contain 200 mg of each element. Each supplement was analysed, and the amounts of magnesium and calcium present in each tablet are presented in Figure 7.46.

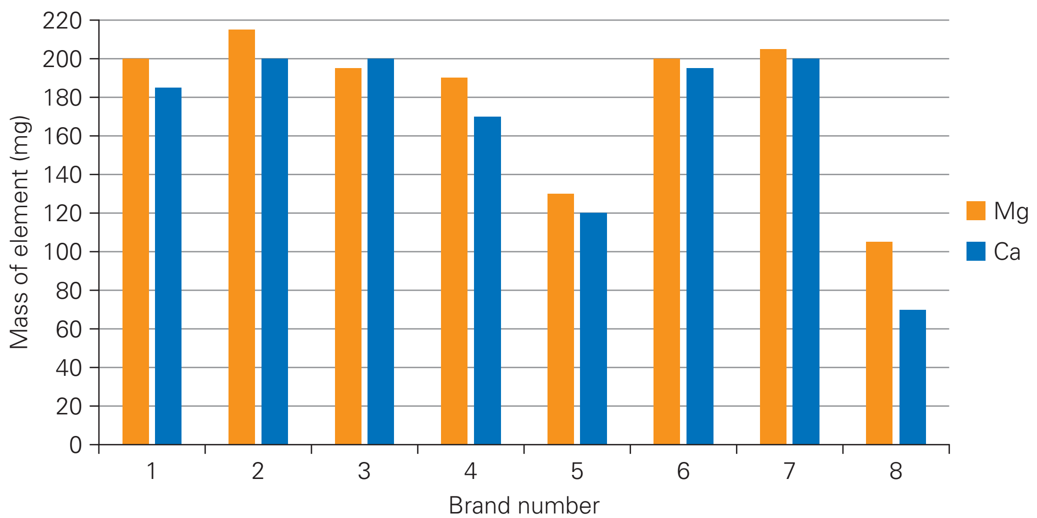


**Figure 7.46** Mass of magnesium and calcium found in eight commercial supplement samples

### Apply

1 **Identify** all samples that had less than the advertised 200 mg of magnesium.

2 Brand 3 advertised that the magnesium content was 200 mg ±10%. **Calculate** the minimum amount of magnesium that could be present in this advertised sample.

3 Use your answer to Question **2** to **determine** whether the analysed brand 3 has a magnesium content within the advertised range.

### Analyse

4 Brand 5 is being investigated for false advertising with its claim that 'we have a more accurate calcium content than (brand 1)'. Explore this statement and **draw conclusions** about its accuracy.

5 A spokesperson for brand 6 has stated that 'the calcium content is more difficult to maintain as it is a more reactive metal than magnesium'. **Contrast** the magnesium and calcium content in brand 6. Does this explanation match the data presented in Figure 7.46?

6 **Identify** the general trend between the mass of magnesium and the mass of calcium in a brand's supplements.

### Interpret

7 The 200 mg magnesium supplements are deemed to be falsely advertised if the content is found to be below 180 mg. **Compare** the data for the eight samples; which brands have falsely advertised?

8 A magnesium content of over 220 mg would also be considered misleading advertising. Use the data to **justify** that no brand is providing misleading information in this regard.

9 Brand 7 has released a new series of magnesium and calcium supplements containing 250 mg each of magnesium and calcium. Use your response to Question **5** to **predict** whether the samples of these products would contain more magnesium or calcium.

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# STEM activity: Creating composite materials

## Background information

Elements have very particular properties, but these properties alone are often not suitable for the range of engineering projects that are required in society. Elements therefore need to be chemically or physically combined to create materials with different properties that are more suited to particular tasks.

Materials engineers study the properties of materials such as metals, ceramics, nanomaterials (extremely small substances) and other substances. They may also combine different materials that have already been combined to produce new materials with properties combined from each of its parts. These are called 'composite materials'.

In composite materials, the combined initial materials do not bond or blend with one another, so it is easy to tell the different materials apart. Mud bricks are an example of a composite material. Mud bricks are made of straw and mud. Mud is strong if you press down on it but breaks when you bend it. Straw is strong if you pull on it, but it easily crumples. Mixing straw and mud together creates bricks that hold shape when squeezed or bent. Mud bricks are great as building blocks, whereas neither mud nor straw individually is good.

**Figure 7.47** Concrete is a composite of cement and sand. The composite materials can be mixed (left) and then used to provide a strong foundation (right) for a building, particularly when combined with metal rods for stability.

**Design brief:** Create a composite material for the purpose of building a specific product.

## Activity instructions

In small groups, consider the type of structure that you would like to build. For example, you could build a beam bridge, an aeroplane, a building or a chair. Then conduct some research and brainstorm what kind of properties you need in the material used to build the product. Think about what kinds of tests would be useful to determine if the material is suitable or not.

Next, design a prototype of the composite material and test it against these properties. Build and test the prototype. Then think of some ways it could be improved and test it again.

## Suggested materials

- internet
- scissors
- ruler
- coins
- paper towels
- tape
- PVA glue
- popsicle sticks
- paper
- cardboard
- elastic bands
- string or yarn
- other materials, where possible

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**Figure 7.48** Modern dental fillings may use a composite material containing acrylic resin and glass. When these materials are combined, a strong a natural-tooth-coloured filling is formed. The liquid composite is added to the tooth (left) and then sets to a solid (right).

## Research and feasibility

1 Research the two composite materials: glass fibre–reinforced concrete (GFRC) and steel-reinforced concrete.

a Copy and complete the table below and add other properties you believe are important.

b What are the differences and what are the benefits of one material over the other?

c How did the discovery of each material change the way we use concrete?

| | Glass fibre–reinforced concrete | Steel-reinforced concrete |
|---|---|---|
| **Strength** | | |
| **Benefits compared to concrete** | | |
| **Temperature variance** | | |

2 As a group, decide on a purpose for creating a new material for manufacture. Research the important properties and features the new composite material will require.

## Design and sustainability

3 You will be testing composite materials made up of different ratios of component materials. List the ratios of each component material used in the composite that your group will be testing and write the method for manufacturing and testing your composite material. (Think about the properties of your materials and which material would be the best.)

4 Design the best possible method to create your new composite material.

5 Discuss the sustainability of your material and its environmental impact. Your new material must have a positive environmental impact and be sustainable to manufacture.

## Create

6 Manufacture the composite material in the various ratios set out in the design phase and allow to set if required.

7 Test your material by applying forces to your material. Record the type of force (such as gravity).

## Evaluate and modify

8 Evaluate the capabilities of the original materials compared to the new material. Discuss and explain the differences.

9 What are the maximum forces that could be applied to each ratio? Explain the effect of the ratios of the single materials when used as a composite material.

10 Suggest ways to improve the composite material. Should another material be added? Should the ratios of the component materials be altered?

11 Predict how the composite material might behave if it was constructed differently but with the same materials.

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# Chapter 8
# Chemical reactions

## Chapter introduction

The chemical industry produces a range of useful substances in vast quantities, many of which you could not do without. These products are a result of chemical reactions, which can be described in word equations, balanced symbol equations or particle diagrams. In this chapter, you will learn how to predict the products of common types of chemical reactions and to predict how changes in the conditions of a chemical reaction could affect the rate at which the reaction progresses. Finally, you will calculate the amount of reactants and products that are used and produced in a chemical reaction using the mole concept.

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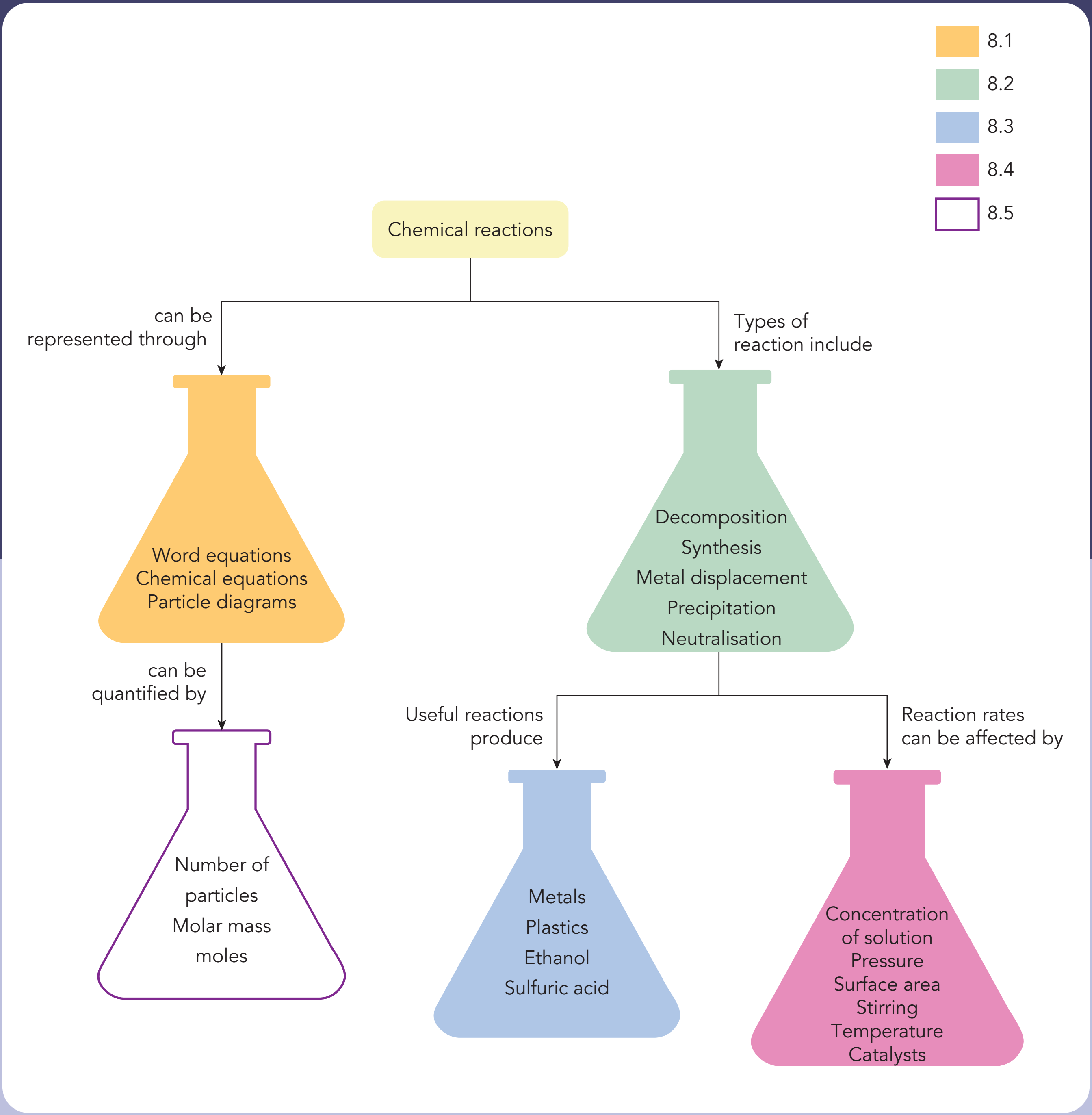
# Concept map

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## Curriculum

| | |
|---|---|
| Identify patterns in synthesis, decomposition and displacement reactions and investigate the factors that affect reaction rates (AC9S10U07) | |
| defining and representing synthesis, decomposition and displacement reactions using a variety of formats such as molecular models, diagrams and word and balanced equations | 8.1, 8.2 |
| identifying reaction type and predicting the products | 8.2 |
| investigating synthesis reactions such as reaction of metals with oxygen, formation of water and sodium chloride; decomposition reactions such as those used to extract metals; and displacement reactions such as metal and acid, neutralisation and precipitation | 8.2 |
| investigating chemical reactions employed by First Nations Australians in the production of substances such as acids and ethanol | 8.3 |
| investigating some of the chemical reactions and methods employed by First Nations Australians to convert toxic plants into edible food products | 8.3 |
| examining reactions that are used to produce a range of useful products | 8.3 |
| investigating the effect of a range of factors, such as temperature, concentration, surface area and catalysts, on the rate of chemical reactions | 8.3, 8.4 |



## Extension

| | |
|---|---|
| recognising that a mole is a precisely defined quantity of matter equal to Avogadro's number of particles | 8.5 |
| understanding that the mole concept relates mass, moles and molar mass | 8.5 |



## Glossary terms

Activation energy
Agitating
Aqueous
Biofuel
Catalyst
Chemical formula
Coefficient
Collisions
Concentrated solution
Concentration
Diatomic
Dilute solution
Displacement reaction
Elementary entity
Molar mass
Mole
Monatomic
Neutralisation
Particle diagram
Precipitation
Pressure
Products
Reactants
Reaction rate
Reactivity series
Relative atomic mass
Salt
Surface area
Synthesis
Thermal decomposition
Word equation

# 8.1 Representing chemical reactions

**Learning goals**

1. To be able to represent a chemical equation using word, symbol and particle equations.
2. To be able to recall the correct use of state symbols in a formula equation.
3. To be able to balance a chemical equation.

WORKSHEET
Representing chemical equations

VIDEO
Indicators of chemical reactions

In a chemical reaction, bonds in **reactants** are broken and new bonds are formed to make the **products**. Reactants are the chemicals that are made to react together and products are the chemicals that are produced in a reaction. In this section, you will learn how to represent chemical reactions as word equations, balanced symbol equations and particle diagrams.

## Word equations

**Word equations** describe the reactants and products of a reaction in words. Below is the word equation for the reaction of two common chemicals. Can you identify the reactants and the products?

sodium hydroxide + hydrochloric acid → sodium chloride + water ✓

Notice that all the reactants are on the left-hand side of the arrow and the products are on the right-hand side. It is very tempting, if you run out of paper, to write the same chemical reaction as in the example below.

sodium hydroxide + hydrochloric acid →
sodium chloride + water ✗

However, you should make sure that the reactants are always on the left and the products are always on the right of the arrow, as in the correct example above.

**Quick check 8.1**

1 Correct the following word equation
$CO_2$ + water → glucose + oxygen

2 Which of the following options should you **not** do if you are running out of paper and still have to finish writing a word equation?
- A Just carry on to the next line, it does not matter where you write the reactants and products.
- B Rewrite the equation, so it fits onto the piece of paper.
- C Split some of the reactants or products over two lines, to ensure that all reactants are on the left of the arrow, and all products are on the right.

## Symbol equations

A second way of representing a chemical reaction is by using a **chemical formula**. They are structured the same way as word equations but use chemical symbols instead of words to represent the substances in the reaction.

**reactants**
the chemicals which react together in a reaction

**products**
the chemicals produced in a reaction

**word equation**
a chemical reaction written using the names of the reactants and products involved

**chemical formula**
the symbols and formulas of the reactants or products

Elemental symbols can be taken from the periodic table. Make sure they are written in the same way. That is, the first letter is capitalised and the second letter (if present) is lower case (see Figure 8.1).

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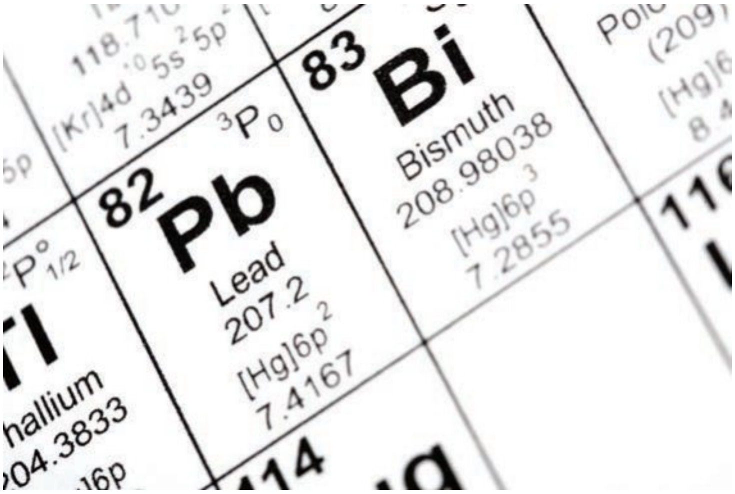


**Figure 8.1** Lead is one of the elements with two letters in its chemical symbol (Pb). One is upper case (capital) the other is lower case. The symbol comes from its Latin name, *plumbum*.

**monatomic**
(also monoatomic) existing as one atom

**diatomic**
existing as two atoms bonded together

All the metallic elements on the periodic table exist as individual atoms on their own and are described as being **monatomic**, meaning existing as one atom. However, many non-metallic elements do not exist on their own but instead, they tend to exist naturally as a gas or liquid with two atoms bonded together. These elements are known as **diatomic**, meaning existing as two atoms. Table 8.1 lists the seven diatomic elements on the periodic table. You will see that it does not include all the gaseous or liquid elements – some, such as helium and neon, are monatomic.

| Element | Formula |
|---|---|
| Hydrogen | $H_2$ |
| Nitrogen | $N_2$ |
| Oxygen | $O_2$ |
| Fluorine | $F_2$ |
| Chlorine | $Cl_2$ |
| Bromine | $Br_2$ |
| Iodine | $I_2$ |

**Table 8.1** Seven diatomic elements

The subscript (small and low) '2' shows that there are two atoms of these elements bonded together.

Substances with no subscript number after the chemical symbol have only one atom of that element present; for example, Ca represents just one atom of calcium.

Working out the formulas of compounds, such as sodium carbonate, is more complicated than working out elements. So, for now, you will need to look them up when formulating a symbol equation.

Let's look at the word equation from before and see if we can turn it into a symbol equation.

$$\text{sodium hydroxide} + \text{hydrochloric acid} \rightarrow \text{sodium chloride} + \text{water}$$

The word equation shows us that sodium hydroxide (NaOH) is reacting with hydrochloric acid (HCl) to form sodium chloride (NaCl) and water ($H_2O$). Using the symbols for these compounds, a chemical equation can be created, like the one below.

$$NaOH + HCl \rightarrow NaCl + H_2O$$

This chemical equation shows you what happens when the compounds sodium hydroxide and hydrochloric acid react. The atoms are rearranged to form two new compounds: sodium chloride and water.

**Quick check 8.2**

1. State the number of atoms in one molecule of sucrose ($C_{12}H_{22}O_{11}$).
2. Explain the term 'diatomic molecule'.
3. Write a chemical equation with symbols for the reaction between iron (Fe) and chlorine ($Cl_2$) to make iron(II) chloride ($FeCl_2$).

## State symbols

Chemical equations give you more information than word equations do about the rearrangement of atoms within compounds.

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You can add more information to chemical equations by using state symbols that show the physical states of the substances in a chemical equation. Table 8.2 summarises the symbols used for each of the four physical states.

| State | Symbol | Example |
|---|---|---|
| Solid | (s) | iron |
| Liquid | (l) | water |
| Gas | (g) | oxygen |
| Aqueous | (aq) | salt water |

**Table 8.2** State symbols are used to represent the physical states of the substances in a chemical equation.

**Figure 8.2** Ocean water is an aqueous solution because salt (sodium chloride) is dissolved in the water.

You may not be familiar with the term **aqueous** (aq). Aqueous is a term used to describe a solution, that is, a solid, liquid or gas dissolved in water. An example is salt water.

You can now make the chemical equation even more informative by adding in state symbols for the four substances in the equation.

$$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$$

Most acids and alkalis you will come across in this chapter are aqueous. In this example, sodium hydroxide (NaOH) is aqueous as it has been made by dissolving solid sodium hydroxide in water. Likewise, hydrochloric acid is also aqueous as it is made by dissolving the acidic gas hydrogen chloride in water.

