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Lead author

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About the cover

The Baw Baw frog (*Philoria frosti*) is the only amphibian species endemic to Victoria. It is only found on the Mount Baw Baw plateau, in a unique ecosystem made up of a collection of bogs containing sphagnum moss, which is featured on the cover of this publication. The Baw Baw frog population has declined significantly due to the spread of chytrid fungus, and it also faces threats including climate change, deforestation and the introduction of invasive species. It is listed as Critically Endangered on Victoria's *Flora and Fauna Guarantee Act* 1988 Threatened List.



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Answers are available online in the Online Teaching Suite.
Teachers can enable or disable answers in their students' accounts.

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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. Cognitive verbs appear in bold. 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 five headings: Remembering, Understanding, Applying, Analysing and Evaluating. Cognitive verbs appear in bold.
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 help consolidate the concepts currently being covered.

Practical/Investigation

These activities focus on developing science inquiry skills, including using laboratory equipment. Practicals can be conducted within one lesson, while Investigations are longer and cover more areas of the experimental design. These activities are also available as Word document downloads in the Interactive Textbook.

Worked example

Worked examples are provided for topics that require calculations, or to reinforce important skills.

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End-of-chapter features

Chapter review

Chapter checklist

Success criteria		Linked questions
1.1	I can explain the choice of independent, dependent and controlled variables in a scientific investigation.	2, 14b
1.1	I can refine a research question to target specific information or data collection techniques.	11, 14a
1.1	I can assess the validity of an investigation by defining the terms repeatability, replicability, reproducibility, accuracy and precision.	6, 8
1.1	I can describe the difference between random and systematic errors, and calculate both absolute and relative uncertainty.	10
1.2	I can assess and minimise experimental risk.	3
1.2	I can apply skills in the use of specialised laboratory equipment, such as titration equipment.	11
1.2	I can explain the use of data loggers, models and simulations for gathering reliable data.	5
1.2	I can describe the ethical considerations of using animal and human participants in research.	7, 14d
1.2	I can outline research design features that might be employed in trials involving human participants that will increase the reliability and validity of the findings.	13, 14c
1.3	I can evaluate the validity of claims in primary and secondary data.	4, 9, 12

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

Data questions

Applying

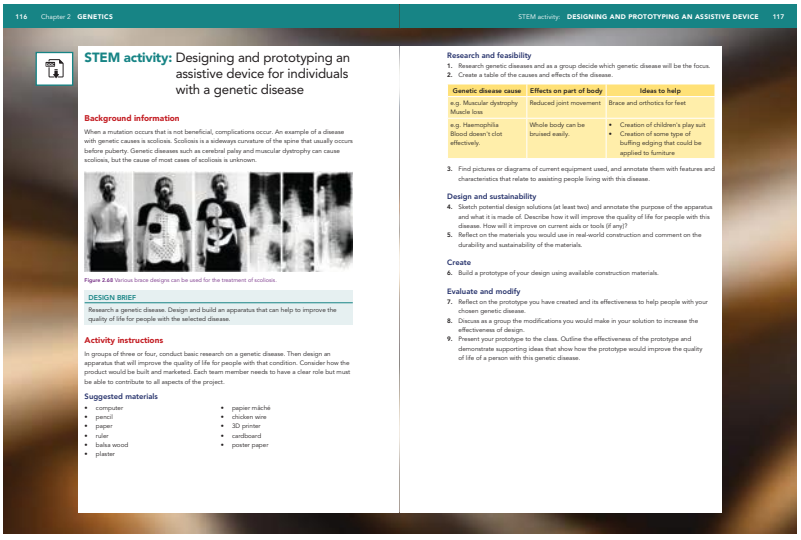
1. The table below shows the effect of changing the pH of a pond on the number of tadpoles in the pond.

Table showing the number of tadpoles according to the pH of pond water

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 and dependent variables in this study.
b) **Identify** the optimum pH for tadpole survival.
c) **Identify** an outlier in the data.

Data questions help students apply their understanding, as well as analyse and interpret different forms of data linked to the chapter content. These questions can be completed in the Interactive Textbook or downloaded as Word documents.


116 Chapter 2 GENETICS

STEM activity: DESIGNING AND PROTOTYPING AN ASSISTIVE DEVICE 117

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 cases of scoliosis is unknown.

Figure 2.68 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.

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.	• Creation of children's play suit • 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 real-world problems and challenges.

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Links to the Interactive Textbook (ITB)

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.

These icons indicate worksheets, activities or question sets can be downloaded from the Interactive Textbook.

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

SCORCHER
Competitive questions can be found in the Interactive Textbook for every chapter review.

These icons indicate questions can be completed in workspaces in the Interactive Textbook.