**aqueous**
a physical state of matter that means dissolved in water

## Quick check 8.3

1. Why is salt water described as an aqueous solution?
2. Which two of the following compounds would be given the state symbol (s) at room temperature: hydrogen gas, copper, sugar (glucose), hydrochloric acid?

## Particle diagrams

Finally, you can also use **particle diagrams** to represent chemical reactions. Here, particle formula diagrams (pictures showing the arrangement of the atoms) are used. You can convert the chemical equation used previously to a particle diagram.

One of the advantages of using a particle diagram to represent a chemical reaction is that you can visualise how the atoms are bonded. For example, the formula for water is $H_2O$. This, however, only shows that water contains two hydrogen atoms and one oxygen atom. The particle diagram tells you this as well, but it also shows that each of the hydrogen atoms is bonded to the oxygen atom. Another advantage is that you can see how the atoms have rearranged in the reaction. In the particle diagram shown in Figure 8.3, the bond between the sodium and oxygen in sodium hydroxide and the bond between hydrogen and chlorine in hydrochloric acid have broken, and these atoms have bonded with other atoms to make different products.

**particle diagram**
a representation of elements and compounds where atoms are drawn as balls or circles

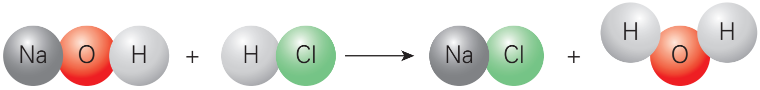


**Figure 8.3** The particle diagram for the reaction between sodium hydroxide and hydrochloric acid

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WORKSHEET
Balancing formula equations

WIDGET
Balancing chemical equations

## Quick check 8.4

1 What are particle diagrams?
2 What is the main advantage of a particle diagram to represent chemical reactions?

## Balancing chemical equations

The law of conservation of mass states that mass is neither gained nor lost in a chemical reaction, but always conserved. Therefore, the mass of reactants must equal the mass of the products in any chemical reaction. Atoms from the products cannot disappear, and similarly, atoms cannot just appear in the products.

A balanced chemical equation has the same number and types of atoms on the left-hand side (reactants) as it does on the right-hand side (products). Looking at the diagram of the particles can make it easier to pinpoint when equations are not balanced.

For example, consider the following equation.

$$NaOH\,(aq) + HCl\,(aq) \rightarrow NaCl\,(aq) + H_2O\,(l)$$

**Figure 8.4** Equations with the same number and type of reactant atoms as product atoms are said to be balanced.

To determine whether this equation is balanced or not, you need to count the number of each atom on both sides of the equation. It helps to do this in a table (as shown in Table 8.3), and it can also be easier to use the particle diagram, shown in Figure 8.5.

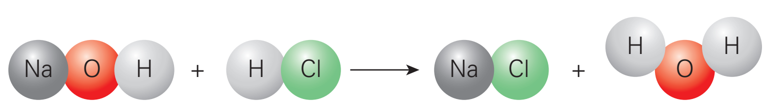


**Figure 8.5** Particle diagram

| | Number of atoms in reactants (left-hand side) | Number of atoms in the products (right-hand side) |
|---|---|---|
| Sodium (Na) | 1 | 1 |
| Oxygen (O) | 1 | 1 |
| Hydrogen (H) | 2 | 2 |
| Chlorine (Cl) | 1 | 1 |

**Table 8.3** It helps to use a table to determine whether an equation is balanced or not. As there are the same number and types of atoms in both the reactants and products, you can determine that this is a balanced formula equation. Therefore, you do not need to modify it in any way.

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In another example, solid sodium metal (Na) reacts with chlorine gas ($Cl_2$) to make solid sodium chloride (NaCl).

$$Na\,(s) + Cl_2(g) \rightarrow NaCl\,(s)$$

Recording the number of each atom on both sides of the equation using the method you used in the previous example gives the results shown in Table 8.4.

| | Number of atoms in reactants (left-hand side) | Number of atoms in the products (right-hand side) |
|---|---|---|
| Sodium (Na) | 1 | 1 |
| Chlorine (Cl) | 2 | 1 |

**Table 8.4** Recording the number of atoms in this equation shows the equation is unbalanced.

You should notice that there is one more chlorine atom in the reactants than there is in the products. This equation is not balanced.

When fixing an unbalanced chemical equation, it is not possible to change the formula of any of the substances in the equation, as you cannot change how the atoms have arranged themselves. For example, you cannot just simply remove one of the chlorine atoms in a $Cl_2$ molecule, as this is not how chlorine exists in the real world (it is a diatomic molecule). The subscript numbers that appear after a chemical symbol indicate how many atoms of that element are present, and they cannot be altered.

Instead, you should add more of each substance to both sides of the equation until the number of atoms balances out. Putting numbers in front of the chemical symbol or chemical formula changes the amount of that substance, for example:

Changing $O_2$ (g) to 2 $O_2$ (g) means there are two molecules of oxygen gas instead of one.

The problem identified in the equation was that there were two atoms of chlorine in the reactants, but only one in the products. To even out the number of chlorine atoms, you can add another unit of NaCl to the products, as shown here.

$$Na\,(s) + Cl_2\,(g) \rightarrow 2\ NaCl\,(s)$$

Use Table 8.5 to see if you have solved the problem.

| | Number of atoms in reactants (left-hand side) | Number of atoms in the products (right-hand side) |
|---|---|---|
| Sodium (Na) | 1 | 2 |
| Chlorine (Cl) | 2 | 2 |

**Table 8.5** Is the equation balanced now?

You have solved the original problem of the unbalanced chlorine atoms, but by adding another unit of sodium chloride (NaCl), you have also altered the number of sodium atoms. Now these do not balance. To make them balance, you need to add another sodium atom to the reactants. See if this works using Table 8.6.

$$2\ Na\,(s) + Cl_2\,(g) \rightarrow 2\ NaCl\,(s)$$

| | Number of the atoms in reactants (left-hand side) | Number of atoms in the products (right-hand side) |
|---|---|---|
| Sodium (Na) | 2 | 2 |
| Chlorine (Cl) | 2 | 2 |

**Table 8.6** A balanced equation

By adding another unit of sodium chloride and a sodium atom, the equation is now balanced. All you have to remember is that the numbers before the chemical symbol (or **coefficients**) indicate the number of formula units, and the small subscript numbers indicate the number of atoms within the formula unit.

**coefficient**
the number placed before a molecule (formula unit) in a chemical equation to ensure it is balanced

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### Quick check 8.5

1 Determine whether the following chemical reactions are balanced or unbalanced.
   a $Fe + O_2 \rightarrow Fe_2O_3$
   b $H_2 + O_2 \rightarrow H_2O$
   c $Zn + CuSO_4 \rightarrow Cu + ZnSO_4$
   d $Be + Cl_2 \rightarrow BeCl_2$
2 Balance these chemical equations. (Draw a particle diagram if you need help. To help you, the first two have spaces to show where you should add coefficients.)
   a __ $H_2 + O_2 \rightarrow$ __ $H_2O$
   b __ $Mg + O_2 \rightarrow$ __ $MgO$
   c $Fe + O_2 \rightarrow Fe_2O_3$
   d $Ca(OH)_2 + HNO_3 \rightarrow Ca(NO_3)_2 + H_2O$
3 Write a balanced chemical equation for the reaction between aluminium (Al) and chlorine ($Cl_2$) to make aluminium chloride ($AlCl_3$).

VIDEO
The Haber process

### Explore! 8.1

**The Haber process**

The German scientist Fritz Haber and his assistant Robert Le Rossignol developed the Haber process, which was later industrialised by Carl Bosch. Haber was awarded a Nobel Prize for his efforts in 1918. The Haber process enabled the production of ammonia ($NH_3$) on a large scale by reacting nitrogen ($N_2$) gas with hydrogen ($H_2$) gas under optimum conditions.

The largest ammonia plant in Australia is on the Burrup Peninsula in the Pilbara region of Western Australia; it produces around 330 000 tonnes each year. Ammonia is mainly used as a fertiliser.

1 Write a word equation for the production of ammonia in the Haber process.
2 Write a balanced symbol equation with state symbols.
3 The Haber process is a reversible reaction. How might this be represented in the word and symbol equations?
4 Why is the large-scale production of ammonia so beneficial?

### Investigation 8.1

**Comparing theoretical equations with experimental data**

**Be careful**

Wear appropriate personal protective equipment (safety glasses, disposable gloves and lab coat).

**Aim**

To consider the accuracy of experimental data compared with the theoretical outcome based on chemical equations.

**Useful formulas**

sodium hydroxide + iron(II) sulfate → iron(II) hydroxide + sodium sulfate

$$2\ NaOH(aq) + FeSO_4(aq) \rightarrow Fe(OH)_2(s) + Na_2SO_4(aq)$$

*continued …*

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*continued …*

calcium carbonate + hydrochloric acid → calcium chloride + water + carbon dioxide

$CaCO_3(s) + 2\ HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

**Materials**

- 4 mL of 1 mol $L^{-1}$ iron(II) sulfate solution
- 5 mL of 1 mol $L^{-1}$ hydrochloric acid solution
- 8 mL of 1 mol $L^{-1}$ sodium hydroxide solution
- small piece of calcium carbonate
- 2 × 10 mL measuring cylinders
- 2 × 50 mL conical flasks
- test tube
- 2 rubber stoppers
- thread
- balance

**Planning**

Refer to the chemical reactions above. For each reaction, predict whether the mass will change during the reaction. Justify your reasoning for this based on details from the theoretical equation.

**Method**

**Part 1: Prepare the results table**

Copy the results table into your science journal.

**Part 2: Measure the mass of the reactants and products of the reaction between iron(II) sulfate and sodium hydroxide**

1. Record the level of uncertainty for the scales you are using in the table.
2. Using a measuring cylinder, measure 8 mL of sodium hydroxide solution.
3. Using a second measuring cylinder, measure 4 mL of iron(II) sulfate solution.
4. Place the conical flask on the scales and press 'tare' to zero.
5. Pour the contents of both measuring cylinders into the conical flask.
6. Record the mass of the combined mixture.
7. Observe the chemical reaction take place and record your observations.
8. When it is finished, record the mass of the final products in the flask.

**Part 3: Measure the mass of the reactants and products of the reaction between calcium carbonate and hydrochloric acid**

1. Using a measuring cylinder, measure 8 mL of hydrochloric acid solution.
2. Place the conical flask on the scales and press 'tare' to zero.
3. Pour the hydrochloric acid into the conical flask. Add the calcium carbonate to the plate beside the flask.
4. Record the mass of the two reactants.
5. Add the calcium carbonate into the conical flask.
6. Observe the chemical reaction take place and record your observations.
7. When it is finished, record the mass of the final products in the flask.

*continued …*

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*continued …*

**Results**

1 Calculate the change in mass for each reaction and record it in the results table.
2 Calculate the range of uncertainty and record it in the table.
3 Calculate the relative uncertainty and record it in the table.
For example, uncertainty = ± 0.05 g

$$\text{relative uncertainty} = \frac{\text{uncertainty value}}{\text{average value}} \times 100 = \frac{0.05\text{ g}}{2.50\text{ g}} \times 100 = 2\%$$

| Independent variable | Dependent variable | | | | | |
|---|---|---|---|---|---|---|
| | Initial mass (g) | Final mass (g) | Change in mass (g) | Uncertainty (± ____) | Relative uncertainty | Other observations |
| Reaction 1 | | | | | | |
| Reaction 2 | | | | | | |

**Analysis**

1 Describe the change in mass for each of the reactions using data.
2 Discuss possible reasons for a change in mass in the two reactions.
3 Relate these results back to the law of conservation of mass and discuss any discrepancies.
4 Discuss whether the experimental data supports the predicted outcome as shown in the chemical reactions above.

**Evaluation**

**Reliability**

1 Uncertainty is a measure of the variability in data. Describe the relative uncertainty for each of the groups.

**Limitations**

2 Identify possible limitations of this method.

**Improvements**

3 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

## Summary of representing reactions

Table 8.7 summarises three ways in which a chemical reaction can be represented.

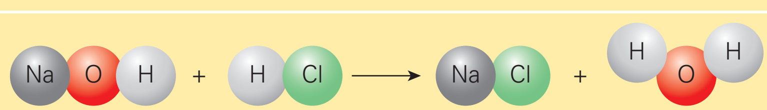
| Type | Example |
|---|---|
| Word equation | sodium hydroxide + hydrochloric acid → sodium chloride + water |
| Balanced chemical equation with state symbols | $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$ |
| Particle diagram |   |

**Table 8.7** Three ways a chemical equation can be represented

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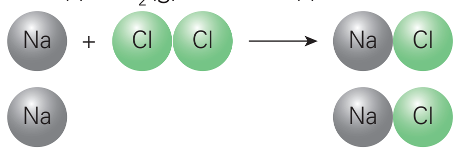
## Section 8.1 questions

QUIZ

### Retrieval

1 **Identify** the type of equation shown in the following examples.
   a Carbon + oxygen → carbon dioxide
   b $2\ Ca(s) + O_2(g) \rightarrow 2\ CaO(s)$
   c 




2 **Name** the state symbols that would represent the following substances.
   a Sodium chloride (salt) b Sulfuric acid c Water d Nitrogen

3 **Identify** which of the following molecules are diatomic.
   a $H_2O$ b $CO_2$ c $N_2$ d $F_2$

4 When sodium is reacted with water containing universal indicator, the water will turn purple as sodium hydroxide (an alkali) is produced. Hydrogen gas is also made.
   a **State** the reactants in the reaction. b **State** the products in the reaction. c **State** the word equation.

5 **Identify** the coefficients in the equations below.
   a $2\ Ca + O_2 \rightarrow 2\ CaO$ b $2\ Fe + 3\ Cl_2 \rightarrow 2\ FeCl_2$ c $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

### Comprehension

6 **Describe** the composition of copper(II) sulfate ($CuSO_4$) in terms of the number of each type of atom.

7 **Explain**, using the term 'conservation of mass', why it is important that chemical equations are balanced.

8 **Represent** different ways of writing a chemical reaction by completing the following for the reaction between solid calcium (Ca) and liquid bromine ($Br_2$) to form solid calcium bromide ($CaBr_2$).
   a Word equation
   b Balanced chemical equation with state symbols
   c Particle diagram

9 **Explain** why it is important to only change coefficients of formulas of substances in a chemical equation and not to change the subscripts.

10 **Balance** the following equation.
   $HNO_3 + Ca \rightarrow Ca(NO_3)_2 + H_2$

11 **Construct** a balanced symbol equation with state symbols for the reaction of potassium metal with oxygen to form solid potassium oxide ($K_2O$).

12 Electricity can be used to break down water ($H_2O$) into its constituent elements. There is no other reactant.
   a **Construct** a balanced symbol equation with state symbols to show this.
   b **Identify** how much more hydrogen is produced in this reaction compared to oxygen.

### Analysis

13 **Analyse** whether the unbalanced equation below has been balanced correctly. If it hasn't, write the correct balanced equation.
   Unbalanced: $H_2(g) + O_2(g) \rightarrow H_2O(l)$
   Balanced: $H_2(g) + O_2(g) \rightarrow H_2O_2(l)$

### Knowledge utilisation

14 **Decide** whether the following equations are balanced or unbalanced, and then correct the unbalanced equations.
   a $Ca + Br_2 \rightarrow CaBr_2$
   b $NaOH + HCl \rightarrow NaCl + H_2O$
   c $CuO + C \rightarrow Cu + CO_2$
   d $C_2H_6 + O_2 \rightarrow CO_2 + H_2O$
   e $Ag + H_2S + O_2 \rightarrow Ag_2S + H_2O$

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# 8.2 Types of chemical reactions

WORKSHEET
The reactivity series

**Learning goals**

1. To be able to identify a reaction type and predict the products.
2. To be able to write balanced chemical equations for synthesis, decomposition, metal displacement and precipitation reactions.
3. To be able to write balanced chemical equations for three types of neutralisation reactions.

This chapter will explore the five common types of chemical reactions:

- synthesis
- decomposition
- metal displacement
- precipitation
- neutralisation.

For these reactions, it is important that you can write balanced chemical equations and predict the products of the reaction.

## Synthesis reactions

**synthesis**
a reaction in which two (or more) elements or reactants combine to form new substances or products

The **synthesis** reaction (sometimes called combination) involves two or more elements or reactants combining to form one or more new substances or products. Synthesis reactions can be represented in this way:

$$A + B \rightarrow AB$$

where A and B are the reactants and AB is the product.

An everyday example of a synthesis reaction is rust forming on iron. Iron metal reacts with oxygen gas in the air to form rust, as shown in the following equations.

Word equation:

iron + oxygen → iron(III) oxide

Chemical equation:

$$4\ Fe + 3\ O_2 \rightarrow 2\ Fe_2O_3$$

This reaction can be classified as a synthesis reaction as two reactants combine to form one new product. Another example is the synthesis of sodium chloride (table salt) using sodium metal and chlorine gas reactants.

Word equation:

sodium + chlorine → sodium chloride

Chemical equation:

$$2\ Na + Cl_2 \rightarrow 2\ NaCl$$

Figure 8.6 Iron has rusted on this bicycle to form brown iron(III) oxide.

## Decomposition reactions

Reactions where one reactant breaks up into multiple products is called a decomposition reaction. Decomposition reactions are essentially the opposite of synthesis reactions and can be represented in this way:

$$AB \rightarrow A + B$$

where AB is the reactant and A and B are the products.

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## Explore! 8.2

### The hydrogen fuel cell

Hydrogen gas is considered a green or renewable fuel, and it can be combusted in oxygen gas to produce water and energy.
The chemical equation for this reaction is:
$2\ H_2\ (g) + O_2\ (g) \rightarrow 2\ H_2O + \text{energy}$

This is a synthesis reaction as two reactants combine to form one product. The reaction vessel is called a 'fuel cell'. The energy released from a fuel cell can be used to power vehicles using hydrogen fuel as a green alternative to petroleum combustion engines.


**Figure 8.7** A model Transdev hydrogen fuel cell bus which will use a synthesis reaction to release energy!

Transdev, a bus operator in Brisbane, has committed to manufacture two buses powered by hydrogen fuel cells to help achieve net zero emissions in the future – so look out for them in Brisbane!

For example, carbonic acid ($H_2CO_3$) is an ingredient in soft drinks. When you open a can of soft drink, the carbon dioxide that escapes is a result of a decomposition reaction that has occurred within the drink.

Word equation:

carbonic acid → water + carbon dioxide

Chemical equation:

$$H_2CO_3 \rightarrow H_2O + CO_2$$

Some compounds break down when heated in a reaction called **thermal decomposition**.

**thermal decomposition** decomposition that occurs when a substance is heated

## Did you know? 8.1

### Thermal decomposition of iron ore

Australia is a world leader in the export of iron ore, which contains iron oxides such as iron(III) oxide ($Fe_2O_3$). However, this compound needs to be reacted to produce pure iron metal that can be used in alloys such as stainless steel.

Iron smelting is a process in which iron oxides are heated with carbon (in the form of coal) in a blast furnace to decompose the iron oxides into iron metal and carbon dioxide. The word and balanced symbol equations for this reaction are shown below.

iron oxide + carbon → iron + carbon dioxide

$2\ Fe_2O_3 + 3\ C \rightarrow 4\ Fe + 3\ CO_2$

Smelting is not a clean process as coal has to be periodically shovelled into a blast furnace, and vast amounts of carbon dioxide are released into the atmosphere. Large amounts of energy are required to heat the furnace to over 1000°C.

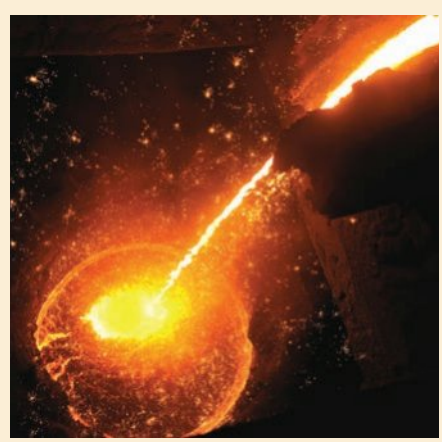

**Figure 8.8** Molten iron spews out of a blast furnace where iron ores are reacted with carbon to form pure iron metal.

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VIDEO
Properties of metals

**reactivity series**
a series of metals ordered by their observable reactivity, from highest to lowest

**displacement reaction**
when a more reactive metal removes a less reactive metal from its compound

## Metal displacement reactions

Metals can be ranked in terms of their observable reactivity in a list called the **reactivity series**. The reactivity series describes the observable reactivity (most likely in terms of rate of reaction) of some common metals with acids and cations. Table 8.8 shows the order of reactivity of some common metals in the periodic table.

| Metal | More reactive |
|---|---|
| Potassium (K) | ↑ |
| Sodium (Na) | |
| Calcium (Ca) | |
| Magnesium (Mg) | |
| Aluminium (Al) | |
| Zinc (Zn) | |
| Iron (Fe) | |
| Nickel (Ni) | |
| Tin (Sn) | |
| Lead (Pb) | |
| Copper (Cu) | |
| Silver (Ag) | |
| Gold (Au) | ↓ |
| | Less reactive |

**Table 8.8** A reactivity series of common metals

The reactivity series shows that tin is more reactive than lead and that zinc is more reactive than gold, for example.

Potassium is the most reactive metal listed, while gold is the least reactive metal listed.

Using the reactivity series, you can predict the outcome of a particular type of reaction involving these metals, called a metal **displacement reaction**. In a displacement reaction, an ion of a more reactive metal will displace (remove or replace) an ion of a less reactive metal from a solution of its compound. The following is an example:

copper sulfate + iron → iron(II) sulfate + copper

$$CuSO_4 + Fe \rightarrow FeSO_4 + Cu$$

In this reaction, because iron is more reactive than copper, the iron atom loses two electrons to form an $Fe^{2+}$ ion and it displaces (or removes) the copper ion ($Cu^{2+}$) from its compound. The iron ion ($Fe^{2+}$) joins with the sulfate ion ($SO_4^{2-}$) and the $Cu^{2+}$ ion gains two electrons to form copper metal.

So what happens when the metal on its own is less reactive than the metal in the compound?

zinc sulfate + tin → X

$$ZnSO_4 + Sn \rightarrow X$$

In this case there is no reaction. Tin is not reactive enough because it is lower in the reactivity series than zinc, so it cannot remove the zinc from its compound.

### Quick check 8.6

1 Decide whether the following statements are true or false. If false, give a reason why.
   a Potassium is the most reactive metal in the reactivity series shown in Table 8.8.
   b Silver is less reactive than gold.
   c Group 1 metals are the most reactive in the reactivity series.
2 Name the only group 13 element in the reactivity series shown in Table 8.8.

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## Investigation 8.2

### Metal displacement reactions

**Be careful**

To avoid risk of contamination from chemicals:

- wear safety glasses and appropriate personal protective equipment at all times
- wash your hands after the practical.

**Aim**

To determine the order of reactivity of metals by the outcome of displacement reactions.

**Prior understanding**

The periodic table was originally developed by grouping together elements that share common physical and chemical properties. The periodic table reveals trends and patterns of chemical properties (such as reactivity) that are determined by the underlying structure of each element.

You will investigate the reactivity of metals using displacement reactions. This is a type of reaction involving a metal salt solution (a metal salt is a compound made from a combination of a metal and a non-metal) and a pure metal. Pure metals with a higher reactivity than the metal within the salt solution will react and 'push out' (displace) the metal that is within the salt solution, forcing the less reactive metal into its pure element form.

**Materials**

- 3 pieces of each metal (zinc, magnesium, copper)
- 1 dropper bottle of zinc nitrate
- 1 dropper bottle of magnesium nitrate
- 1 dropper bottle of copper(II) nitrate
- dimple tile or spotting tile

**Planning**

1. Write a brief rationale that explains the factors that affect a metal's reactivity and the purpose of the reactivity series. You may want to talk about atomic radius or valence electrons.
2. Develop a hypothesis using the reactivity series as to how the position of a metal in the reactivity series will affect its reactivity with a metal lower in the series.
3. Draw a results table that will allow you to collect sufficient data.

**Method**

1. Add 3 drops of copper(II) nitrate to 4 dimples in a row, as shown in Figure 8.9.
2. Add 3 drops of magnesium nitrate to 4 dimples in a row.
3. Add 3 drops of zinc nitrate to 4 dimples in a row.
4. Add a piece of the first test metal to each dimple in the second column and record your observations in the results table.

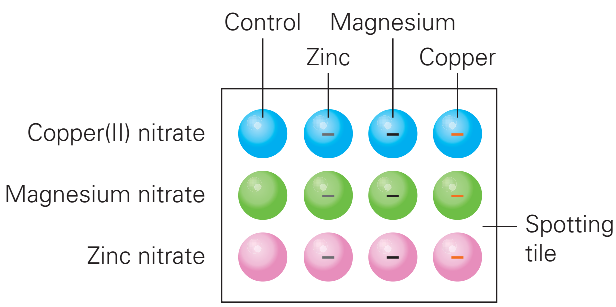


**Figure 8.9** Arrangement of solutions on dimple tile

5. Repeat step **4** for each of the other 2 test metals, placing them in the third and fourth columns of dimples.

*continued …*

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*continued …*

**Analysis**

1. Describe the observations you used to determine whether a displacement reaction had taken place.
2. Identify the reactions that did not show displacement. What can you conclude from this result?
3. Write word equations for each of the successful displacement reactions.

**Conclusion**

Draw a conclusion regarding the order of reactivity of the elements in the investigation. Justify your answer with data.

### Quick check 8.7

1. For the following mixtures of metals and metal compounds, state whether a reaction will occur.
   a. Iron(II) chloride + nickel
   b. Copper(II) sulfate + zinc
   c. Iron(II) sulfate + aluminium
   d. Sodium sulfate + gold
2. Describe the term 'metal displacement reaction'.

## Neutralisation reactions

The metal reactivity series can also describe the observable reactivity of metals with acids. Before we learn about that reaction, it is important to know how to write the formula of a common product of acid–metal reactions, a salt. A salt will be one of the products formed in all reactions involving acids, which here will be called 'neutralisation reactions' because an acid is used up, or neutralised, in the reaction.

In chemistry, a **salt** is a substance that forms when acids react with metals, bases or metal carbonates. Salts are generally made up of metals and non-metals. You need to be able to predict the name of the salt formed when acids react with metals, bases and metal carbonates. The type of acid used affects the name of the salt. Table 8.9 summarises the type of salt formed when different acids react.

| Type of acid | Type of salt |
|---|---|
| Hydrochloric acid | Chloride |
| Nitric acid | Nitrate |
| Sulfuric acid | Sulfate |
| Phosphoric acid | Phosphate |
| Ethanoic acid | Ethanoate |

**Table 8.9** A summary of the type of salt formed when different acids react

The other reactant in acid reactions will be, or contain, a metal. For example, the base called sodium hydroxide contains the metal sodium, and the carbonate called calcium carbonate contains the metal calcium. The reactant other than the acid provides us with the first name of the salt. The type of acid provides the second name of the salt. Table 8.10 summarises how to predict the name of a salt produced in reactions that involve acids.

**salt**
a product formed when an acid reacts with a metal, base or carbonate; generally made up of metals and non-metals

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| Reactant 1 | Metal present | Reactant 2: type of acid | Type of salt | Name of salt |
|---|---|---|---|---|
| Magnesium (metal) | Magnesium | Hydrochloric acid | Chloride | Magnesium chloride |
| Calcium hydroxide (base) | Calcium | Nitric acid | Nitrate | Calcium nitrate |
| Sodium carbonate (carbonate) | Sodium | Sulfuric acid | Sulfate | Sodium sulfate |

**Table 8.10** Examples of how to name the salt produced in the three types of acid reactions

**Quick check 8.8**

1 Name the salt produced when calcium carbonate reacts with sulfuric acid.
2 Describe the two rules for naming a salt.

## Acid–metal reactions

Acid–metal reactions occur when an acid reacts with a metal to produce a salt and hydrogen ($H_2$). The hydrogen produced in the reaction can be identified using a simple squeaky pop test. In that test, when a flame is placed near the gas produced, a 'squeaky pop' will be heard as evidence that the gas produced is hydrogen.

The general word equation for any acid reacting with any metal is:

acid + metal → salt + hydrogen

When hydrochloric acid reacts with magnesium, the salt magnesium chloride is formed, and the other product in the reaction is hydrogen:

hydrochloric acid + magnesium → magnesium chloride + hydrogen

Remember that the first part of the salt name comes from the metal and the second part comes from the type of acid used. Hydrogen is produced no matter what the acid or metal is. These acid–metal reactions can also be described by looking at the reactivity table (Table 8.8). The least reactive metals (gold, silver, copper, platinum) do not react with dilute acids, and there is no visible reaction.

The reaction between acids and metals is a problem in everyday life. There is acid in rain, and this can cause damage to the many buildings made of metals.

**Figure 8.10** The orange toxic water produced here is due to the reaction of acid rain with the metal in this abandoned mine.

**Quick check 8.9**

1 What is the general word equation for when any metal reacts with any acid?
2 List four metals that do not react with dilute acids.
3 Complete the word equation below.
nitric acid + ______ → zinc ______ + hydrogen

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## Practical skills 8.1

### Reaction of acids with metals

> **Be careful**
> Wear appropriate personal protective equipment.

**Aim**

To observe what happens when metals react with acids.

**Materials**

- 1 mol $L^{-1}$ dilute hydrochloric acid
- 0.5 mol $L^{-1}$ dilute sulfuric acid
- small granules of copper, zinc, magnesium and iron
- 8 test tubes
- test-tube rack
- 4 rubber stoppers to fit the test tubes
- wooden splints
- Bunsen burner

**Method**

1. Copy the results tables into your science journal.
2. Place the 8 test tubes in the test-tube rack.
3. In 4 of the test tubes, add 2–3 cm depth of hydrochloric acid.
4. In the other 4 test tubes, add 2–3 cm depth of sulfuric acid.
5. To each of the hydrochloric acid test tubes, add a different type of metal. Place a rubber stopper loosely in the top of the test tube and note your observations. NOTE: Ensure all metal samples have been cleaned before adding them to the acid. Also note that the reaction between the acid and metals may be rather slow and not produce enough hydrogen gas to cause a pop.
6. After about 30 seconds, light a wooden splint, remove the stopper and hold the flame to the mouth of the test tube. Again, record your observations.
7. Add the same types of metal to the test tubes containing sulfuric acid, place a rubber stopper in the top of the test tubes and note your observations.
8. After about 30 seconds, light a wooden splint, remove the stopper and hold the flame to the mouth of the test tube. Again, record your observations.

**Results**

Reactions with hydrochloric acid

| Metal | Observations | Hydrogen produced? |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

Reactions with sulfuric acid

| Metal | Observations | Hydrogen produced? |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

**Analysis**

1. Discuss which of the metals reacted with the hydrochloric and sulfuric acids. How did you know?
2. Write word equations for each of the reactions you carried out in this practical.
3. State what happened to some of the reactions when the lit splint was put at the mouth of the test tube.
4. Explain what this experiment tells you about the reactivity of metals.
5. During this reaction, you may have felt the temperature of the reaction increase. Recall the name of this type of reaction.

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## Acid–base reactions

Acid–base reactions occur when any acid reacts with any base to produce a salt and water. Notice that a salt is produced, just like in acid–metal reactions, but instead of hydrogen being the other product, water is made. A base is a substance that typically contains an oxide ($O^{2-}$) or hydroxide ($OH^-$) anion. Bases that can dissolve in water (alkalis) tend to be bitter and feel soapy on the skin. Common bases that you may have in your house are hand soap and oven cleaner. Bases that you will come across in your science laboratory include sodium hydroxide, calcium hydroxide and magnesium hydroxide.

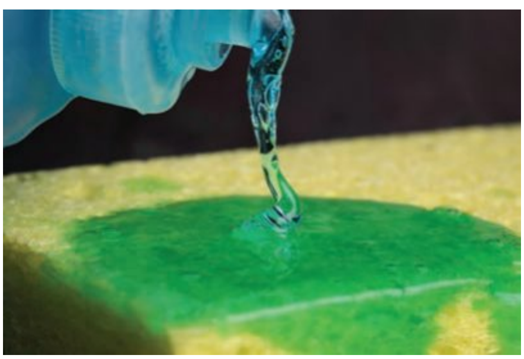

**Figure 8.11** Washing-up liquid is an example of a household base.

The general word equation for any acid reacting with any base is:

acid + base → salt + water

For example, when nitric acid reacts with sodium hydroxide, the salt sodium nitrate is formed:

nitric acid + sodium hydroxide → sodium nitrate + water

If you are unsure why this is the name of the salt, go back to the start of this section and remind yourself of the rules for naming salts.

Acid–base reactions are also known as **neutralisation** reactions. This is because when acids and bases with the same volume and concentration react, they make a neutral solution (pH 7). Soothing indigestion with an antacid and a wasp sting with vinegar are examples of common neutralisation reactions.

**neutralisation**
a reaction between an acid and a base, forming a solution that has a pH of 7

**Figure 8.12** A wasp sting injects a base into human skin!

### Quick check 8.10

1. What is the general word equation for when any base reacts with any acid?
2. Identify the name for a reaction between an acid and a base.
3. Complete the word equation below.

   sulfuric acid + _______ → iron _______ + water

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## Practical skills 8.2

### Reaction of acids with bases

**Be careful**
Wear appropriate personal protective equipment.

**Aim**
To observe what happens when acids react with bases.

**Materials**
- 0.5 mol $L^{-1}$ hydrochloric acid
- 0.5 mol $L^{-1}$ sodium hydroxide
- 250 mL beaker
- 25 mL measuring cylinder
- dropping pipette
- stirring rod
- universal indicator paper for checking pH and colour chart (full range)
- spotting tile
- pH meter

**Method**
1. Copy the results table into your science journal.
2. Using a 25 mL measuring cylinder, measure 25 mL of hydrochloric acid and add to the 250 mL beaker.
3. Add a small piece of universal indicator paper to each of the 6 hollows on the spotting tile.
4. Using the stirring rod, add a drop of the acid onto one of the pieces of universal indicator paper on the spotting tile and record the pH in your table.
5. Measure the pH of the acid in the beaker using the pH meter and record it in your table.
6. Using the 25 mL measuring cylinder, measure 5 mL of sodium hydroxide and add this to the beaker containing the acid.
7. Repeat steps **4** and **5**, recording your results in the results table.
8. Now add 5 mL of sodium hydroxide and repeat steps **4** and **5**. Record the result against the total volume of sodium hydroxide added. Continue these steps until the table is complete.

**Results**

| Volume of sodium hydroxide (mL) | pH using universal indicator paper | pH using digital meter |
|---|---|---|
| 0 | | |
| 5 | | |
| 10 | | |
| 15 | | |
| 20 | | |
| 25 | | |

**Analysis**
1. Describe what happened to the pH as you gradually added more and more base.
2. Identify the type of reaction that you carried out in this experiment.
3. Write a word equation for the reaction that you investigated.

**Evaluation**
1. Compare the differences in the readings from the universal indicator and the pH meter. Which one is more accurate and why?
2. To demonstrate this type of reaction, explain why it is important to use the same concentration and volume of the acid and base.

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## Acid–carbonate reactions

Acid–carbonate reactions occur when any acid reacts with any metal carbonate ($CO_3^{2-}$, e.g. $CaCO_3$) or metal hydrogen carbonate ($HCO_3^-$, e.g. $Ca(HCO_3)_2$) to produce a salt, water and carbon dioxide. As with acid–metal and acid–base reactions, a salt is produced, but the other products are different. You can test for the presence of carbon dioxide produced in an acid–carbonate reaction by bubbling the gas through limewater. Limewater goes from colourless to milky white in the presence of carbon dioxide.

The general word equation for any acid reacting with any carbonate or hydrogen carbonate is:

acid + metal hydrogen carbonate → salt + water + carbon dioxide

When sulfuric acid reacts with calcium carbonate or calcium hydrogen carbonate, the salt calcium sulfate is formed:

sulfuric acid + calcium hydrogen carbonate → calcium sulfate + water + carbon dioxide

If you are unsure why this is the name of the salt, go back to the start of this section and remind yourself of the rules for naming salts.

As a balanced chemical equation, the reactions with calcium carbonate (Eq. 1) or calcium hydrogen carbonate (Eq. 2) can be described as follows:

$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + H_2O + CO_2$ Equation 1

$H_2SO_4 + Ca(HCO_3)_2 \rightarrow CaSO_4 + 2\ H_2O + 2\ CO_2$ Equation 2

## Precipitation reactions

Chemical reactions that involve the mixing of two solutions to produce a solid are called **precipitation** reactions. This is because the solid that is formed is a called a precipitate. These solids are insoluble, which means they are unable to dissolve in water. Precipitates are often very colourful, and some are used as pigments in paint.

**precipitation**
a reaction that involves the mixing of two solutions to produce a solid called a precipitate

For example, when a blue solution of copper(II) nitrate and a colourless solution of potassium hydroxide are added together, a blue precipitate, copper(II) hydroxide, forms. This observation is depicted in Figure 8.13.

Word equation:

copper(II) nitrate + potassium hydroxide → copper(II) hydroxide + potassium nitrate

Chemical equation:

$Cu(NO_3)_2 + 2\ KOH \rightarrow Cu(OH)_2 + 2\ KNO_3$

Figure 8.13 A blue solution is added to a colourless solution to form a blue precipitate in a colourless solution.

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QUIZ

## Section 8.2 questions

**Retrieval**

1 **Name** five types of chemical reactions.
2 **Recall** the general equation for a decomposition reaction.
3 **Write** a balanced equation for the decomposition of calcium carbonate ($CaCO_3$) to calcium oxide (CaO) and carbon dioxide ($CO_2$).

**Comprehension**

4 **Write** a balanced equation for the reaction of lead(II) nitrate ($Pb(NO_3)_2$) and sodium iodide (NaI) to form the yellow solid lead(II) iodide ($PbI_2$) and sodium nitrate ($NaNO_3$).
5 **Predict** the products of the reaction between sulfuric acid ($H_2SO_4$) and sodium hydroxide (NaOH).

**Analysis**

6 **Discuss** whether an acid–carbonate reaction should be considered a neutralisation reaction.
7 **Explain** the importance of the synthesis reaction that takes place in a hydrogen fuel cell.

**Knowledge utilisation**

8 **Write** a balanced chemical equation for the metal displacement reaction of lead (Pb) with silver nitrate ($AgNO_3$).
9 **Write** a balanced chemical equation for the reaction of calcium metal (Ca) with nitric acid ($HNO_3$).

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# 8.3 Reactions that make useful products

**Learning goals**

1. To explore useful chemical reactions to produce polymers, ethanol and sulfuric acid.
2. To be able to describe how First Nations Australians used pyrolysis and fermentation reactions to produce useful products.

DOC WORKSHEET Making plastics

Chemical reactions produce a large variety of different products. The chemical industry is involved in producing almost all substances that do not occur in vast quantities naturally.

In this section, you will explore some useful products that are created using chemical reactions.