Overview of the Interactive Textbook

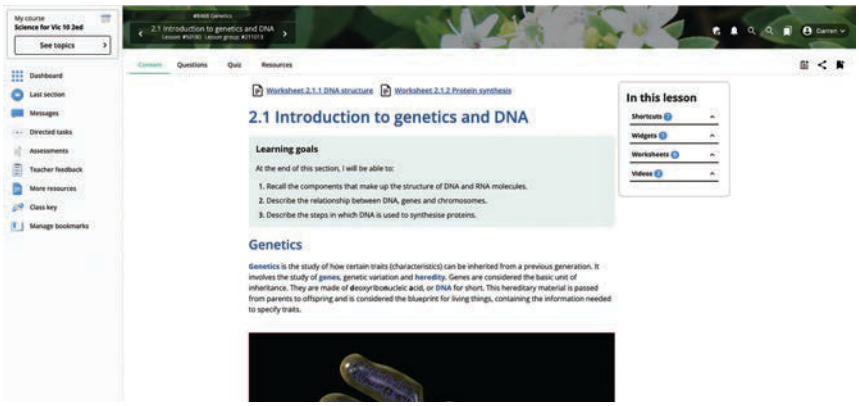
The **Interactive Textbook (ITB)** is an online HTML version of the print textbook, powered by the Edjin platform. It is included with the print book or available as a separate digital-only product.

Definitions pop up for key terms in the text.

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

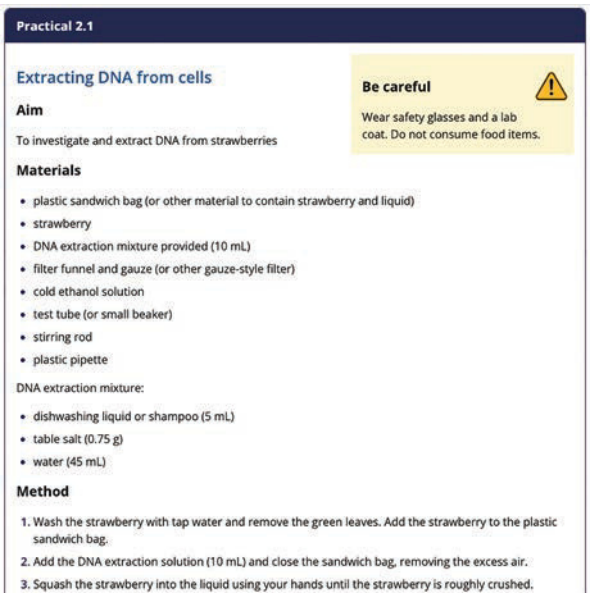
Worksheets are provided as downloadable Word documents.

Videos summarise, clarify or extend student knowledge.



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

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

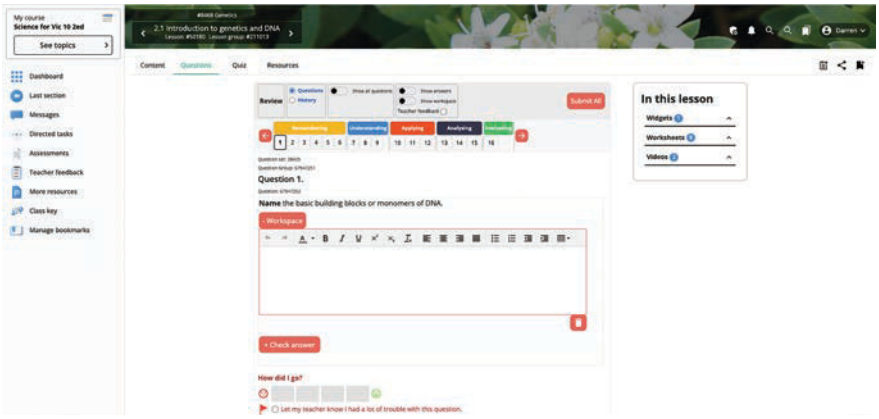


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Workspaces enable students to enter working and answers online and to save them. Input is by typing, handwriting and drawing, or by uploading images of writing or drawing.

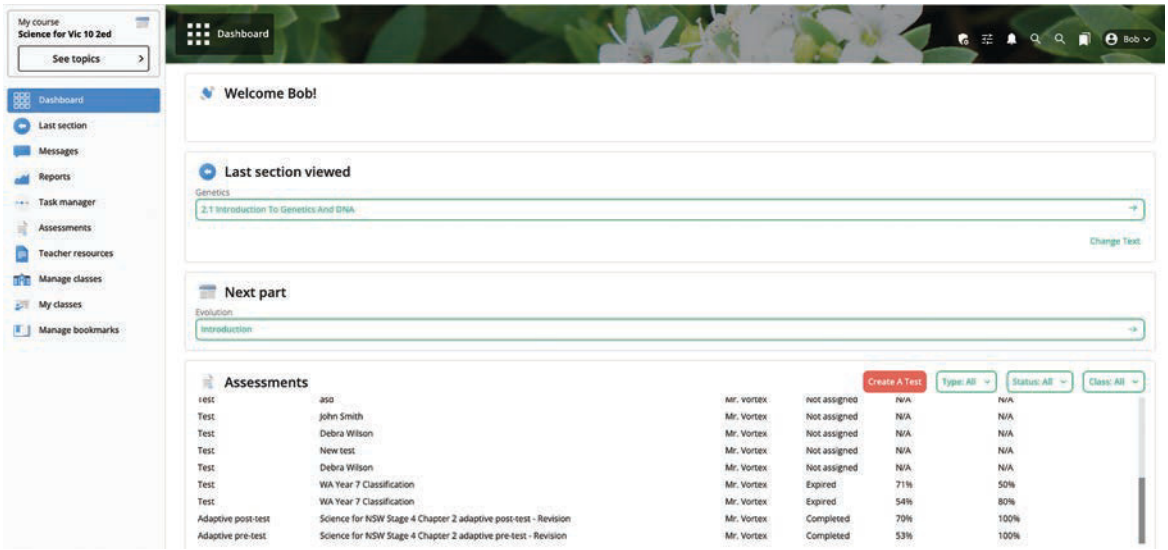
Self-assessment tools enable students to check answers, mark their own work and rate their confidence level in their work. Student accounts can be linked to the learning management system used by the teacher in the Online Teaching Suite.