## Making thinking visible 8.1

**Chalk talk: useful chemical reactions**

*Chemical reactions are used to make useful products that humans use every day.*

1 What ideas and examples come to mind when you read the above statement?

2 Share your ideas with a partner.

3 Which of your ideas connect with your partner's responses?

4 What questions do you have after considering your partner's responses?

The *Chalk talk* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education

## Explore! 8.3

**Pyrolysis**

Pyrolysis describes the burning of plant matter in a low-oxygen environment. You have likely seen this type of chemical reaction in action when watching a campfire and a dark smoke appears. While the surface of the wood has a lot of oxygen to burn, the inside of the wood is still burning but is in a low-oxygen environment. Groups of First Nations Australians use the pyrolysis reaction for a variety of cultural purposes, including for medicine.

**Figure 8.14** Groups of First Nations Australians in Central Australia pyrolyse biomass in the form of twigs and leaves as a source of calcium oxide.

In Central Australia, First Nations Australians of the area pyrolyse the plant matter of a plant species known to have a high calcium content. The calcium is converted to calcium oxide in the pyrolysis and collected in the resulting ashes. These ashes are then combined with the leaves of a medicinal plant for chewing. The calcium oxide enhances the release of the medicinal chemicals from the plant leaves, creating a very effective medicine.

This is only one example of how pyrolysis is used traditionally by First Nations Australians. Explore some other ways that different groups of First Nations Australians traditionally use the pyrolysis chemical reaction using appropriate sources for research.

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## Plastic from crude oil

Plastics are an integral part of our everyday lives. They form the wrap used on sandwiches and the pen that you use to write with in school, to name only two uses. Plastics are incredibly useful, but because they do not biodegrade readily they are harmful to the environment when they are not disposed of correctly.

**catalyst**
a substance that speeds up a chemical reaction by lowering the energy needed to break and form bonds (activation energy), and does not get used up in the process

VIDEO
Fractional distillation – crude oil

### Explore! 8.4

**Recycling symbols**

Plastics can be classified in seven different ways from a recycling perspective. Research the meaning of the seven different recycling symbols found on plastic products.

Plastics are made from individual chemical units called monomers joined together to make a giant molecule called a polymer. The reaction that joins them is known as polymerisation. The polymers are then modified to form plastics with different properties. Polyethene (also known as polyethylene, abbreviated PE) is used to make plastic shopping bags and is one of the most common plastics used today. It is made by reacting ethene (also known as ethylene) monomers obtained from crude oil. Under high temperatures and pressures, and with the help of a **catalyst** to speed up the reaction, these ethene monomers join together to form PE (Figure 8.16). Note how the single ethene molecule (the monomer) has a double bond between the two carbon atoms: this molecule is said to be unsaturated. When the ethene molecules join together, the double bond is broken and the carbon atoms instead share an electron with the ethene molecule to either side, forming the polymer named polyethene.

Figure 8.15 Plastic waste is harmful to the environment.

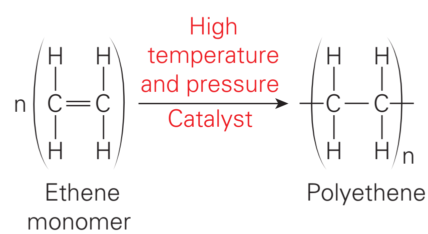


**Figure 8.16** Many ethene monomers join together to make a long-chain polymer called polyethene. The 'n' in the diagram relates to any number of ethene monomers joining together to make a polymer of any length.

Many other polymers, such as polyvinylchloride (PVC) and polyester, a synthetic fibre, are formed using similar methods. PVC has many applications, including credit cards, toys, pipes and shower curtains. Polyester is used in car tyres, clothing and pillow stuffing. Notice that the name of a polymer is often the monomer name with a prefix of 'poly'. This system of naming is consistent across a range of addition polymers, so the polymer name is easy to predict from its monomer.

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## Science as a human endeavour 8.1

**Ultra-high-molecular-weight polyethylene (UHMWPE) body armour**

Polymers can be manufactured for the development of super strong but lightweight ballistic (bullet-resistant) body armour. In fact, polyethene has been synthesised by reaction of ethene monomers under conditions that create a substance known as ultra-high-molecular-weight polyethene (UHMWPE) that has the strength to stop bullets! In recent years, scientists have also been experimenting with combining plates of stainless steel alloys with UHMWPE polymer to create even stronger materials for armour used in the military and by police.

**Figure 8.17** Could UHMWPE body armour be used by Australian police?

## Quick check 8.11

1 What is the name of the monomer used to make polyethene?
2 What is the name of the polymer made from combining methyl methacrylate monomers?
3 Why are plastics called polymers?

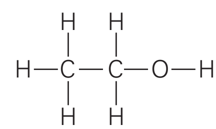


**Figure 8.18** The structure of ethanol. The O-H functional group in the molecule makes ethanol an alcohol (think alc**OH**ol, to memorise the functional group).

## Fermentation to produce ethanol

Many Australian drivers can now purchase petrol that contains a certain percentage of bioethanol. Alcohols such as ethanol contain carbon, hydrogen and oxygen. Bioethanol is added to petrol because it produces heat energy when burned but burns more 'cleanly' than petrol does, releasing fewer smog-producing chemicals. Also, bioethanol is more sustainable than fossil fuels as the car is burning bioethanol made from plant matter that has recently taken up carbon dioxide in photosynthesis, which balances out the carbon dioxide emitted.

Recently grown and decayed plant material can be fermented to produce ethanol that can be burned as a **biofuel**. During fermentation, yeast (a microorganism) breaks down glucose (sugars) in the absence of oxygen to produce ethanol and carbon dioxide, shown in the following reaction.

**biofuel**
a fuel that comes from living materials

glucose → ethanol + carbon dioxide

$$C_6H_{12}O_6\,(aq) \rightarrow 2\ C_2H_5OH\,(l) + 2\ CO_2\,(g)$$

This process is not only used to manufacture biofuels but also used to produce alcoholic beverages such as beer and wine.

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## Did you know? 8.2

**Fermentation of cycad seeds**

When James Cook's fleet arrived in Australia in 1770, many of his crew became very ill after consuming the toxic seeds of the cycad plant. Many First Nations Australians, particularly those most in contact with the cycad plant in north Queensland, had already mastered the detoxification processes of the seeds. Processes include grinding and washing the seeds with water to remove soluble toxic chemicals and fermenting the seeds by allowing mould to grow on them, which breaks down the toxic chemicals. These techniques allow First Nations Australians of the area to prepare meals from the seeds without harm from toxic chemicals.

**Figure 8.19** Seeds of a cycad plant (*Macrozamia moorei*) in northern Queensland

## Quick check 8.12

1. Name the microorganism needed to break down sugars in fermentation.
2. Name the fuel that is made by fermenting sugars.

## Making sulfuric acid

Sulfuric acid is one of the most important compounds made in the chemical industry. It is used to make hundreds of other useful compounds, such as fertilisers, paints and paper.

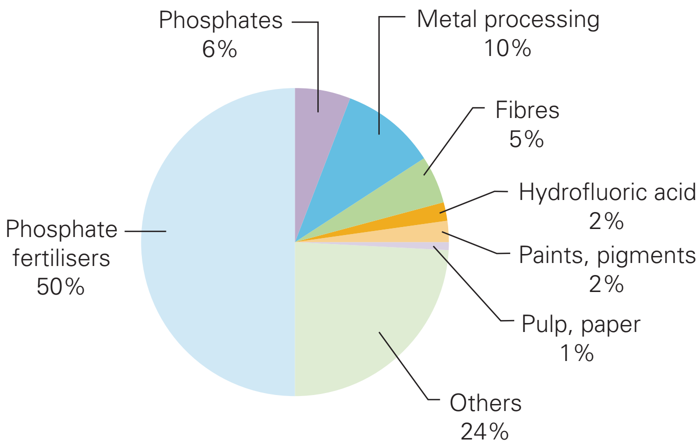


**Figure 8.20** Sulfuric acid is required for the production of many substances.

To make sulfuric acid, sulfur is combusted in oxygen to make sulfur dioxide. The sulfur dioxide is then further combusted in oxygen, in the presence of a catalyst, to make sulfur trioxide, which then reacts with water to produce sulfuric acid. The final chemical reaction step of the procedure is shown below:

$$\text{sulfur trioxide} + \text{water} \rightarrow \text{sulfuric acid}$$

$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$$

## Quick check 8.13

1. State two uses for sulfuric acid.
2. Name the reactants used in the final reaction which produces sulfuric acid.

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## Section 8.3 questions

QUIZ

**Retrieval**

1 **State** the raw material used to make plastics.
2 **Recall** the elements and molecules used to produce sulfuric acid.
3 **Recall** the elements present in all alcohols.

**Comprehension**

4 **Summarise** what happens when ethene monomers are reacted under high temperatures and pressures with a catalyst.
5 **Describe** how you could model polymerisation using paperclips.
6 **Describe** a use of the fermentation reaction as used by groups of First Nations Australians to prepare useful products.

**Analysis**

7 **Analyse** the importance of the chemical industry in producing the substances that have been discussed in this section.
8 **Explain** how different First Nations Australians' cultural knowledge of pyrolysis reactions is used to prepare effective medicines.

**Knowledge utilisation**

9 **Evaluate** the advantages and disadvantages of biofuels produced by fermentation.
10 **Decide** whether making plastics from crude oil is a sustainable process.

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# 8.4 Rate of a chemical reaction

WORKSHEET
Factors affecting reaction rates

**Learning goals**

1. To be able to calculate the reaction rate of a chemical reaction.
2. To be able to describe how six factors affect the frequency of collisions between reacting particles.
3. To be able to describe how six factors affect the rate of a chemical reaction.
4. To be able to define the role of a catalyst in a chemical reaction.

## Reaction rate

**reaction rate**
the quantity of reactant or product used up or made per unit of time; how quickly the reaction progresses

**surface area**
the area of the outer part or surface of an object

How quickly a reaction progresses towards completion is described by the term **reaction rate**. The reaction rate for a chemical reaction can be calculated by measuring the quantity of a reactant used or the quantity of product formed over time.

$$\text{reaction rate} = \frac{\text{quantity of reactant used up}}{\text{time}}$$

$$\text{reaction rate} = \frac{\text{quantity of product formed}}{\text{time}}$$

The quantity of a reactant or product can be measured by the mass (in grams) or volume (in millilitres), and the time should be measured in units of seconds. Therefore, the units for rate of reaction may usually be given as g $s^{-1}$ or mL $s^{-1}$. In some cases, when a quantity of reactant or product has not been measured, a reaction rate can be calculated just from the time taken for the reaction to go to completion.

$$\text{reaction rate } (s^{-1}) = \frac{1}{\text{time (s)}}$$

In any case, the faster a product forms, a reactant is used up or the reaction goes to completion, the greater the rate of reaction.

### Practical skills 8.3

**Monitoring reaction rates**

**Be careful**
Wear appropriate personal protective equipment.

**Aim**
To determine how the surface area of zinc affects the rate of reaction with nitric acid, by using the upturned measuring cylinder technique.

**Prior understanding**
Although you are changing the mass of zinc in this experiment, you are actually changing the **surface area** of the metal. In this experiment, the nitric acid is in excess relative to each of the masses of zinc. That is, there will always be more than enough nitric acid to completely react with all of the zinc. So, by increasing the mass of zinc, you are effectively increasing the surface area. By measuring the volume of gas produced after 1 minute, the effect of increasing the surface area of zinc on the reaction rate can be determined.

*continued …*

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**Materials**

- zinc powder
- nitric acid (2 mol $L^{-1}$)
- 25 mL measuring cylinder
- 50 mL measuring cylinder
- 250 mL conical flask
- large bowl or container
- bung and delivery tube
- weighing boat
- bosshead and clamp
- electronic balance
- stopwatch

**Planning**

Write a hypothesis for your investigation regarding the effect that the mass of zinc will have on the rate of the reaction.

**Method**

1. Copy the results table into your science journal.
2. Half fill the large bowl or container with water.
3. Fill a 50 mL measuring cylinder with water and carefully invert it in the large bowl of water. Do not lose any water out of the measuring cylinder.
4. Clamp the measuring cylinder in place using a bosshead and clamp.
5. Using the 25 mL measuring cylinder, measure 20 mL of 2 mol $L^{-1}$ nitric acid and pour the acid into the conical flask.
6. Using the electronic balance, measure 0.5 g of zinc powder into a weighing boat.
7. Set up the delivery tube so the end without the bung runs underneath and into the upturned measuring cylinder (see Figure 8.21 to help you).
8. Pour the zinc powder into the conical flask containing the acid. At the same time, put the bung on top of the flask and start the stopwatch.
9. After 1 minute, record the volume of water displaced from the measuring cylinder. This is the same as the volume of gas produced.
10. Repeat once more with the same mass of zinc powder.
11. Repeat the steps for the other masses of zinc powder.

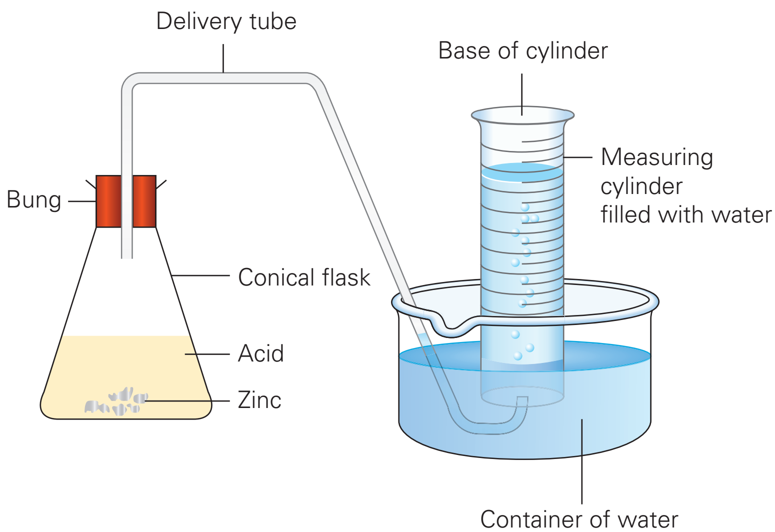


**Figure 8.21** Diagram showing how to set up an upturned measuring cylinder to monitor reaction rate

*continued …*

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*continued …*

**Results**

| Mass of zinc (g) | Volume of gas collected after 1 minute (mL) | | |
|---|---|---|---|
| | Trial 1 | Trial 2 | Mean |
| 0.50 | | | |
| 1.00 | | | |
| 1.50 | | | |
| 2.00 | | | |

**Evaluation**

1 Calculate the mean volume of gas released for each mass of zinc.
2 List the independent and dependent variables in this investigation.
3 Give 3 controlled variables.
4 Plot a graph with mass on the *x*-axis and volume of gas on the *y*-axis.
5 What does your graph tell you about the relationship between the mass (that is, surface area) of zinc and reaction rate?
6 Write a balanced chemical equation with state symbols for the reaction between zinc metal (Zn) and nitric acid ($HNO_3$) to form zinc nitrate ($Zn(NO_3)_2$) and hydrogen ($H_2$).
7 List other methods you could have used to monitor the rate of this reaction.

**Conclusion**

1 Make a claim about the effect of the surface area of zinc on the rate of the reaction in this experiment.
2 Support your statement by using the data you gathered and include potential sources of measurement uncertainties or experimental faults.
3 Explain how the data supports your statement.

**collisions**
the violent coming together of two or more particles; a requirement for a chemical reaction to occur

**activation energy**
the minimum collision energy required to break and form bonds

## Factors that affect the rate of reaction

In the chemical manufacturing industry, it is important to know how to change the reaction rate of chemical reactions to ensure the most efficient, cost-effective and time-effective method is being used.

For a chemical reaction to occur, reactant particles must collide with one another to cause bonds to break and new bonds to form. However, not all **collisions** are 'successful' in forming new products. This is because bonds will only break if the reactant particles collide with at least a certain level of energy, called the **activation energy**, which is unique to each chemical reaction. The activation energy is the minimum energy required to break bonds in the reactants so they are able to form new bonds and make the products. To increase the rate of reaction, it is important to increase the frequency of collisions and/or increase the proportion of particles that reach the activation energy for a successful collision to occur. Six factors can affect chemical reactions in these ways, and they will be explored here.

**Quick check 8.14**

1 State two requirements for a successful chemical reaction.
2 Define the term 'activation energy'.

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**Figure 8.22** Industrial chemical plants rely on knowledge of reaction rates to produce maximum amounts of product in minimal amounts of time.

## Concentration

The **concentration** of a solution is a measure of the number of particles per unit volume. It is usually measured as moles per litre (mol $L^{-1}$), where moles are a measure of the amount of solute. You may also see these units written as a capital M, which is the same as mol $L^{-1}$.

A solution which contains a high number of solute particles within a given volume of solvent is called a **concentrated solution**. In contrast, a solution which contains a low number of solute particles within a given volume of solvent is called a **dilute solution**. Increasing the concentration of a solution means that there are more particles per unit volume.

If the concentration of a solution is increased, the particles are more likely to collide each second; there will be more frequent collisions and the reaction rate will increase.

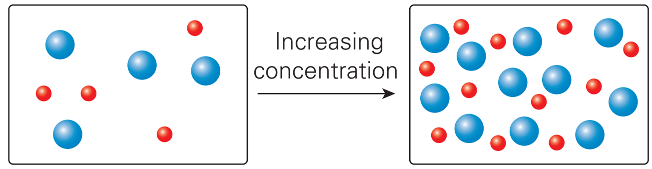


**Figure 8.23** Increasing the concentration of a solution increases the number of particles within the same volume, increasing the frequency of potential collisions between particles.

Although increasing the concentration increases the frequency of collisions, it does not affect the activation energy. Particles still need to collide with the same activation energy for collisions to be successful. However, as collisions are occurring more frequently, successful collisions will also occur more frequently.

**concentration**
the amount of substance in a given volume

**concentrated solution**
a solution which contains a relatively large amount of solute compared to solvent

**dilute solution**
a solution which contains a relatively small amount of solute compared to solvent

### Quick check 8.15

1 Decide whether the following statements are true or false. If false, state a reason why.
   a A dilute solution contains few reactant particles in a given volume.
   b Increasing the concentration of a reactant decreases the activation energy needed for collisions.

WORKSHEET How does concentration affect reaction rate?

### Practical skills 8.4

**Concentration and reaction rate**

**Aim**

To determine how changing the concentration of sodium thiosulfate affects the rate of reaction with hydrochloric acid.

**Materials**

- hydrochloric acid (2 mol $L^{-1}$)
- sodium thiosulfate solution (0.15 mol $L^{-1}$)

**Be careful**

Wear appropriate personal protective equipment.
This experiment must be performed in a fume hood.
Do not breathe in fumes when making observations.

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- 250 mL conical flask
- 10 mL measuring cylinder
- 50 mL measuring cylinder
- stirring rod
- piece of white paper
- black marker pen
- stopwatch

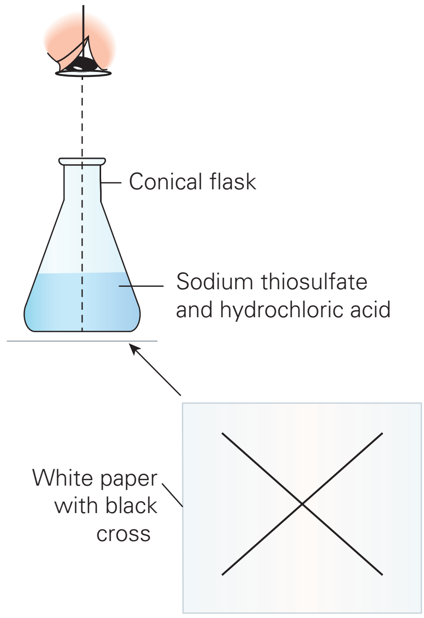


**Figure 8.24** Diagram of centring the 'X' under the conical flask

### Planning

Construct a hypothesis regarding how the sodium thiosulfate concentration will affect the reaction rate.

### Method

1. Copy the results table into your science journal.
2. Using the black marker, draw a large 'X' on the white paper.
3. Using a 50 mL measuring cylinder, measure 50 mL of sodium thiosulfate and pour it into the 250 mL conical flask. In the fume hood, centre the conical flask on the black cross (Figure 8.24).
4. Using the 10 mL measuring cylinder, measure 5 mL of hydrochloric acid.
5. Pour the acid into the conical flask, stir with a stirring rod and start the stopwatch.
6. Stop timing when the cross is no longer visible and record the time in your results table.
7. If available, dispose of the reaction mixture in a fume cupboard, otherwise pour it down the sink, rinsing with lots of cold water (taking care not to splash).
8. Repeat the steps for each concentration of sodium thiosulfate in the results table. The concentration of the sodium thiosulfate you add does not change (it is 0.15 mol $L^{-1}$); however, adding water dilutes the solution.

### Results

| Concentration of sodium thiosulfate (mol $L^{-1}$) | Volume of sodium thiosulfate (mL) | Volume of water (mL) | Time taken for cross to disappear (s) | Reaction rate $\frac{1}{\text{time}}$ ($s^{-1}$) |
|---|---|---|---|---|
| 0.15 | 50 | 0 | | |
| 0.12 | 40 | 10 | | |
| 0.09 | 30 | 20 | | |
| 0.06 | 20 | 30 | | |
| 0.03 | 10 | 40 | | |

### Processing data

1. Work out the relative rate of the reaction by calculating: $\frac{1}{\text{reaction time}}$
2. Plot a graph of concentration (*x*-axis) versus rate (*y*-axis).

### Analysis

1. Using your graph, describe how increasing the concentration of sodium thiosulfate affects the rate of this chemical reaction.
2. Explain why increasing the concentration of a reactant normally increases the rate of reaction.
3. Explain why the disappearing cross method was suitable for this reaction, using the equation below:

$$Na_2S_2O_3(aq) + 2\,HCl(aq) \rightarrow S(s) + SO_2(g) + 2\,NaCl(aq) + H_2O(l)$$

### Conclusion

1. State a conclusion regarding the concentration of sodium thiosulfate and the effect this has on the rate of reaction.
2. Support your statement by using the data you gathered.

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## Pressure

To increase the **pressure** of gaseous particles you can increase the number of particles and/or decrease the volume of the container.

Gaseous particles under high pressure are more likely to collide more frequently as there are more particles per unit of volume.

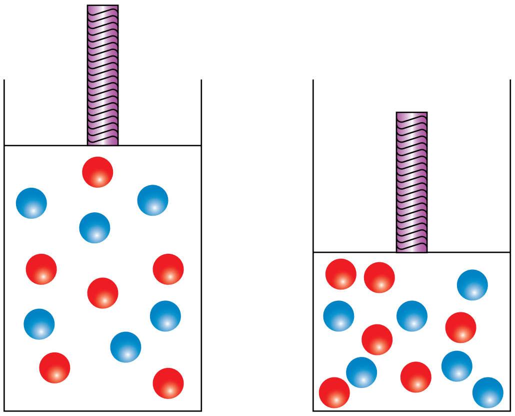


**Figure 8.25** Reducing the volume of the container increases the pressure of gaseous molecules.

Therefore, increasing the pressure increases the rate of reaction. This can only happen if one of the reactants is a gas because solid and liquid particles are nearly impossible to compress. It is a bit like the comparison between a class of 30 students running around a sports hall with the same class running around in a classroom. The smaller space increases the pressure, meaning you are more likely to collide. The energy with which the students collide, however, is not affected.

### Quick check 8.16

1. Describe why increasing the pressure of a solid and liquid does not affect reaction rate.
2. Describe a way in which the pressure of gas in a container can be increased.

## Surface area

When solids react, only the particles on the surface are in contact with particles of the other reactant when they collide. By making a solid smaller, by cutting it into pieces or grinding it into a powder, the surface area is increased and more particles are exposed to possible collisions. Imagine a loaf of bread: when its surface area is increased by cutting into slices, there is a greater area of the bread exposed to the air, so it dries out or becomes stale more quickly.

**pressure** the force produced by collisions of gas particles per unit area of the container walls

Increasing the surface area of a solid will cause the reaction rate to increase. This is because there are more particles exposed to the reaction, increasing the frequency of collisions and, by extension, the frequency of successful collisions. However, just like increasing the concentration, the energy with which the particles collide is not affected, so the proportion of successful collisions does not change.

**Figure 8.26** Cutting bread into slices increases its surface area.

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## Did you know? 8.3

**Swallow, don't crush**

The pharmaceutical industry manufactures a wide variety of medicines through chemical reactions to produce a specific chemical to help an immune response or reduce pain. Often pharmaceutical medicines are sold in tablet form and are meant to be swallowed in that form – not crushed! The chemicals in the tablet can react with stomach acid to release the active ingredients into the bloodstream in a controlled fashion. However, if the tablet is crushed, the surface area of the reactant is increased and the reaction in the stomach becomes much faster and less controlled. Therefore, there is a possibility of overdosing, or other side effects may occur, as the medicine has been released into the body too quickly. Moreover, it might also render the medicine less effective. Pharmaceuticals in tablet form are designed to both give you relief from illness and provide the medicine in the right amount of time.

**Figure 8.27** If swallowing tablets is difficult, it may be worthwhile asking a pharmacist whether the medicine comes in other forms.

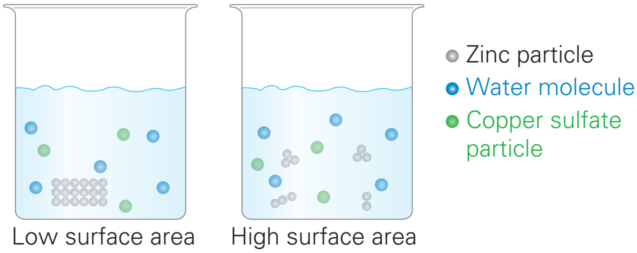


**Figure 8.28** To increase the surface area of a solid reactant, cut it into smaller pieces or grind it into a powder.

## Quick check 8.17

1. List two ways that the surface area of a solid can be increased.
2. A chemical reaction contains two different gaseous reactants. Justify whether increasing their surface area is a reasonable strategy to increase the reaction rate.
3. Explain why increasing the surface area of a reactant increases the reaction rate.

## Investigation 8.3

### Surface area and reaction rate

**Be careful**

Risk of acid burns. Wear appropriate personal protective equipment. Wear safety glasses at all times. Do not consume food items.

#### Aim

To investigate how changing the surface area affects reaction rate.

#### Prior understanding

Rhubarb contains oxalic acid, which will react with pink-coloured acidified potassium permanganate to form colourless manganese(II) ions. This provides an ideal end point for measuring the rate of reaction.

*continued …*

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*continued …*

**Materials**

- measuring cylinder
- beakers
- potassium permanganate crystals
- 1 mol $L^{-1}$ sulfuric acid
- white tile
- rhubarb stalks with leaves removed
- cutting tile
- knife
- stopwatch
- tweezers

**Planning**

1. Identify the independent variable from the information in the aim and describe the different groups that will be set up for the experiment.
2. Define the dependent variables and how they will be measured.
3. Identify and list the controlled variables to be monitored. For each variable, you must define the property that will be measured (numerically if possible) to ensure they are not changing throughout the experiment, for example, temperature (to be maintained at 25°C).
4. Develop a hypothesis by predicting how a change in the independent variable will affect the dependent variable.
5. Write a risk assessment for this investigation.
6. Create a results table that will allow you to collect sufficient and relevant raw data, in addition to calculating the mean and uncertainty.

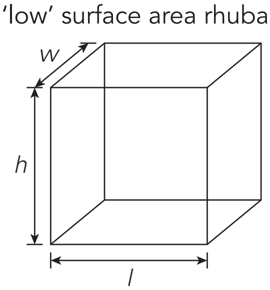
**Method**

**Part 1: Prepare the potassium permanganate solution**

Add 2 potassium permanganate crystals to 150 mL of 1 mol $L^{-1}$ sulfuric acid and stir well. Add another 150 mL of 1 mol $L^{-1}$ sulfuric acid to this solution, resulting in a light purple colour.

**Part 2: Prepare the rhubarb**

1. Cut 9 identical lengths of rhubarb, ensuring they are as uniform as possible. You may need to use your knife to create straight edges and remove any excess.
2. Take 3 of the lengths and calculate the approximate surface area of one of these lengths by using the following calculation. These will be your 'low' surface area rhubarb.




$$SA = 2lw + 2lh + 2wh$$

**Figure 8.29** Calculating the surface area of a cube

3. Take another 3 of the lengths and cut them each in half. Calculate the total surface area for the 2 halves. This will be your 'medium' surface area rhubarb.
4. Take another 3 of the lengths and cut them into 4 even pieces. Again, calculate the total surface area for the 4 quarters. This will be your 'high' surface area rhubarb.

**Part 3: Measure the reaction time**

1. Add 30 mL of acidified potassium permanganate to a beaker and place on a white tile.
2. Using tweezers, add a piece of the low-surface-area rhubarb to the beaker. Be careful not to splash the acid.

*continued …*

ISBN 978-1-009-40459-4 Dale et al. 2023 

*continued …*

3 Immediately start the stopwatch. Stir the solution until the purple colour disappears, then stop the timer. You may want to have a beaker of water next to the reaction beaker for a comparison.
4 Empty, wash and dry the reaction beaker.
5 Complete **Part 3** steps **1–3** twice more with another piece of low-surface-area rhubarb.
6 Repeat steps **1–4** with the other samples.

**Data processing**

1 Calculate the mean reaction rate for each rhubarb sample.
2 Draw a scatterplot to analyse the relationship between the numerical independent variable and its dependent variable.
3 Plot a graph and insert a copy below the results table in your science journal.

**Analysis**

1 Describe any trends, patterns or relationships that are found in your results.
2 Use your graph to predict the value of the dependent variable if you were given rhubarb pieces that were halfway between the sizes of the medium-surface-area and high-surface-area groups.
3 Extrapolate your data to predict the value of the dependent variable if you were given rhubarb pieces that had been cut into 8 pieces.

**Evaluation**

**Reliability**

1 How much variation was observed between the measurements between different student groups within the class?

**Limitations**

2 Were other variables that could affect the validity of the results successfully controlled during the experiment?

**Improvements**

3 Suggest any other changes that could be made to the method to improve the validity of the results in future experiments.

**Conclusion**

1 Propose a conclusion regarding the type of relationship between the surface area of the rhubarb and reaction rate. Justify your answer with data.
2 Use your own knowledge and scientific research to explain the theory behind your conclusion.

## Stirring (agitation)

Stirring or **agitating** a chemical reaction increases the reaction rate as it causes more frequent collisions of reactant particles. When a chemical reaction like the one in Figure 8.30 is left undisturbed, the product forms on the surface of the solid reactant, creating a barrier for any further reaction. As with increasing concentration and surface area, stirring a chemical reaction only increases the frequency of collisions and, by extension, the frequency of successful collisions. Stirring and agitation do not change the activation energy of the reaction and so do not affect the proportion of successful collisions.

**agitating**
stirring, swirling or shaking a mixture

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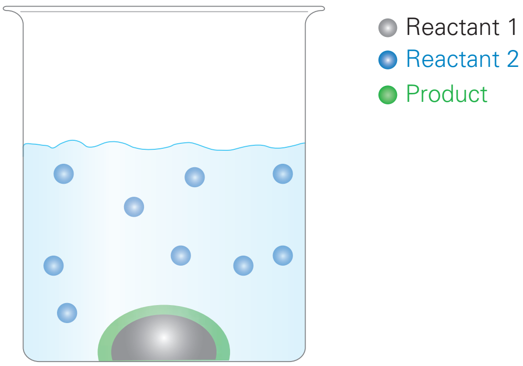


**Figure 8.30** Stirring this reaction mixture would allow more of reactant 1 to come into contact with reactant 2.

### Quick check 8.18

1 Explain why reaction rate increases when a mixture is agitated.

## Temperature

When you increase the temperature of a reaction, the rate of reaction also increases. The thermal energy added to the reaction is converted into kinetic (movement) energy, so the particles move at greater velocity. Particles are therefore more likely to collide more frequently, and because they move at greater velocities, they are also more likely to collide with more force. Thus, a greater proportion of particle collisions will reach the activation energy.

Increasing the temperature of a chemical reaction increases the frequency of collisions and, by extension, the frequency of successful collisions. It also increases the proportion of collisions that are successful as more particles have the energy required to reach the activation energy.

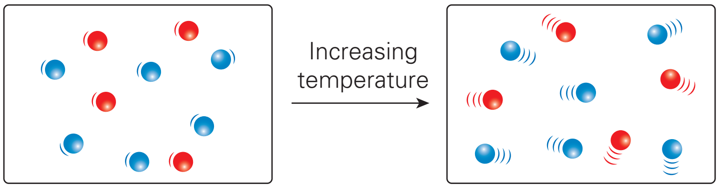


**Figure 8.31** Increasing the temperature of a reaction increases kinetic (movement) energy of the reactant particles, increasing the number of successful collisions.

### Quick check 8.19

1 When heat is applied to a chemical reaction, the particles convert this energy into which one of the following types of energy?
   - A Chemical energy
   - B Gravitational potential energy
   - C Kinetic energy
   - D Light energy

2 Describe why increasing the temperature of a chemical reaction increases the frequency of successful collisions.

### Try this 8.1

**Glowsticks**

**Figure 8.32** A chemical reaction causes glow sticks to release light.

Get three glasses and fill one with ice-cold water, one with room temperature water and one with hot water. Crack three glow sticks and add one to each glass. Observe which one glows the brightest.

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## Practical skills 8.5

### Temperature and reaction rate

**Be careful**

Hydrochloric acid is corrosive. Heat the hydrochloric acid using a water bath only. Do not heat the acid directly with the Bunsen burner or hotplate. Do not seal the test tube while reacting the acid and magnesium. Wear appropriate personal protective equipment. Wear safety glasses. Work under a fume hood.

**Aim**

To determine the effect of temperature on reaction rate.

**Materials**

- 3 pieces of magnesium ribbon (3 cm in length)
- 2 mol $L^{-1}$ hydrochloric acid, initially at room temperature
- 10 mL measuring cylinder
- beaker
- 3 boiling tubes
- ice
- stopwatch
- thermometer
- Bunsen burner (NOTE: Water baths or a hotplate may be used if available.)
- gauze
- tripod
- bench mat
- matches

**Planning**

1 Create a research question that can be easily and safely investigated.
2 Write a hypothesis for your investigation regarding the effect of temperature on reaction rates.
3 Identify the independent and dependent variables in this investigation.
4 Give 2 controlled variables and state why they needed to be controlled.

**Method**

1 Copy the results table into your science journal.
2 Using the 10 mL measuring cylinder, measure 10 mL of the room temperature 2 mol $L^{-1}$ hydrochloric acid and pour it into the boiling tube.
3 Add one piece of magnesium ribbon to the acid and start timing immediately.
4 Time how long it takes for the magnesium to disappear.
5 Repeat another 2 times.
6 Using either a Bunsen burner, water bath or hotplate, heat a beaker of water to 40°C. This will be your water bath.
7 Once your water bath has reached 40°C, reduce the heat to maintain the temperature but not allow it to increase.
8 Measure another 10 mL of 2 mol $L^{-1}$ hydrochloric acid and pour it into the boiling tube. Place this boiling tube in your water bath and wait for it to reach thermal equilibrium (when the temperature stops changing). Switch off the hotplate or Bunsen burner.
9 Repeat steps **3–5**.
10 Finally, create a cold ice bath by placing ice in a beaker of water.
11 Measure another 10 mL of 2 mol $L^{-1}$ hydrochloric acid and pour it into the boiling tube. Place this boiling tube in your cold ice bath and wait for it to reach thermal equilibrium.
12 Repeat steps **3–5**.

*continued …*

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*continued …*

**Results**

| Temperature (°C) | Time taken for magnesium to disappear (s) | | | | Uncertainty $\frac{\text{max} - \text{min}}{2}$ |
|---|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Mean | |
| | | | | | |
| | | | | | |
| | | | | | |

**Data processing**

1 Calculate the mean time taken for the magnesium to disappear at each temperature.
2 Calculate the uncertainty for each set of trials at each temperature.
3 Plot a graph of your results, including a line of best fit.
4 Extrapolate your graph to predict the time it would take for the magnesium to disappear at 50°C and 60°C.

**Analysis**

1 Identify any patterns, trends or relationships in your results.
2 Write a word equation and a balanced chemical equation with state symbols for the reaction of magnesium (Mg) with hydrochloric acid (HCl) to form magnesium chloride ($MgCl_2$) and hydrogen gas ($H_2$).

**Conclusion**

1 State a conclusion regarding the effect of temperature on reaction rate based on this experiment.
2 Support your statement by using the data you gathered.
3 Explain how the data supports your statement and link your explanation to collision theory.

## Catalysts

A catalyst is a substance that can be added to a chemical reaction to increase the reaction rate. There is no net consumption of a catalyst, so it is present at the beginning and end of the reaction in the same quantity. For this reason, a catalyst is shown above the arrow in a chemical equation rather than on the reactant or product side of the equation.

$$\text{starch} \xrightarrow{\text{amylase}} \text{water} + \text{glucose}$$

Catalysts increase the reaction rate by providing an alternative pathway with a lower activation energy for the reaction.

It is a bit like sheep jumping over a fence. The sheep are the reactant particles and the fence is the activation energy. If the fence (activation energy) is high, fewer sheep (particles) will reach the other side (fewer collisions will produce a successful reaction). On the other hand, if the fence is lowered by adding a catalyst, more sheep will be able to jump the fence (there will be a greater number of successful collisions).

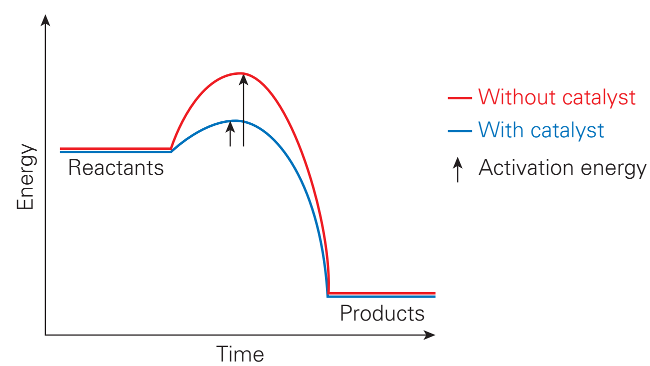


**Figure 8.33** Adding a catalyst to a chemical reaction decreases the activation energy required, increasing the number of successful collisions and therefore the reaction rate.

For example, when you eat carbohydrate-rich foods, the starch molecules react with water and broken down into glucose. The enzyme amylase, which is found in your saliva, acts to catalyse this reaction.

**Quick check 8.20**

1 Define the term 'catalyst'.
2 Describe how a catalyst increases the reaction rate.

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## Practical skills 8.6

### Catalysts and reaction rate

**Be careful**
Wear appropriate personal protective equipment.

#### Aim

To determine the most effective catalyst to decompose hydrogen peroxide.