Overview of the Online Teaching Suite (OTS)

The **Online Teaching Suite (OTS)** 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:

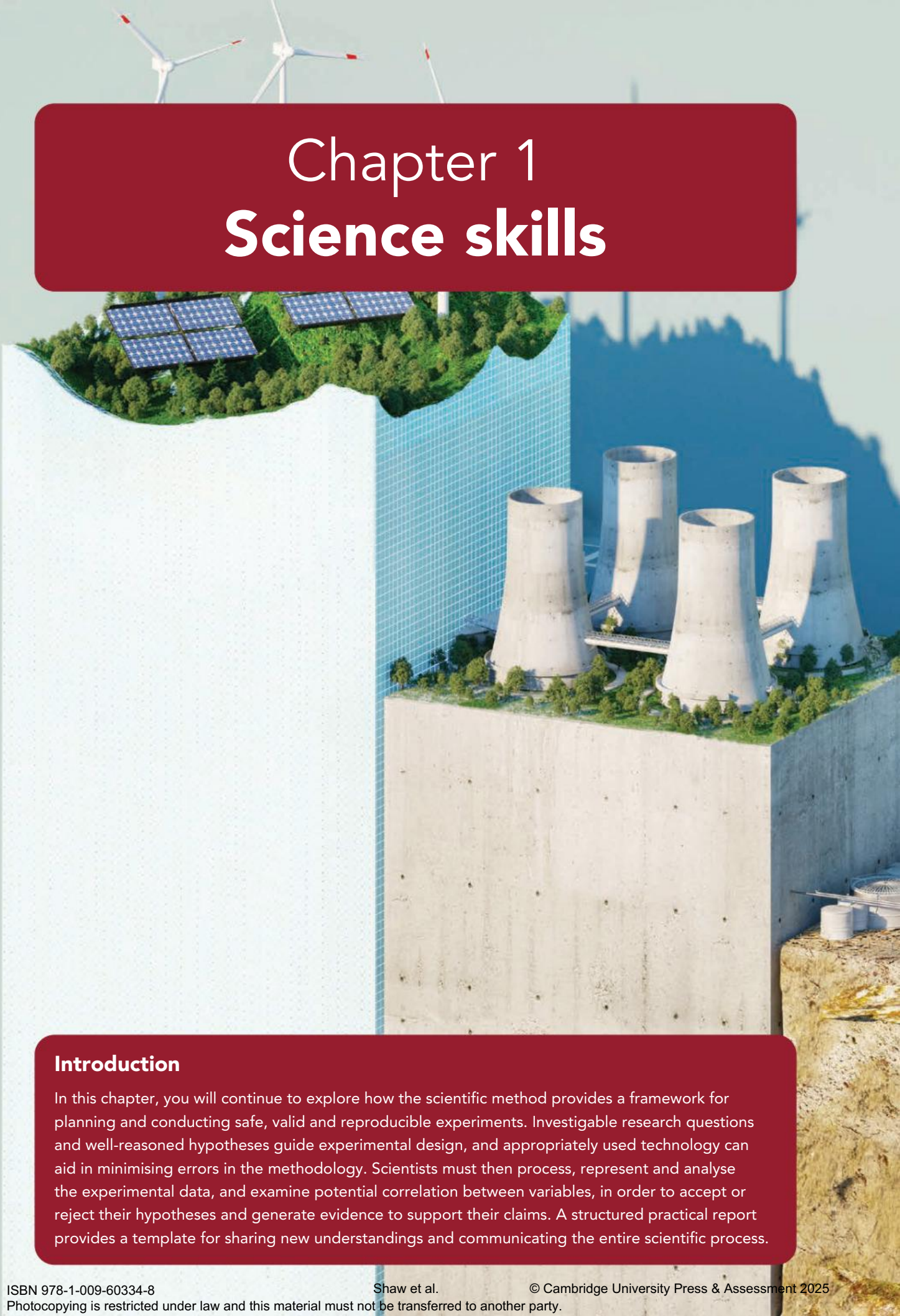
- the **Edjin learning management** system with class and student analytics and reports, and communication tools
- teacher's view of **students' working and self-assessment**
- **chapter tests** and **worksheets** as PDFs and as editable Word documents with answers
- editable **curriculum grids** and **teaching programs**
- **teacher notes** (including suggested responses if relevant) for Practicals, Try this, Making thinking visible, Explore! and STEM activities.
- **adaptive tools**, including ready made pre- and post-tests and intuitive reporting.