#### Materials

- 0.5 g manganese (IV) oxide
- 0.5 g iron(III) oxide
- 50% vol hydrogen peroxide solution
- 1 $cm^3$ piece of potato
- 1 $cm^3$ piece of liver
- 1 $cm^3$ piece of celery
- dishwashing detergent
- 5 × 250 mL measuring cylinders
- plastic tray

#### Method

1. Copy the results table into your science journal.
2. Line up the 5 measuring cylinders on the tray and add about 1 mL of dishwashing detergent to each measuring cylinder.
3. Add 25 mL of the 50% vol hydrogen peroxide to each measuring cylinder.
4. Add the manganese oxide to one of the measuring cylinders and start the stopwatch.
5. Measure the height of the foam when it stops rising.
6. Rinse the measuring cylinder and repeat this method for 2 more trials.
7. Repeat steps **1–6** for each of the catalysts.

#### Results

| Catalyst | Height of foam (cm) | | | | Uncertainty of foam height $\frac{\text{max} - \text{min}}{2}$ |
|---|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 3 | Mean | |
| Manganese oxide | | | | | |
| Iron oxide | | | | | |
| Potato | | | | | |
| Liver | | | | | |
| Celery | | | | | |

#### Processing data

1. Calculate the mean height of foam for each catalyst.
2. Calculate the uncertainty in your results.

#### Analysis

1. Identify the catalyst that was the *most* effective at decomposing the hydrogen peroxide. How did you know?
2. Identify the catalyst that was the *least* effective at decomposing the hydrogen peroxide. How did you know?
3. Write a balanced chemical equation including state symbols for the decomposition of hydrogen peroxide ($H_2O_2$) into water ($H_2O$) and oxygen ($O_2$).
4. One of the products produced, water or oxygen, relights a glowing splint. Identify this product.

#### Evaluation

1. Identify any limitations of your experiment.
2. Describe any changes you could make that would improve the reliability of your results.

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## A summary of changing reaction rates

WORKSHEET Reactions: keyword review

Table 8.11 summarises how each factor discussed in this section influences the rate of a chemical reaction.

<table>
<tr><th>Factor affecting reaction rate</th><th>Effect on the frequency of collisions</th><th>Effect on proportion of successful collisions</th><th>Effect on rate</th></tr>
<tr><td>Increasing concentration of reactants</td><td rowspan="5">Increases</td><td rowspan="4">Not affected</td><td rowspan="6">Increased</td></tr>
<tr><td>Increasing pressure of gaseous reactants</td></tr>
<tr><td>Increasing agitation (stirring)</td></tr>
<tr><td>Increasing surface area of solid reactants</td></tr>
<tr><td>Increasing temperature</td><td rowspan="2">Increased</td></tr>
<tr><td>Adding a catalyst</td><td>Not affected</td></tr>
</table>

**Table 8.11** A summary of how each factor discussed affects reaction rate

### Section 8.4 questions

QUIZ

**Retrieval**

1 **State** three factors that can affect the rate of a chemical reaction.

2 **State** whether the following statements are true or false. If false, state a reason why.
   a Increasing the rate of stirring has no effect on the rate of reaction.
   b Changing the surface area of liquid reactants will increase the reaction rate.
   c Changing the pressure of a reaction mixture will only affect reactions containing gaseous reactants.
   d Increasing the temperature of a reaction increases the frequency and energy of collisions.

3 **Define** the term 'collision'.

4 **Recall** the name of chemicals that are added to a chemical reaction to reduce the activation energy.

5 a **Identify** the two solutions in Figure 8.34 that have the same concentration.
   b **Identify** if the solution in the remaining beaker is more concentrated or more dilute, giving reasons for your choice.

6 **Recall** the relationship between surface area and reaction rate.

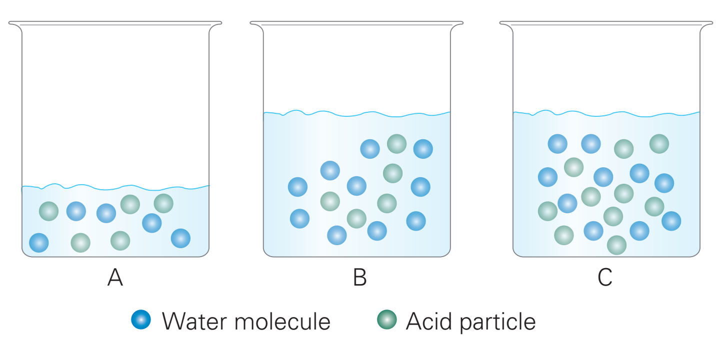


**Figure 8.34** Solution concentrations

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**Comprehension**

7 **Summarise** the requirements for a chemical reaction to occur.

8 **Summarise** the relationship between temperature and reaction rate.

9 Custard powder can explode when thrown into the air in the presence of a spark, but not when it is tightly packed in a container. **Explain** why.

10 Scientists often use magnetic stirrers to stir chemical reactions. **Explain** why this continuous stirring increases the rate of reaction.

**Analysis**

11 **Contrast** a dilute and concentrated solution.

**Knowledge utilisation**

12 Children are advised to take fewer tablets than adults. **Decide** the factor affecting reaction rate that is influencing this advice.

13 The chemical reaction that occurs when you bake cake mixture requires a large amount of heat for it to be successful. What can you **deduce** about the activation energy of this reaction?

14 A student conducted an experiment to determine how changing the concentration of hydrochloric acid affected the rate of reaction with sodium thiosulfate. They plotted a graph of their results, which can be seen in Figure 8.35. **Discuss** what can be concluded about the effect of increasing the concentration of acid in this reaction, giving detailed reasoning why this may be the case.

15 A student has two beakers of the same solution. They both have the same concentration. To increase the concentration of the solution, the student pours them into the same beaker. **Explain** whether the student has changed the concentration of the solution.

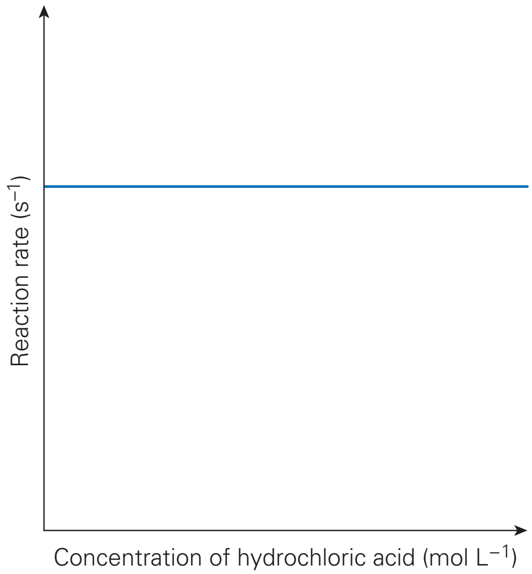


**Figure 8.35** Graph of experiment

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# 8.5 Extension: Chemistry calculations

## Learning goals

1. To be able to define Avogadro's constant.
2. To be able to calculate the molar mass for an atom or compound.
3. To be able to use the mole equation to solve problems including moles and mass.

WORKSHEET The Avogadro constant

In order to measure the efficiency of chemical reactions, scientists need to know how many particles are colliding and reacting in the chemical reaction. Take the following chemical reaction for example:

$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

By analysing the coefficients of the chemical species, we know that *two* hydrogen molecules will react with *one* oxygen molecule to produce *two* water molecules. However, it will be very difficult to measure exactly two hydrogen molecules and one oxygen molecule to complete this reaction.

In fact, it will also be difficult on a larger scale to measure out two million hydrogen molecules and one million oxygen molecules. Scientists need an easier way to measure specific quantities of reacting particles.

## The mole

To make this next concept simpler, imagine that you have a bag of rice grains and you measure *one* cup of rice grains in a measuring cup. A measuring cup might contain 8612 rice grains; however, a recipe will not tell you to measure 8612 rice grains, but instead to measure *one* cup of rice. This makes measuring rice a lot easier than counting individual rice grains 8612 times!

Figure 8.36 Imagine if recipes required you to count individual grains of rice!

Now let us treat **elementary entities** as rice grains and one cup as a **mole** ($n$). Elementary entities can include small particles such as atoms, compounds, molecules and ions. One mole contains $6.02 \times 10^{23}$ of these elementary entities, also known as Avogadro's constant ($N_A$).

**elementary entity**
a small particle such as an atom, compound, molecule or ion

**mole**
$6.02 \times 10^{23}$ elementary entities

### Did you know? 8.4

**Amadeo Avogadro**

The number of elementary entities in a mole, $6.02 \times 10^{23}$, is also known as Avogadro's constant, $N_A$, after the Italian scientist, Amadeo Avogadro. His work in the early 1800s on the number of atoms in a given volume of gas was an important foundation for the mole concept, which would be defined later that century. Another scientist, Jean Perrin, named the constant after Avogadro in the early 1900s to celebrate his early influence on this field of chemistry. In 2019, Avogadro's constant was updated to be exactly $6.022\,140\,76 \times 10^{23}$ elementary entities. However, for simplicity we will use the number $6.02 \times 10^{23}$ in our calculations.

Figure 8.37 Amadeo Avogadro was born in 1776 in Turin, Italy.

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Therefore, if a scientist were to now measure one mole of oxygen gas ($O_2$), they would have $6.02 \times 10^{23}$ molecules to be exact, just as one cup of rice would contain 8612 rice grains in the previous example.

This relationship between the mole and Avogadro's constant can be expressed mathematically:

$$\text{Number of moles} = \frac{\text{number of elementary entities}}{\text{Avogadro's constant}}$$

Or

$$n\,(\text{mol}) = \frac{\text{number of elementary entities}}{N_A\,(\text{mol}^{-1})}$$

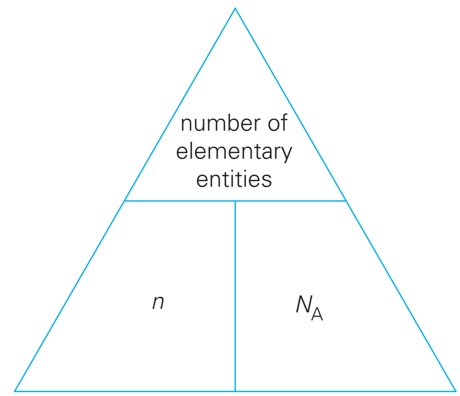


**Figure 8.38** The formula triangle for the number of elementary entities. To use the formula triangle, cover the variable you want to calculate. If the other variables are on the same row, multiply them together. If they are on different rows, divide the top variable by the bottom variable.

### Quick check 8.21

1. Identify the number of hydrogen molecules in one mole.
2. Identify the number of hydrogen molecules in two moles.
3. Calculate the number of water molecules in 3.5 moles.
4. Identify the number of moles of sodium in $1.806 \times 10^{23}$ atoms of sodium.

### Worked example 8.1

1. Calculate the number of moles of gold atoms if there are $3.01 \times 10^{24}$ atoms.
2. Calculate the number of molecules of hydrogen gas ($H_2O$) in 0.5 moles.

| Working | Explanation |
|---|---|
| **1** Substitute values into the equation and solve. | |
| $n = \frac{\text{number of elementary entities}}{N_A}$<br>$\frac{3.01 \times 10^{24}\text{ atoms}}{6.02 \times 10^{23}\text{ atoms mol}^{-1}} = 5\text{ mol}$ | To solve for the number of moles, substitute the number of atoms as the number of elementary entities and Avogadro's constant, $6.02 \times 10^{23}$, for $N_A$. |
| **2** Rearrange the equation to solve for number of molecules. | |
| number of elementary entities = $n \times N_A$<br>$= 0.5\text{ mol} \times 6.02 \times 10^{23}\text{ mol}^{-1}$<br>$= 3.01 \times 10^{23}$ entities or molecules | Rearrange the equation to solve for number of molecules (elementary entities). Substitute the number of moles and Avogadro's constant to solve. |

The mole is a useful concept. However, we still have not answered the question: How can we measure a mole of a chemical species? How can we measure $6.02 \times 10^{23}$ molecules, and where did Avogadro's constant come from?

## Molar mass

In the early 1900s, a scientist, Jean Perrin, set out to answer the question of how many molecules of oxygen gas ($O_2$) were in exactly 32 grams of the gas. From the periodic table,

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we can see that the atomic number of oxygen is 8 – that is also the number of protons in the nucleus of an oxygen atom. The periodic table also shows a number of **relative atomic mass**, which is the mass of the number of protons plus the average number of neutrons in the nucleus (relative to an atom of carbon-12). Many periodic tables will show this number to be 15.9994 for oxygen and in this example, we will round that number to 16.00.

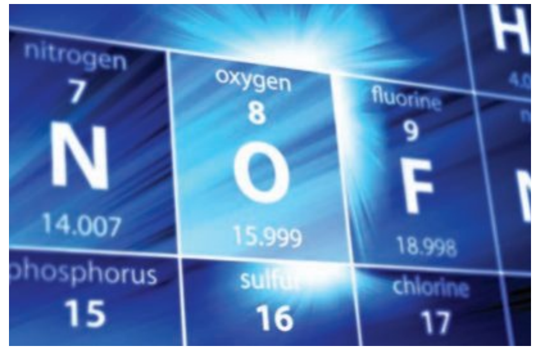


**Figure 8.39** The relative atomic mass of oxygen on the periodic table

A molecule of oxygen gas ($O_2$) has two oxygen atoms and therefore the overall relative atomic mass of this molecule can be calculated as: 16 + 16 = 32. Thus, Perrin wanted to know how many molecules were present in a measurable mass of 32 grams; a number similar to the relative atomic mass of oxygen gas of 32. This number of molecules was found to be $6.02 \times 10^{23}$ molecules. Perrin then named it Avogadro's constant, the number of elementary entities in a mole.

Therefore, if 32 grams of oxygen gas contains $6.02 \times 10^{23}$ molecules, and one mole of oxygen gas contains $6.02 \times 10^{23}$ molecules, then 32 grams of oxygen gas contains one mole of oxygen gas. This concept is known as the **molar mass** ($M$), and the molar mass of a molecule of oxygen gas can be determined from the relative atomic mass provided on the periodic table.

**relative atomic mass**
the mass of the number of protons and average number of neutrons in an atom relative to carbon-12

**molar mass**
the mass of one mole of an elementary entity

For example: $M(O_2) = 32\ g\ mol^{-1}$

In other words, there are 32 grams per mol of oxygen gas.

Avogadro's constant and molar mass can be used to communicate quantities of any atom, molecule or compound by referring to the relative atomic masses shown on the periodic table.

## Worked example 8.2

1 Calculate the molar mass of carbon.
2 Calculate the molar mass of water.
3 Calculate the molar mass of sodium chloride.

| Working | Explanation |
|---|---|
| **1** Molar mass of a single atom | |
| Relative atomic mass of C = 12.01 g $mol^{-1}$<br>$M$(C) = 12.01 g $mol^{-1}$ | For a single atom, the molar mass is the same as the relative atomic mass shown on the periodic table with units of g $mol^{-1}$. |
| **2** Molar mass of a molecule | |
| Relative atomic mass of O = 16.00 g $mol^{-1}$<br>Relative atomic mass of H = 1.01 g $mol^{-1}$<br>$M(H_2O)$ = 1.01 + 1.01 + 16.00 = 18.02 g $mol^{-1}$ | For a molecule, add all relative atomic masses from the periodic table with units of g $mol^{-1}$. Remember, there are 2 hydrogen atoms per $H_2O$ molecule. |
| **3** Molar mass of a compound | |
| Relative atomic mass of Na = 22.99 g $mol^{-1}$<br>Relative atomic mass of Cl = 35.45 g $mol^{-1}$<br>$M$(NaCl) = 22.99 + 35.45 = 58.44 g $mol^{-1}$ | For a compound, add all relative atomic masses from the periodic table with units of g $mol^{-1}$. |

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### Quick check 8.22

1. Calculate the molar mass of nitrogen gas ($N_2$).
2. Calculate the molar mass of elemental gold (Au).
3. Calculate the molar mass of ammonia ($NH_3$).
4. Calculate the molar mass of calcium phosphate ($Ca_3(PO_4)_2$).

WORKSHEET
The mole equation

## The mole equation

The mole, Avogadro's constant and the molar mass can now be brought together to create an equation relating the measurable mass of a substance to the number of moles or even elementary entities. This is known as the mole equation:

$$\text{Number of moles} = \frac{\text{mass}}{\text{molar mass}}$$

Or

$$n\ (\text{mol}) = \frac{m\ (\text{g})}{M\ (\text{g mol}^{-1})}$$

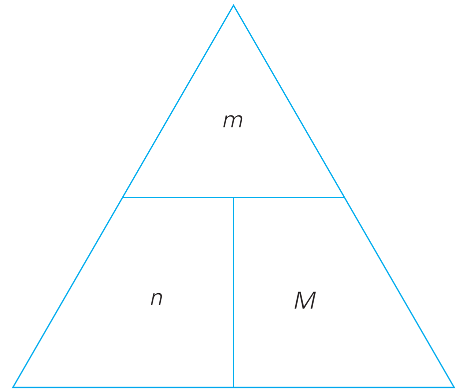


**Figure 8.40** The formula triangle for molar mass. To use the formula triangle, cover the variable you want to calculate. If the other variables are on the same row, multiply them together. If they are on different rows, divide the top variable by the bottom variable.

Using this equation, scientists can calculate a measurable mass of chemical substance for a given number of moles of that substance.

### Worked example 8.3

1. Calculate the number of moles of silver (Ag) in 0.25 g of metallic silver.
2. Calculate the number of moles of water ($H_2O$) in 5 g of the liquid.
3. Calculate the mass of 1.35 mol of barium bromide ($BaBr_2$).

| Working | Explanation |
|---|---|
| **1** Number of moles of Ag | |
| $m$ = 0.25 g<br>$M$(Ag) = 107.87 g mol$^{-1}$ | Identify the mass and molar mass of atomic silver. You need to refer to the periodic table for the molar masses. |
| $n = \frac{m}{M} = \frac{0.25\ \text{g}}{107.84\ \text{g mol}^{-1}} = 0.0023\ \text{mol}$ | Substitute known values of mass and molar mass (from periodic table) and solve for moles. |
| **2** Number of moles of $H_2O$ | |
| $m$ = 5 g<br>$M$(O) = 16.00 g mol$^{-1}$<br>$M$(H) = 1.01 g mol$^{-1}$<br>$M(H_2O)$ = 2 × 1.01 + 16.00 = 18.02 g mol$^{-1}$ | Identify the mass and molar mass of $H_2O$. (Add values of oxygen and 2 hydrogen from periodic table.) |
| $n = \frac{m}{M} = \frac{5\ \text{g}}{18.02\ \text{g mol}^{-1}} = 0.277\ \text{mol}$ | Substitute known values of mass and molar mass and solve for the number of moles. |
| **3** Mass of $BaBr_2$ | |
| $n$ = 1.35 mol<br>$M$(Ba) = 137.33 g mol$^{-1}$<br>$M$(Br) = 79.90 g mol$^{-1}$<br>$M(BaBr_2)$ = 137.33 + 2 × 79.90 = 297.13 g mol$^{-1}$ | Identify the number of moles $n$ and molar mass $M$ of $BaBr_2$. (Add values of barium and 2 bromine from periodic table.) |
| $m = n \times M$<br>= 1.35 mol × 297.13 g mol$^{-1}$<br>= 401.13 g | Rearrange equation to solve for mass. Substitute known values of moles and molar mass. |

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### Quick check 8.23

1 Calculate the number of moles in 1 g of hydrogen gas ($H_2$).
2 Calculate the mass of 15 mol of lithium metal (Li).
3 Calculate the molar mass of an unknown compound that has 2 mol of particles in 72.9 g.

## Bringing it all together

As we know, a given number of moles of a substance is directly related to Avogadro's constant and also the mass. We can therefore relate a mass to number of elementary entities.

See the two equations used in this chapter once more:

$$n\,(\text{mol}) = \frac{\text{number of elementary entities}}{N_A\,(\text{mol}^{-1})}$$

$$n\,(\text{mol}) = \frac{m\,(\text{g})}{M\,(\text{g mol}^{-1})}$$

WORKSHEET Bringing it all together

### Worked example 8.4

1 Calculate the number of water molecules in 0.65 g of the liquid.
2 Calculate the mass of $1.138 \times 10^{24}$ molecules of methane ($CH_4$).

| Working | Explanation |
|---|---|
| **1** Finding the number of molecules, given the mass | |
| $m = 0.65$ g<br>$M = 18.02$ g mol$^{-1}$ (see Worked example 8.2) | Identify the mass and molar mass. |
| $n = \frac{m}{M}$<br>$= \frac{0.65\text{ g}}{18.02\text{ g mol}^{-1}}$<br>$= 0.0361$ mol | Use the molar mass triangle. Substitute known values of mass and molar mass and solve for moles. |
| number of molecules = $n \times N_A$<br>$= 0.0361\text{ mol} \times 6.02 \times 10^{23}\text{ mol}^{-1}$<br>$= 2.17 \times 10^{22}$ elementary entities<br>There are $2.17 \times 10^{22}$ molecules of water in 0.65 g. | Use the moles and Avogadro's constant triangle to solve for the number of molecules. |
| **2** Finding the mass, given the number of molecules | |
| number of molecules = $1.138 \times 10^{24}$ molecules<br>$N_A = 6.02 \times 10^{23}$ molecules mol$^{-1}$ | Identify the number of molecules and Avogadro's constant. |
| $n = \frac{\text{number of molecules}}{N_A}$<br>$= \frac{1.138 \times 10^{24}\text{ molecules}}{6.02 \times 10^{23}\text{ molecules mol}^{-1}}$<br>$= 1.89$ mol | Use the moles and Avogadro's constant triangle. Substitute known values of molecules and Avogadro constant's and solve for moles. |
| $M(\text{C}) = 12.01$ g mol$^{-1}$<br>$M(\text{H}) = 1.01$ g mol$^{-1}$<br>$M(CH_4) = 12.01 + 4 \times 1.01 = 16.05$ g mol$^{-1}$ | Calculate the molar mass. |
| $m = n \times M$<br>$= 1.89\text{ mol} \times 16.05\text{ g mol}^{-1}$<br>$= 30.33$ g | Use the moles and the molar mass triangle to solve for the mass. |

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QUIZ

## Section 8.5 questions

### Retrieval

1 **State** the number and units of Avogadro's constant.

2 **Define** the mole in relation to chemistry.

### Comprehension

3 **Describe** why the units of molar mass are g $mol^{-1}$. In your response, refer to Avogadro's constant.

4 **Determine** the molar mass of carbon dioxide ($CO_2$).

5 **Determine** the molar mass of ammonium sulfate ($(NH_4)_2SO_4$).

6 **Determine** the molar mass of tryptophan ($C_{11}H_{12}N_2O_2$).

### Analysis

7 **Calculate** the number of moles of carbon monoxide (CO) present in 90.25 g.

8 **Calculate** the number of moles if $6.02 \times 10^{22}$ atoms of platinum (Pt) are present.

9 **Calculate** the mass of 3.41 mol of ozone ($O_3$).

10 **Calculate** the mass of 0.999 mol of uranium oxide ($UO_2$).

11 An unknown compound of 1.5 g was analysed to contain $1.048 \times 10^{22}$ particles. Use this information to **explain** how one could find the molar mass of the unknown compound, and determine this value.

12 The unknown compound in Question **11** was identified as hexane ($C_6H_{14}$). **Confirm** that the molar mass that was determined in Question **11** matches that of this compound.

### Knowledge utilisation

13 A sample of water ($H_2O$) was weighed and a mass of 5.00 grams was recorded. **Justify** that the number of water molecules in the sample can be determined from this measurement.

14 For the same sample in Question **13**, **justify** that the number of hydrogen atoms present in the sample can be determined.

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# Chapter review

## Chapter checklist

You can download this checklist from the Interactive Textbook to complete it.

| **Success criteria** | | **Linked questions** | **Check** |
|---|---|---|---|
| **8.1** | I can represent chemical reactions in word and balanced chemical equations. | 8, 10 | |
| **8.1** | I can use appropriate notation to show chemical species as gas, liquid, solid or aqueous. | 8 | |
| **8.2** | I can identify a reaction type and predict the products. | 12, 14 | |
| **8.2** | I can write balanced chemical equations for synthesis, decomposition, metal displacement and precipitation reactions. | 8 | |
| **8.2** | I can write balanced chemical equations for the three types of neutralisation reactions. | 3 | |
| **8.3** | I can describe how chemical reactions can be used to create useful products such as polymers, ethanol and sulfuric acid. | 6, 19 | |
| **8.3** | I can describe some useful chemical reactions used by First Nations Australians. | 17 | |
| **8.4** | I can determine the rate of reaction through experimental procedures and calculations. | 11 | |
| **8.4** | I can name and explain the factors that affect rates of reactions. | 2 | |

## Extension

| | | | |
|---|---|---|---|
| **8.5** | I can calculate the number of moles from a given mass or number of particles of substance. | Section 8.5 questions | |

## Review questions

SCORCHER

### Retrieval

**1** **Name** three diatomic elements on the periodic table.

**2** **State** six factors that affect the rate of a reaction.

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3 **Recall** the products of an acid reaction with the following.
   a Metal
   b Base
   c Carbonate

4 **Recall** one factor which speeds up the rate of a chemical reaction solely by affecting the frequency of collisions.

5 **Recall** the relationship between reaction rate and the time a reaction takes to reach completion.

6 **Identify** why sulfuric acid is such an important chemical to the chemical industry.

### Comprehension

7 **Explain** why alcohol is added to petrol.

8 **Write** a balanced equation for the reaction of magnesium metal (Mg) and hydrochloric acid (HCl), showing state symbols.

9 **Describe** what is meant by a 'successful collision'.

10 **Represent** the following balanced equation as a word equation.

$$H_2SO_4 + Na_2CO_3 \rightarrow Na_2SO_4 + CO_2 + H_2O$$

11 **Calculate** the rate of a reaction in which 1.5 grams of solid product was formed in 56 seconds.

12 **State** whether the following reactions are synthesis or decomposition reactions.
   a $CuCO_3 \rightarrow CuO + CO_2$
   b $H_2 + O_2 \rightarrow H_2O$

### Analysis

13 **Analyse** the equation to find a mistake.

$$4\ HNO_3(aq) + Cu(g) \rightarrow Cu(NO_3)_2(aq) + H_2O + 2\ NO_2\ (g)$$

14 **Predict** the outcome of the following displacement reactions.
   a Iron oxide + carbon
   b Copper nitrate + zinc
   c Magnesium sulfate + zinc
   d Gold + zinc nitrate

15 **Classify** the following as more or less reactive metals than iron.
   a Potassium
   b Gold
   c Copper
   d Zinc

### Knowledge utilisation

16 **Discuss** the importance of balancing equations in the chemical industry.

17 **Write** a balanced equation for the pyrolysis of calcium (Ca) in oxygen ($O_2$) to form calcium oxide (CaO), a product used by groups of First Nations Australians in creating effective medicines.

18 The reaction of hydrogen gas and ethene ($C_2H_4$) produces ethane ($C_2H_6$) in the presence of a palladium (Pd) catalyst. **Write** a balanced equation for this chemical reaction.

19 **Discuss** the importance of our understanding of reaction rates on the chemical industry.

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## Data questions

A group of chemistry students is measuring the rate of a reaction of magnesium metal and hydrochloric acid under different conditions. In three separate test tubes, the students added a strip of magnesium to 1 mol $L^{-1}$ HCl, powdered magnesium to 1 mol $L^{-1}$ HCl, and powdered magnesium in 2 mol $L^{-1}$ HCl, respectively. The data points are presented in Figure 8.41. Note that the mass of magnesium used was the same for each reaction.

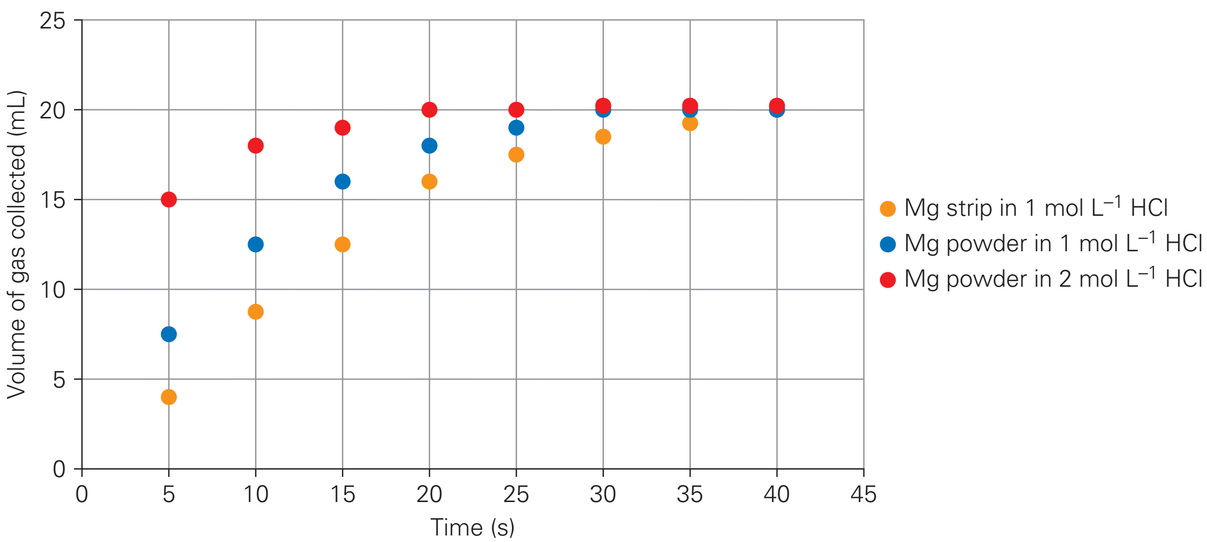


**Figure 8.41** Volume of gas collected over time from reactions of magnesium metal and hydrochloric acid

### Apply

1 **Identify** the conditions in which the reaction went to completion fastest.

2 **Calculate** the rate of the reaction (in mL $s^{-1}$) for the magnesium strip in 1 mol $L^{-1}$ HCl from the time 0 to 40 seconds.

3 The rate of the reaction for the magnesium powder in 1 mol $L^{-1}$ HCl is 0.67 mL $s^{-1}$. Use this information and your answer to questions **1** and **2** to **determine** which reaction has the slowest reaction rate.

### Analyse

4 **Identify** the trend in the plot which is similar for all three experiments.

5 **Contrast** the effect of the magnesium surface area on the volume of gas produced and the rate of the reaction.

6 **Analyse** the data presented in Figure 8.41 for the three experiments. What would be the volume of gas collected for each experiment at 0 seconds (before reactants were mixed)?

### Interpret

7 A student has stated that when all magnesium and hydrochloric acid has reacted, the volume of gas produced will be 20 mL. **Justify** this conclusion with reference to the data in Figure 8.41.

8 **Extrapolate** the data for the magnesium strip in 1 mol $L^{-1}$ HCl experiment and estimate the volume of gas produced after 120 seconds.

9 The students would like to run another experiment with the same mass of magnesium powder in 5 mol $L^{-1}$ HCl. **Predict** (using Figure 8.41 as a template) how the data might be different in this experiment.

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# STEM activity: Designing airbags

## Background information

Airbags work on the principle of increasing the time of impact between two objects. In a car crash this could be the difference between life and death. A sensor is connected to an electrical circuit and once activated will send a signal that ignites the guanidinium nitrate ($CH_6N_4O_3$) and releases nitrogen at high speed. Airbags are not without risk, though. Failures include burns from the explosive chemical reaction and injuries from the projectile velocity of the bag itself, which can reach 330 $km\,h^{-1}$.

**Design brief:** Design and create an airbag prototype that uses environmentally friendly chemicals and materials in its manufacture. The airbag will need to create gas rapidly to work effectively.

## Activity instructions

In groups you will design an airbag that uses a chemical reaction to produce a safe gas that fills the airbag space. Your design will incorporate features that would make your airbag safe through the whole chemical reaction and environmentally friendly for disposal. If you cannot source the materials you need, you can produce a model and state the chemical reaction.

### Suggested materials

- various types of acid (e.g. vinegar)
- various types of bases (e.g. baking soda)
- beakers of various size
- measuring cylinder
- rubber tubing
- thermometer
- plastic bags
- stopwatch
- balloons
- various building materials

**Figure 8.42** Car airbags after they have been deployed and then deflated

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## Research and feasibility

1 Research how airbags work at present and how the chemicals are reacted in a safe way in the bag.
2 Research safe chemical reactions and different catalysts that could be used.
3 Discuss in your group the available materials you have and research environmental concerns regarding the disposal of these materials.

## Design and sustainability

4 Decide as a group the chemical reaction you will use and how you will increase the rate of reaction of gas produced.
5 Design how your airbag will work, and sketch ideas before deciding on the final design. Remember, you will need to capture the gas. You may want to think about how you will test the effectiveness of your chemical reaction that is occurring within the bag.
6 Complete a risk management table for the chemicals you are using. Risk management should include how to minimise any risks associated with the experiment as well as how to deal with risks that emerge. Make a note of any special disposal conditions the chemicals may have.

| Material | Hazard | Risk management |
|---|---|---|
| e.g. 2 mol $L^{-1}$ hydrochloric acid | Burning skin and/or clothing | Use gloves and wear aprons, be careful when handling |
| | | |
| | | |

## Create

7 Create your prototype airbag and test the effectiveness of your design.

## Evaluate and modify

8 Discuss the positives and negatives about your design. You may use a positive, negative, interesting (PNI) table, as shown below, to present your findings to the class.

| Positives | Negatives | Interesting |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

9 Evaluate the effectiveness of your chemical reaction at producing gas, the reaction time for gas to be produced, the completion time of the reaction and how safe the chemical reaction was.
10 Recommend changes you would make in your design of the airbag, and the chemical reaction choice.

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# Glossary

**Absolute dating** determining the actual age of a material

**Absolute uncertainty** the size of the range of values within which the actual 'true value' of a measurement probably lies

**Absorption spectrum** a spectrum showing dark lines representing specific wavelengths that have been absorbed by a substance

**Acceleration (*a*)** the change in velocity of an object over time

**Accuracy** how closely measures match the 'true' or accepted values

**Activation energy** the minimum collision energy required to break and form bonds

**Adaptation** a characteristic that contributes to an individual's ability to survive in its environment

**Agitating** stirring, swirling or shaking a mixture

**Alkali metals** group 1 metals

**Alkaline earth metals** group 2 metals

**Allele** different form of the same gene

**Allele frequency** the relative proportion of a specific allele within a population

**Analogous structures** structures that have a similar function but evolved separately

**Aneuploidy** the presence of an abnormal number of chromosomes in a cell

**Anion** a negatively charged ion formed from the gain of electrons

**Anthropogenic** caused or influenced by people

**Aqueous** a physical state of matter that means dissolved in water

**Arcsecond** 1/3600th of a degree

**Artificial selection** intentional breeding of organisms with particular characteristics to produce offspring with more desirable traits

**Astronomical unit** the distance between Earth and the Sun

**Atmosphere** the mixture of gases above the surface of Earth

**Autosome** any chromosome that is not a sex chromosome. In humans, these are chromosome pairs 1 to 22

**Average speed** change in distance over a time interval

**Average velocity** the rate at which an object is displaced or changes position over a time interval

**Base triplet** a set of three nitrogenous bases that code for an amino acid

**Baseline** a line between the two viewpoints used to calculate parallax angle (1 AU is the baseline used for calculating star parallax)

**Big Bang** the rapid expansion of matter that marked the origin of the universe

**Biodiversity** the variety of life on Earth, including the diversity of species, the genetic differences within a species, and the ecosystems where species are found

**Biofuel** a fuel that comes from living materials

**Biogeography** the study of the geographical distribution of plants and animals

**Biosphere** all the areas on Earth and in its atmosphere that contain life

**Biostratigraphy** a branch of stratigraphy focused on dating rock layers using the fossils found in them

**Biota** all the living organisms found within a particular region or ecosystem

**Black hole** the extremely dense remnant of a massive star; a region in space where gravity is so strong that nothing can escape, not even light

**Blue shift** a spectrum shifted towards shorter wavelengths

**Bottleneck effect** the decrease in genetic diversity resulting from a rapid reduction in the size of a population, due to events such as natural disasters or human activities such as overhunting

**B–V colour index** the difference in brightness measured through blue and green filters, indicating the colour of a star

**Calibrate** to mark or check measuring equipment against a known standard value to ensure its accuracy

**Carrier** an individual with a recessive allele for a disease but who does not have the disease due to being heterozygous

**Catalyst** a substance that speeds up a chemical reaction by lowering the activation energy and does not get used up in the process

**Cation** a positively charged ion formed from the loss of electrons

**Centromere** a structure that holds two sister chromatids together

**Chemical formula** the symbols and formulas of the reactants or products

**Chromatin** a mixture of DNA and proteins that form chromosomes

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**Chromosome** a thread-like structure of tightly wound DNA and proteins

**Chromosome mutation** a mutation involving large segments of DNA

**Climate** the average or prevailing weather conditions of an area over long periods of time

**Codominance** both alleles are expressed equally in the phenotype

**Codon** three nucleotides (base triplet) on mRNA that code for an amino acid

**Coefficient** the number placed before a molecule (formula unit) in a chemical equation to ensure it is balanced

**Collisions** the violent coming together of two or more particles; a requirement for a chemical reaction to occur

**Complementary base pairing** adenine only binds with thymine and cytosine only binds with guanine

**Concentrated solution** a solution which contains a relatively large amount of solute compared to solvent

**Concentration** the amount of substance in a given volume

**Confidentiality** participants' data and results must be kept private

**Confounding variable** a variable that influences the independent and/or dependent variable/variables

**Constant velocity** when an object is travelling at the same speed and is not accelerating or decelerating

**Constellation** a group of stars as seen from Earth that appear to form a familiar shape

**Continuous spectrum** a continuous range of colours (wavelengths)

**Controlled variable** a variable that is kept constant so as not to affect the dependent variable during an experiment

**Cosmic microwave background** electromagnetic radiation left over from the early stages of the universe

**Covalent bond** a strong bond almost always between two non-metals which share electrons, forming a molecule

**Dark energy** a theoretical force responsible for accelerating the expansion of the universe

**Dark matter** matter that does not emit light and is responsible for unidentified gravity in the universe

**Data logging** the process of using electronic equipment to collect data independently through sensors where information needs to be collected faster or for longer or more accurately than a human can do

**Deceleration** when an object is slowing down

**Deletion** where a nucleotide is deleted from the sequence

**Dependent variable** the variable that is measured in response to the independent variable

**Diatomic** existing as two atoms bonded together

**Dilute solution** a solution which contains a relatively small amount of solute compared to solvent

**Diploid (2*n*)** a cell containing two sets of chromosomes

**Direct (evidence)** evidence that supports an assertion without intervening inferences

**Displacement (*s*)** the length and direction of an object from its origin, measured in metres

**Displacement reaction** when a more reactive metal removes a less reactive metal from its compound

**Distance (*d*)** total length travelled measured in metres

**DNA** the molecular unit of heredity, containing the genetic information responsible for the development and function of an organism (deoxyribonucleic acid)

**DNA hybridisation** a technique that measures genetic similarity between two organisms

**Dominant** a characteristic in which the allele responsible is expressed in the phenotype, even in those with heterozygous genotypes