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Chapter 1
Science skills



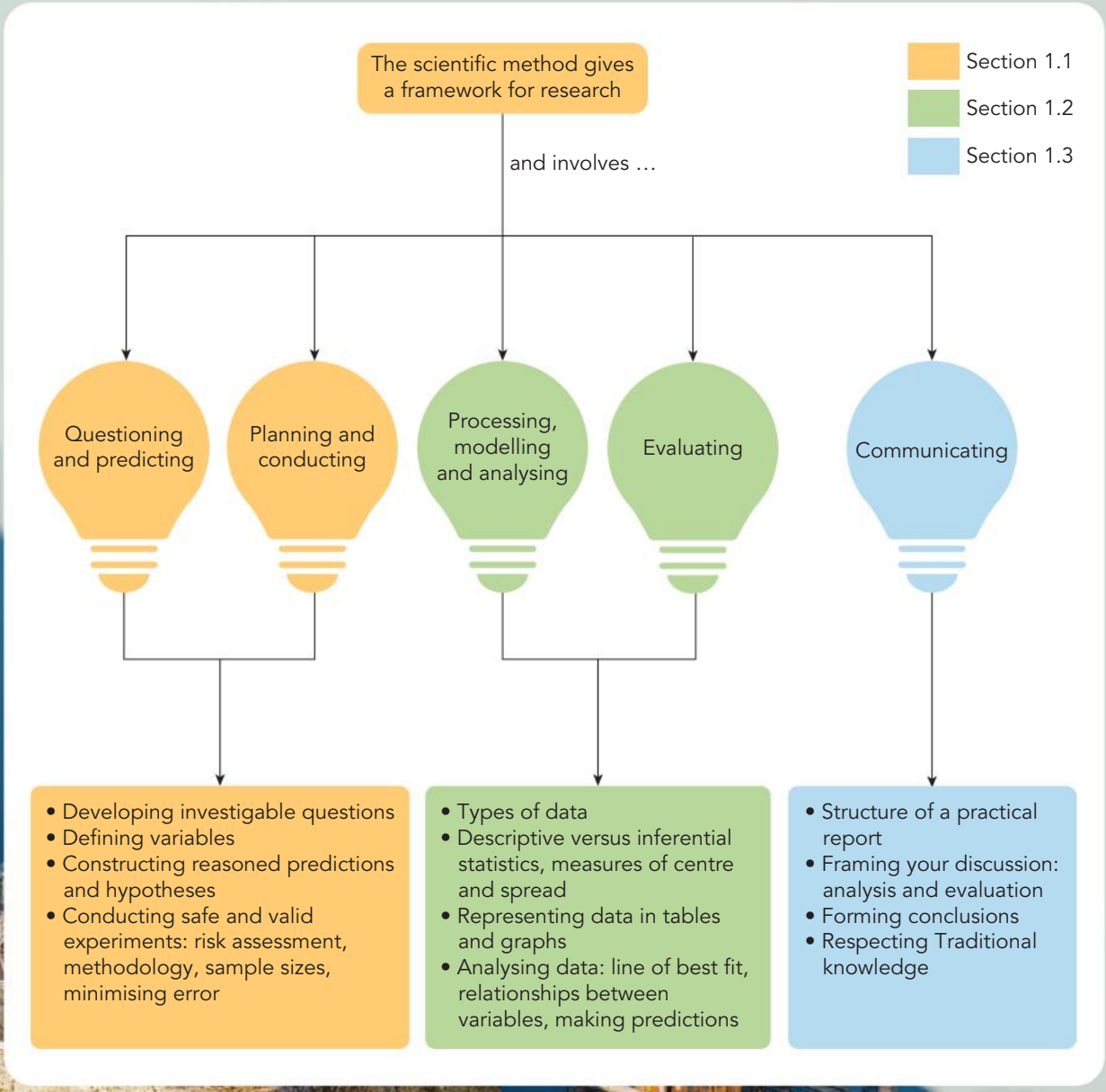
Introduction

In this chapter, you will continue to explore how the scientific method provides a framework for planning and conducting safe, valid and reproducible experiments. Investigable research questions and well-reasoned hypotheses guide experimental design, and appropriately used technology can aid in minimising errors in the methodology. Scientists must then process, represent and analyse the experimental data, and examine potential correlation between variables, in order to accept or reject their hypotheses and generate evidence to support their claims. A structured practical report provides a template for sharing new understandings and communicating the entire scientific process.

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Concept map



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Curriculum content

Questioning and predicting	
investigable questions, reasoned predictions and hypotheses can be used in guiding investigations to test and develop explanatory models and relationships (VC2S10I01)	1.1
Planning and conducting	
valid, reproducible investigations to answer questions and test hypotheses can be planned and conducted, including identifying and controlling for possible sources of error and bias in sampling or in making observations; safe, ethical investigations include undertaking risk assessments and following protocols when accessing cultural sites and artefacts on Country and Place (VC2S10I02)	1.1
equipment can be selected and used to generate and record data sets that show precision, including consideration of sample size and using digital tools as appropriate (VC2S10I03)	1.1
Processing, modelling and analysing	
data and information can be organised, processed and summarised by selecting and constructing representations including tables, graphs, descriptive statistics, models, symbols, formulas and mathematical relationships (VC2S10I04)	1.2
information and processed data can be analysed and compared to identify and explain qualitative and quantitative patterns, trends, relationships and anomalies (VC2S10I05)	1.2
Evaluating	
the validity and reproducibility of investigation methods and the validity of conclusions and claims can be evaluated, including by identifying assumptions, conflicting evidence, biases that may influence observations and conclusions, sources of error and areas of uncertainty (VC2S10I06)	1.3
arguments based on a variety of evidence can be constructed to support conclusions or evaluate claims, including consideration of any ethical issues and cultural protocols associated with accessing, using or citing secondary data or information (VC2S10I07)	1.3
Communicating	
communicating and justifying scientific ideas, findings and arguments for diverse audiences involves the selection of appropriate presentation formats, content, scientific vocabulary, conventions, models and other representations, and may include the use of digital tools (VC2S10I08)	1.3

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Glossary terms

Accurate	Extrapolation	Non-linear
Causation	Half-life	Ordinal data
Continuous data	Hypothesis	Origin
Control group	Independent variable	Outlier
Controlled variable	Inferential statistics	Personal error
Correlation	Interpolation	Prediction
Culturally responsive	Investigable	*p*-value
Dependent variable	Linear	Random error
Descriptive statistics	Mean	Repeatability
Discrete data	Median	Safety data sheet
Exponential	Mode	Systematic error
Extraneous variable	Nominal data	Validity

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1.1 Experimental design

Learning goals

At the end of this section, I will be able to:

1. Recall the steps of the scientific method.
2. Develop an investigable research question.
3. Identify the independent, dependent, controlled and extraneous variables in a scientific investigation.
4. Construct a hypothesis to test an identified relationship.
5. Plan and conduct a safe and valid experiment.
6. Discuss how to minimise errors using technology.

The scientific method

Scientists the world over, from students through to research professionals, follow a systematic approach towards experimentation known as the scientific method. The framework shown below outlines the steps involved in planning, conducting, analysing and reporting upon an investigation to ensure the claims are valid.

STEP 1: Observe and ask questions
A research question may be identified once an area of scientific interest has been analysed.

↓

STEP 2: Do background research (rationale)
A rationale is a concise version of a literature review. A scientist who is interested in conducting an experiment on a certain topic of interest will first search relevant scientific literature. This requires the ability to find and analyse past research articles and results.

↓

STEP 3: Define variables and state a hypothesis
A hypothesis is a testable prediction about the relationship between two or more variables. It is formulated using the scientific knowledge obtained from the scientific literature. It is not just simply a haphazard guess without any prior knowledge – it is more of an educated guess. You should also state your independent, dependent and controlled variables.

↓

STEP 4: Outline methodology
An experiment may include controlled laboratory experiments, naturalistic observations, case studies, surveys and interviews. Conducting the experiment requires a specific methodology. The methodology usually contains at least two sections:
- materials (lists the scientific equipment and materials required to conduct the experiment)
- method (a step-by-step procedure of how the experiment is conducted).

There may also be a section detailing how risks are to be managed during the experiment, including how any waste products should be disposed of. If human participants are used, the methodology should detail their demographics, how they are to be sampled and allocated, the research design and the ethics approval process.

↓

STEP 5: Collect and record the data
Data collection is of utmost importance in any scientific experiment. This step involves organising, summarising and representing the data that was collected in the experiment (raw data) in a meaningful way. Generally, descriptive statistics are used to organise and summarise the data. Graphs and tables can be used to represent the data, and calculation of means, medians or modes can be used to summarise the data. Error bars can 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 there should be an identification of the uncertainty and limitations of evidence.

↓

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

↓

STEP 9: Communicate your findings
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.

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The success of a scientific investigation depends on several factors before it even begins:

- a specific and worthwhile research question
- reasoned predictions and precisely controlled variables
- careful planning and identification of risks, sources of error and ethical issues before they arise.

Developing a research question

investigable able to be tested through research or experimentation

Science is a discipline that relies heavily on collecting and analysing data. The aim of any scientific investigation is to gather data that can be analysed to provide answers to research questions. The research question should be **investigable**, and practical in terms of the skills and resources required. Scientists must also consider if the research question is worthwhile. Ideally, the conclusions drawn would offer some new scientific understanding or demonstrate a concept in a new way.

For a question to be investigable, it needs to meet the criteria outlined in Table 1.1.

Criteria	Description
Specific	The question needs to be clear and unambiguous. It should be well defined so that it can be investigated systematically.
Testable	The question should be testable through experimental procedures. It should be possible to collect data or information that can be used to answer the question.
Relevant	The question should be relevant to the field of study. It should address an important issue or problem and have the potential to contribute to existing knowledge.
Feasible	It should be possible to collect the necessary data or information, and conduct the investigation using the available resources, time and budget.
Novel	Ideally, the question should not have been investigated before or should have a different approach or perspective from previous investigations.