**Doppler effect** a change in the frequency of sound or light waves emitted from an object when it moves towards or away from an observer

**Ecosystem diversity** the variation in ecosystems in a given area

**Electron** smallest subatomic particle in an atom arranged around the nucleus in shells

**Electron configuration** the arrangement of an atom's electrons in the shells around the nucleus

**Electron shell** the energy level in which the electrons orbit the nucleus of an atom

**Element** chemical substance made up of only one type of atom

**Elementary entity** a small particle such as an atom, compound, molecule or ion

**Embryo** the initial stage of early development in multicellular organisms

**Emission spectrum** a spectrum showing bright lines at wavelengths specific to emission from a substance

**Endangered** a species that is in danger of becoming extinct

**Endemism** a state of being confined to a small defined geographic location

**Epoch of recombination** the point in time when electrons and ions could combine to form atoms

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**Ethics** the standards used to appraise and guide what is considered as acceptable conduct

**Evolution** change in the genetic composition of a population during successive generations, which may result in the development of new species

**Evolutionary tree** a diagram used to represent evolutionary relationships between organisms

**Exoplanet** a planet outside our solar system, orbiting a star other than our Sun

**Extinct** a species that has no living members

**Fertile** able to reproduce

**Fertilisation** the fusion of male and female gametes to form a zygote

**Fieldwork** practical work conducted by a scientist in a natural environment rather than in a laboratory

**Force** any interaction that, when unopposed, will change the motion of an object

**Fossil** the shape or impression of a bone, a shell or a once living organism that has been preserved for a very long period of time

**Fossil record** the record of past life and evolution inferred from fossils

**Fossilisation** the process of forming a fossil

**Founder effect** the decrease in genetic diversity that occurs when a population is descended from a small population that separated from a larger one

**Galaxy** a gravitationally bound system containing billions of stars and planets

**Gametes** sex cells (sperm and ova) with half the usual number of chromosomes

**Gene** a length of chromosome made of DNA, the basic unit of inheritance

**Gene flow** the movement of genetic information from one population to another through migration

**Gene mutation** a permanent alteration in the DNA sequence that makes up a gene

**Gene therapy** a process by which a copy of a functional gene is introduced into an organism

**Genetic diversity** the number of different alleles of genes in a population

**Genetic drift** the random change in allele frequencies in a population from generation to generation

**Genetic engineering** deliberately modifying genetic material to manipulate the characteristics of an organism

**Genetic screening** genetic tests carried out across the population to identify people at risk of genetic disorders

**Genetic variation** the differences in DNA sequences between individuals within a population

**Genetically modified organism** an organism that has had its genome altered using genetic engineering techniques

**Genetics** the study of genes, genetic variation and heredity

**Genome** the complete set of genetic material in an organism

**Genotype** the combination of alleles an organism has for a particular gene

**Geocentric** a model of the solar system with Earth at the centre

**Geosphere** includes Earth's magma, lava, rocks and minerals

**Germline mutation** a mutation of DNA in gametes which can be inherited

**Glacial period** a period in Earth's history when a reduction in global temperatures is sustained for a long period of time

**Goldilocks zone** the habitable zone around a star where the temperature is not too hot and not too cold

**Gonads** the sexual organs: testes in males and ovaries in females

**Gradient** in physics, how quickly something changes, or the rate of change. The gradient of a graph is calculated as the rise over the run

**Greenhouse effect** the trapping of the Sun's warmth by a layer of gases in the lower atmosphere

**Greenhouse gases** gases that contribute to the greenhouse effect

**Ground state** the lowest energy level of an atom

**Group** a vertical column in the periodic table

**H–R diagram (Hertzsprung–Russell diagram)** a graph where the star luminosity is plotted against spectral type/temperature

**Half-life** the length of time needed for the radioactivity of a radioactive substance to be reduced by half

**Halogens** group 17 elements

**Haploid (*n*)** a cell containing only one set of unpaired chromosomes

**Heliocentric** a model of the solar system with the Sun at the centre

**Heredity** the genetic passing on of traits from one generation to the next

**Heterozygous** having two different alleles at a particular gene locus

**Homologous chromosomes** a matching pair of chromosomes, with one having been inherited from each parent

**Homologous structure** a similar physical feature in organisms that have evolved from the same common ancestor

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**Homozygous** having two identical alleles at a particular gene locus

**Hubble's law** the further away a galaxy is from Earth, the faster it is moving away from us

**Hydrogen bonds** chemical bonds that hold the two DNA strands together

**Hydrosphere** all of the water found on Earth (e.g. lakes and rivers)

**Hypothesis** a proposed explanation or educated guess that can be tested through further investigation and experimentation

**Incomplete dominance** a form of inheritance in which both alleles are partially expressed, producing a third intermediate phenotype

**Independent variable** the variable that is systematically manipulated or changed in order to investigate its effect on the dependent variable

**Index fossil** a fossil used as the basis for dating the strata it occupied

**Indirect (evidence)** evidence that requires inferences to be made

**Induced mutation** a mutation produced by environmental factors

**Inertia** the tendency of an object to remain in its state of motion in the same direction unless acted upon by an external force

**Informed consent** where possible, participants are informed about the risks and procedures involved in an experiment and they sign to say they agree to participate

**Insertion** where one or more extra nucleotides are inserted into the DNA

**Instantaneous speed** the speed at a given point in time

**Instantaneous velocity** the velocity of an object measured at a particular moment in time

**Interferometry** a technique that uses the interference of waves to measure distances

**Interglacial period** a period in Earth's history when an increase in global temperatures is sustained for a long period of time

**Inversion** where two nucleotides reverse their order

**Ion** a charged version of an atom, formed from the loss or gain of electrons

**Ionic bond** a strong bond between an anion and a cation, formed via electron donation

**Karyotype** the chromosomes of an individual, often displayed according to size and gene band patterns

**Light year** the distance that light travels in one year (about 10 trillion km)

**Lithosphere** the geological parts of Earth's crust and upper mantle only

**Locus** the location of a gene on a chromosome

**Luminosity** the intrinsic brightness of a celestial object

**Lustrous** in metals, having a shiny surface

**Main sequence** the phase during which stars convert hydrogen into helium in their cores

**Mass** the quantity of matter

**Mean** sum of all the values divided by the number of values

**Median** the middle value of the dataset after all the values have been ranked (sorted in ascending order). There should be as many numbers below the median as there are above

**Megafauna** large animals with a body mass of over 45 kilograms

**Meiosis** the process by which the gonads make the haploid gametes

**Metalloids** elements in the periodic table that are situated close to the border between metals and non-metals; they share properties and appearance characteristics with both metals and non-metals

**Mitosis** the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair

**Mode** the most frequently occurring value or values in a dataset

**Model** a simplified representation of a real-world system or phenomenon used to understand, analyse or predict its behaviour

**Molar mass** the mass of one mole of an elementary entity

**Mole** $6.02 \times 10^{23}$ elementary entities

**Monatomic** (also monoatomic) existing as one atom

**Monohybrid cross** a type of genetic cross or breeding experiment that considers the inheritance of a single trait or characteristic, typically controlled by a single gene with two alleles

**Monomer** a single subunit that when joined together repeatedly makes a polymer

**Mutagenic** causing mutations in DNA

**Mutation** a change in the genetic code of a cell

**Natural selection** a process in which organisms whose phenotype is best adapted to their environment are more likely to survive and reproduce

**Net force** the sum of all the forces acting on an object

**Neutralisation** a reaction between an acid and a base, forming a solution that has a pH of 7

**Newton's first law of motion** an object will remain at rest or moving at a constant speed in a straight line unless acted upon by an external force

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**Newton's second law of motion** an object acted upon by a force experiences acceleration in the same direction proportional to the magnitude of the net force and inversely proportional to the mass of the object

**Newton's third law of motion** for every action, there is an equal and opposite reaction

**Noble gases** group 18 elements

**Non-disjunction** the failure of homologous chromosomes or sister chromatids to separate correctly in meiosis

**Non-homologous chromosomes** chromosomes that do not belong to the same pair

**Nuclear fusion** the process of joining two nuclei to produce energy

**Nucleotide** a monomer subunit of a nucleic acid, consisting of a phosphate group bound to a five-carbon sugar, which in turn is bound to a nitrogenous base

**Observable universe** the spherical region of the universe that can be observed from Earth or space telescopes; it encompasses everything close enough that light has had time to reach Earth

**Octet rule** atoms tend to lose, gain or share valence electrons to achieve eight electrons in their outer shell

**Optical telescope** a device that collects and focuses light from the visible spectrum to form an image

**Origin** the 0 point on the *y*-axis of a displacement–time graph

**Outlier** anomalous data value that does not seem to fit the rest of the data

**Ova** (singular: **ovum**) mature female reproductive cells

**Parallax** the effect by which the position of an object seems to change when it is observed from different locations

**Parallax error** a measurement taken that is not the true value due to the position of the object along various lines of sight

**Parsec** the distance at which a star appears to move one arcsecond in six months (equal to 3.26 light years or 30 trillion km)

**Particle diagram** a representation of elements and compounds where atoms are drawn as balls or circles

**Pedigree** a chart that shows relationships between family members and indicates which individuals have certain genetic traits

**Period** a horizontal row in the periodic table

**Phenotype** the observable characteristics of an organism, resulting from both genotype and the environment

**Point mutation** a mutation in which a single nucleotide is changed

**Polymer** a molecule made from many repeating subunits called monomers

**Polypeptide** a chain of amino acids, forming part or the whole of a protein molecule

**Population (ecological)** a group of a particular species living and interbreeding in the same geographical area

**Precipitation** a reaction that involves the mixing of two solutions to produce a solid called a precipitate

**Precision** how closely repeated measures agree with each other

**Prediction** a statement that describes what is expected to happen if the hypothesis is true

**Pressure** the force produced by collisions of gas particles per unit area of the container walls

**Products** the chemicals produced in a reaction

**Punnett square** a specialised grid to show genetic crosses

**Radio telescope** a device that receives radio waves emitted by stars and other celestial objects

**Radioisotope** a radioactive isotope of a chemical element with an unstable nucleus that emits excess energy (radiation)

**Random error** error caused by limitations of the measurement device or the observer that does not follow a regular pattern

**Range** the difference between the highest and lowest values in the dataset

**Reactants** the chemicals which react together in a reaction

**Reaction rate** the quantity of reactant or product used up or made per unit of time; how quickly the reaction progresses

**Reactivity series** a series of metals ordered by their observable reactivity, from highest to lowest

**Reading error** a reading or measurement that is not the true value

**Recessional velocity** the rate at which a star is moving away from Earth

**Recessive** a characteristic in which the allele responsible is only expressed in the phenotype if there is no dominant allele present

**Recombination** the rearrangement of genetic material, especially by crossing over

**Red giant** a very large, bright, cool star that has run out of hydrogen in its core

**Red shift** a spectrum shifted towards longer wavelengths

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**Reduction division** cell division which results in a reduction of genetic material in the daughter cells

**Relative atomic mass** the mass of the number of protons and average number of neutrons in an atom relative to carbon-12

**Relative dating** determining the order of past events without the specific age

**Relative uncertainty** the ratio of the absolute uncertainty to the reported value, often expressed as a percentage

**Reliability** how repeatable, replicable and reproducible the results are

**Repeatability** how well the results match up when the same scientist repeats the experiment under the same conditions as the original experiment, including the same equipment and laboratory or field site

**Replicability** how well the results match up when a different scientist repeats the experiment under the same conditions as the original experiment, including the same equipment and laboratory or field site

**Reproducibility** how well the results match up when a different scientist repeats the experiment under different conditions to the original experiment, including different equipment and laboratory or field site

**Reproductive isolation** when members of two related populations can no longer interbreed

**Retrograde motion** apparent backwards motion of a planet as seen from Earth

**Right to withdraw** the right for a participant to leave a study at any time for any reason

**Safety data sheet** a document that provides information regarding hazardous chemicals and substances

**Salt** a product formed when an acid reacts with a metal, base or carbonate; generally made up of metals and non-metals

**Selection pressure** a factor that affects the relative fitness or reproductive success of individuals within a population, leading to natural selection and potential changes in allele frequencies over time

**Selective advantage** the characteristic of an organism that enables it to survive and reproduce better than other organisms in a population

**Selective breeding** another term for artificial selection

**Sex chromosomes** chromosomes that determine the sex of an organism

**Sexual reproduction** form of reproduction that involves two parents and introduces variation to the offspring

**Simulation** a computer program that uses a model to replicate the behaviour of a system over time

**Singularity** a point at which infinitely dense matter occupies an infinitely small space

**Sister chromatids** two copies of the same chromosome, connected at a centromere

**Somatic cells** the body cells of an organism

**Somatic mutation** a mutation that occurs in somatic (body) cells which cannot be inherited

**Speciation** the process by which populations evolve to become distinct species

**Species** a group of organisms consisting of similar individuals who can interbreed with one another

**Species diversity** the number and abundance of different species in a given area

**Spectral class** a group into which stars are classified based on their spectra

**Speed** change in distance divided by time

**Spontaneous mutation** a naturally occurring mutation

**Stationary** not moving

**Stratigraphy** the branch of geology studying the rock layers

**Substitution** where one nucleotide is swapped for another

**Supernova** the explosion of a massive star

**Surface area** the area of the outer part or surface of an object

**Synthesis** a reaction in which two (or more) elements or reactants combine to form new substances or products

**Systematic error** error that occurs through a poorly calibrated device (consistently high or consistently low)

**Telomeres** structures made from DNA and proteins that protect the ends of chromosomes

**Test cross** a genetic cross between a homozygous recessive individual and an individual of unknown genotype showing the dominant trait to determine the unknown genotype

**Thermal decomposition** decomposition that occurs when a substance is heated

**Titration** a procedure used to determine the concentration of an unknown solution

**Trace fossil** a trace of an animal, such as footprint or imprint, that has become fossilised

**Transcription** the first stage of protein synthesis in which the base sequence of DNA is copied into mRNA

**Transgenic organism** an organism that possesses a foreign gene or segment of foreign DNA in its genome because of human experimentation

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**Transition metals** the block of metals containing the elements in groups 3 to 12 and in periods 4 to 7 in the periodic table

**Translation** the second stage of protein synthesis in which a sequence of mRNA is translated into a sequence of amino acids

**Trisomy** when an organism has a third copy of a chromosome

**Valence electrons** the electrons in the outer shell of an element

**Valence shell** the outermost shell of the atom that contains electrons

**Validity** the degree to which we accept the suitability of an experiment in addressing the research question, and whether it measures what it says it measures

**Variation** the range of differences or diversity in traits, characteristics or genetic make-up among individuals

**Vector** a quantity having both magnitude and direction

**Velocity ($v$)** change in displacement divided by change in time

**Viable** able to survive

**Weather** the atmospheric conditions (such as temperature, cloud, rain or wind) at a particular time over a particular area

**Weight** the force of gravity on the mass of an object

**White dwarf** a small, dense, dim star that has lost its outer layers and is at the end of its lifetime

**Word equation** a chemical reaction written using the names of the reactants and products involved

**Zero calibration error** a measuring instrument giving a non-zero reading when the true value should be zero

**Zygote** a fertilised egg produced by the fusion of male (sperm) and female (ovum) gametes

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# Index



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CIGOLINI, 3.46 / Sylvain CORDIER, 3.49(1) / Joe McDonald, 3.49(2) / ncognet0, 3.52(1) / TED MEAD, 3.52(2) / Boy_Anupong, 3.52(3) / Print Collector, 3.56 / Peter Funnell, 3.59(1) / Schafer & Hill, 3.59(2) / imageBROKER/ Ulrich Reichel, 3.59(3) / Verónica Paradinas Duro, 3.59(4) / Ирина Мещерякова, 3.62 / Corey Ford/Stocktrek Images, 3.64 / Geography Photos, 3.66e / Alex Potemkin, 3.68(1) / Cavan Images, 3.68(2) / Stocktrek Images, Chapter 4 Opener / Jean-Luc LUYSSEN / Contributor, 4.3 / jamesbenet, 4.9 / Science & Society Picture Library, 4.15 / Ron Miller/Stocktrek Images, 4.37 / The Washington Post / Contributor, 4.43 / Boyer, 4.45 / Science Photo Library - NASA/ESA/STSCI/M.ROBBERTO,HST ORION TREASURY TEAM, 4.46 / Photos.com, 4.47 / Javier Zayas Photography, p.197 / MARK GARLICK/SCIENCE PHOTO LIBRARY, 4.49 / Aaron Foster, Chapter 5 Opener / A. Savin, 5.7 / Jules Ingall, 5.13 / Michael Hall, Table 5.1(1) / Vicki Smith, Table 5.1(2) / Thomas Barwick, Table 5.1(3) / DKAR Images, Table 5.1(4) / Pramote Polyamate, Table 5.1(5) / Bloomberg / Contributor, 5.21 / Ashley Cooper, 5.22 / visionandimagination.com, 5.24 / Chase Dekker Wild-Life Images, 5.28 / filo, 5.32 / uschools, Table 5.2(3) / Ashley Cooper, 5.39 / Yew! Images, Chapter 6 Opener / RG-vc, 6.2 / Kieran Stone, 6.3 / Dave Williams, 6.7(a) / Ralf Bitzer / EyeEm, 6.7(b) / Photography by Mangiwau, 6.7(c) / Matthew Micah Wright, 6.7(d) / SW Photography, 6.10 / Tobias Titz, 6.11 / Graiki, 6.15 / SolStock, 6.16 / Solovyova, 6.18 / Medesulda, p.256 / Diane Keough, 6.31 / imaginima, Table 6.4(1) / parameter, Table 6.4(2) / Digital Vision, Table 6.4(3) / parameter, Table 6.4(4) / AndreyPopov, 6.35(1) / Westend61, 6.35(2) / Johannes Kroemer, 6.37 / Marlon Trottmann, 6.38(1) / mbbirdy, 6.38(2) / Kevin Sabitus / Contributor, 6.39 / Antagain, p.274 / Eternity in an Instant, 6.41 / Cameron Spencer / Staff, 6.42 / Robert Cianflone / Staff, 6.43 / SimonSkafar, 6.47 / Lawrence Lawry, Chapter 7 Opener / Nastasic, p.283(1) / Print Collector / Contributor, p.283(2) / Science & Society Picture Library / Contributor, 7.3 / API / Contributor, p.284(3) / Ted Streshinsky Photographic Archive / Contributor, 7.8 / Betka82, 7.14 / Artur Debat, 7.16(1) / Bettmann / Contributor, 7.16(2) / ALFRED PASIEKA/SCIENCE PHOTO LIBRARY, 7.18 / nemoris, 7.26, 7.27 / Peter Dazeley, 7.38 / Winslow Productions, 7.43 / ADAM BRACKENBURY/SCIENCE PHOTO LIBRARY, 7.45 / Avalon_Studio, 7.47(1) / Vesnaandjic, 7.47(2) / Lighthaunter, 7.48(1) / Kelly Cheng Travel Photography, Chapter 8 Opener / davidf, 8.1 / Roy Alexander / 500px, 8.2 / DNY59, 8.4 / Marcel Rudolph / EyeEm, 8.6 / sdlgzps, 8.10 / Michelle Arnold / EyeEm, 8.12 / Uma Shankar sharma, p.344 / Darknstormy Images, 8.14 / leonard_c, p.346 / Richard Bosomworth / Contributor, 8.15 / Loop Images / Contributor, 8.17 / Sergi Escribano, 8.19 / MirageC, p.349 / Tammy616, 8.22 / Adam Gault, 8.26 / AsiaVision, 8.27 / Jakovo, 8.32 / Peter Dazeley, 8.36 / jcrosemann, 8.42; Image is CC-BY 3.0 AU by M. 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