Table 1.1 The criteria for a question to be considered investigable

Try this 1.1

Investigable questions: The effect of exercise

After going for a run, you may have noticed several physiological responses, such as sweating, feeling hot, vasodilation (the dilation of blood vessels, which gives your skin a red appearance), and an elevated heart rate and rate of breathing.



Figure 1.1 An example of an investigable question related to exercise is 'How does the height of a box jump influence my chance of injury?'

1. Formulate an investigable research question regarding exercise and one of the responses mentioned above.
2. Critique your research question against the criteria from Table 1.1:
   a) Is it specific and unambiguous?
   b) Is it possible to conduct an experiment to test it? Some of the physiological responses shown above are much easier to objectively measure than others.
   c) Is it relevant?
   d) Is it feasible? (What materials would you require? Do you have the skills, time and access to the necessary resources?)
   e) Is it novel?

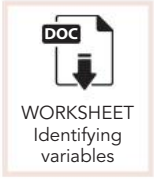
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Once an investigable question has been developed, it is necessary to conduct some background research on the topic. This may involve reading about explanatory models, reviewing publications of other scientists' results and writing a short rationale that justifies the need for your research. This will also help in defining the experimental variables and informing the materials, method and data analysis techniques you will use.

Quick check 1.1

1. **List** the first four steps in the scientific method.
2. **Name** three criteria an investigable question should meet.
3. **Develop** an investigable question regarding plant growth.

Defining experimental variables



WORKSHEET
Identifying variables

Your research question might lead to an experiment that investigates whether there is a cause-and-effect relationship between two variables. For example, you might be interested in how the height of a ramp influences the distance a toy car will travel. The variable that is deliberately changed by the experimenter is known as the **independent variable**. The variable being measured, as a result of changes to the independent variable, is the **dependent variable**.

In the example shown below (see Figure 1.2), the experimenter might conduct multiple trials of the experiment, changing the height of the ramp each time. Therefore, the height of the ramp (in centimetres) is the independent variable. The distance the car travels (in centimetres; i.e. the distance it takes to come to a stop) is the dependent variable. It is important to specify the units of measurement you will use for your variables.

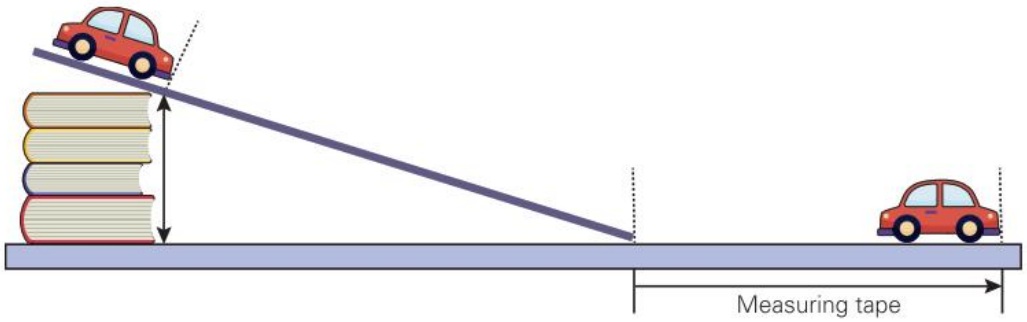


Figure 1.2 How does the height of a ramp affect the stopping distance of a toy car?

Other factors can have an impact on the investigation, either by introducing a source of error or by affecting the dependent variable. These are referred to as **extraneous variables**. In the experiment shown above, the floor surface (such as tiles versus carpet) could have a significant effect. In order to make a claim regarding **causation**, the scientist conducting the experiment must keep all extraneous variables the same throughout the experiment. This process is called controlling the variable. For example, if temperature or time of day is likely to affect the dependent variable, you would keep the temperature of the room consistent or conduct each trial at the same time of day. In this way, the influence of extraneous variables is eliminated, and they become **controlled variables**.

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

extraneous variable
a variable other than the independent variable that may affect the dependent variable; if not controlled, it can influence experimental results and lead to false conclusions

causation
where one event is caused by another event occurring

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

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control group
a group that is not subjected to the independent variable in an experiment and therefore provides a baseline for comparison

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

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

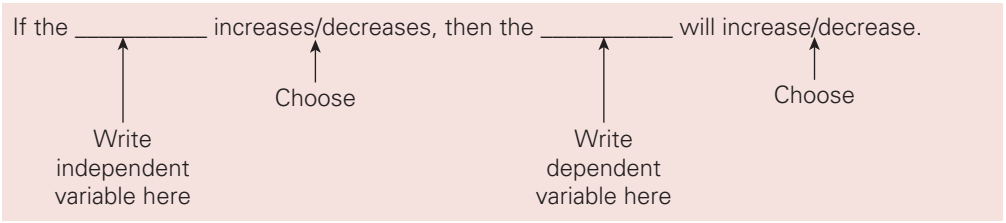
In certain experimental designs, it is appropriate and necessary to include a **control group**. This allows for a direct comparison of the effect of the independent variable. The control group do not receive the 'intervention' of having the independent variable changed. For example:

- In an experiment investigating how moderate exercise affects heart rate, there should be a control group in which the participants do not undertake any exercise. The participants in the control group would take repeated measures of their heart rate at rest over the same time period as the intervention (exercising) group, and the data would act as a baseline for comparison. This would allow the experimenter to infer that it was the exercise resulting in the increased heart rate, rather than an environmental factor such as an increase in temperature during the experiment.
- In an experiment investigating how increasing temperature affects the action of enzymes in breaking down food, matched test tubes at each temperature (without the enzyme present) act as control groups. They allow the experimenter to infer that it is the enzyme that is having an effect (breaking down the food), rather than the change in temperature itself.

Constructing a hypothesis

A **hypothesis** is based on existing knowledge and observations. It is an educated guess that is made before conducting an experiment or making observations. For a hypothesis to be considered scientific, it must be testable and should be able to be supported or refuted (shown to be wrong). It is typically a statement that can be tested through experimentation or observation, and which indicates the expected effect the independent variable will have on the dependent variable.

You can use the following 'If … then …' framework for constructing a hypothesis:



For example:

'If the height of the ramp (in centimetres; cm) increases, then the stopping distance of the car (in cm) will increase.'

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

Quick check 1.2

1. **Describe** the difference between an extraneous variable and a controlled variable.
2. **Construct** a hypothesis, using the 'If ... then ...' framework, relating to plant growth and amount of sunlight.

Conducting your investigation

The culmination of your background research and thorough experimental design is conducting a safe and valid investigation. As a researcher, you must select appropriate methods and techniques for data collection and analysis, consider risk, minimise sources of bias and uphold ethical principles throughout experimentation.

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Risk management

Identifying potentially hazardous materials and processes used in experimental investigations is an essential part of planning and conducting experiments. Hazards can include biological and chemical materials, such as infectious bacteria and flammable liquids, respectively.

Researchers must carefully evaluate the risks associated with the use of these materials and take appropriate measures to ensure the safety of themselves, their colleagues and the environment. This may involve:

- using personal protective equipment (PPE), such as gloves, safety glasses and respirators to prevent exposure to hazardous substances
- complying with safety protocols, as specified on the **safety data sheet** (SDS), for handling and disposing of materials
- ensuring that all equipment is properly maintained and calibrated
- ensuring everyone is familiar with emergency procedures (e.g. what to do in the case of a chemical spill or fire and when to evacuate).





Figure 1.3 Personal protective equipment (PPE) varies according to the materials and equipment being used.

Experimental method

It is crucial to choose an appropriate method for an experiment to ensure that the results are valid and reproducible. **Validity** refers to the extent to which an experiment measures what it is intended to measure. A valid experiment should produce results that are a true reflection of the phenomenon being studied. **Repeatability** refers to the ability to repeat an experiment and obtain consistent results each time it is performed.

Ensuring both validity and repeatability relies upon:

- using reliable and **accurate** measurement tools
- selecting large enough sample sizes
- adequately controlling any extraneous variables
- using appropriate data analysis techniques
- clearly documenting procedures in a step-by-step method so that other researchers could reproduce the study. This is true of both laboratory experiments and other methodologies, such as fieldwork and observational studies.

Experimental errors

When designing and conducting scientific experiments, it is important to identify and address potential sources of error to ensure that the results are accurate and reliable. Errors can include **systematic errors**, such as consistent errors in instruments or the experimental procedure, and unpredictable **random errors** that occur due to chance. **Personal errors** are a type of random error and include mistakes and miscalculations.

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

validity the extent to which a study accurately measures or tests what it was intended to measure or test

repeatability how consistent the results are when the same scientist repeats the experiment under the same conditions as the original experiment

accurate measures closely match the 'true' or accepted values

systematic error an error that causes measurements to differ from the true result by a consistent amount, often due to faulty or uncalibrated equipment

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

personal error a type of random error that arises from mistakes or miscalculations by the person conducting the experiment



WORKSHEET
Valid scientific methods

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To identify these sources of error, researchers need to carefully examine the methods used in the experiment. Once potential sources of error have been identified, researchers may need to conduct further testing or implement additional controls to minimise their impact. This may involve using more precise instruments, repeating experiments to establish consistency, or controlling variables that could influence the results.

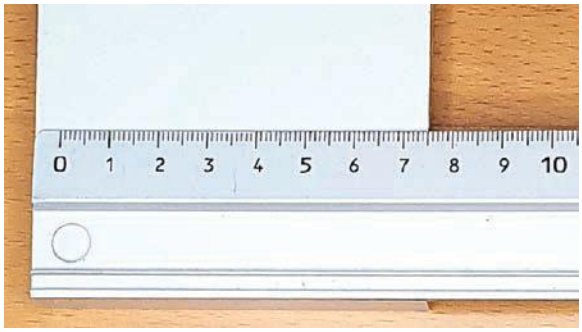


Figure 1.4 What systematic error can you identify in this picture?

Appropriate sample sizes

When designing and conducting an experiment, it is important to use an appropriately sized sample. A large sample size reduces the chance that the results have been obtained due to random errors, and yields more accurate and reliable results.

For example, when investigating the effects of a new fertiliser, it should be trialled on hundreds of different seedlings in different conditions before drawing conclusions about its efficacy. The data could be collated and averaged to reduce the statistical impact of plants that grew extremely poorly or unusually well. When using a sample size that is too small, the results become highly subject to chance. If a sample size of just five seedlings was used, and the plants failed to grow because by chance the lighting conditions were inadequate, then the scientist might falsely conclude that the fertiliser was ineffective. Likewise, if the five seedlings used were somehow not representative of normal seedlings (e.g. they were all poor specimens), then the results would not be valid or useful.

However, a large sample size is not always necessary or feasible, particularly in cases where the data is highly consistent, or due to experimental or financial limitations. A balance must be struck.



Figure 1.5 Often, the larger the sample size, the more representative of the population it is, and the more accurate and reliable the research results are.

Quick check 1.3

1. **State** whether a small sample size affects the validity or repeatability of a scientific study.
2. **Recall** what 'SDS' stands for.
3. **Contrast** random and systematic experimental errors.

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Minimising errors using technology

When completing an experiment, it is essential to use appropriate instruments that provide the required degree of accuracy. The accuracy of an instrument refers to its ability to measure a value close to the true value. Different instruments have varying degrees of accuracy. For example, a measuring cylinder can be used to measure liquids, but it has a lower degree of accuracy than a pipette (see Figure 1.6).

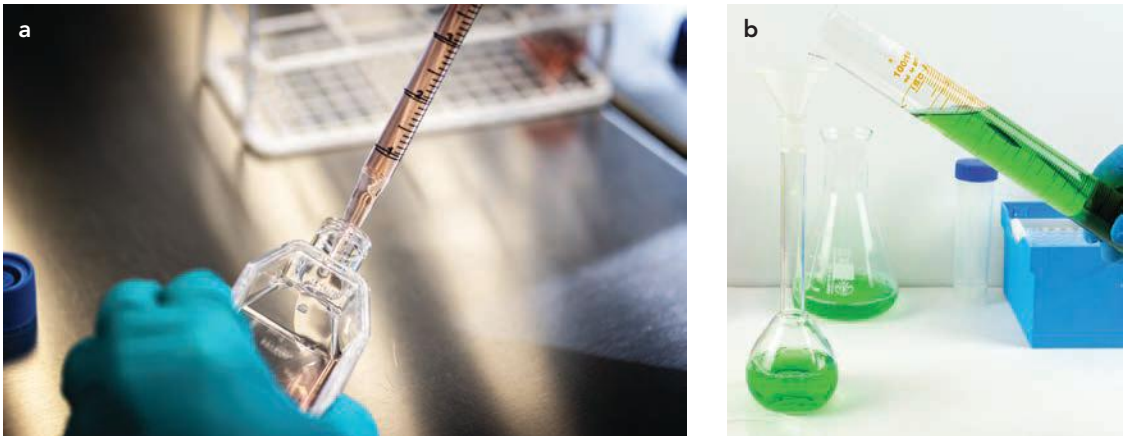


Figure 1.6 (a) A pipette gives a greater degree of accuracy for measuring out liquids than does **(b)** a measuring cylinder.

A data logger is an electronic instrument used to collect data over time. They can be attached to other devices, such as temperature and pH probes, to monitor how a variable changes over the course of an experiment. This saves the experimenter time as they do not have to take repeated measurements manually, and it reduces the possibility of experimenter error in timing their measurements or interpreting the scale on the measurement instruments. Data loggers can also be used with equipment such as weather stations to monitor environmental conditions over longer periods of time.



Figure 1.7 Weather stations are systems that measure and record weather conditions such as temperature, humidity, wind speed and direction, and precipitation. They typically contain a variety of sensors and instruments that are connected to a data logger, which collects and stores the data.

When using data loggers, it is important to choose the correct scale and select the appropriate range of values for the data logger to measure. For example, if you are monitoring the outdoor temperature in Melbourne, you might choose a scale that ranges from –5°C to 50°C, which is wide enough to capture the expected range of temperatures.

Digital tools have revolutionised the way scientific data is collected, managed and analysed, and they can make data collection more efficient for larger sample sizes. Digital tools such as online surveys, mobile apps and wearable devices can be used to collect large amounts of data quickly and accurately.

Relying on digital tools for data collection can reduce the potential for human error and bias. For example, online surveys can be programmed to skip irrelevant questions, ensuring that respondents only answer questions that apply to them. Wearable devices can capture physiological data automatically, reducing the risk of participants measuring data incorrectly or responding in subjective ways.

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Digital tools can also help in data management and analysis, particularly for larger sample sizes. Digital tools can be used to automate data entry, reducing the time and resources required for collecting and collating data. They can also facilitate complex data analysis, allowing large amounts of data to be analysed quickly and efficiently.

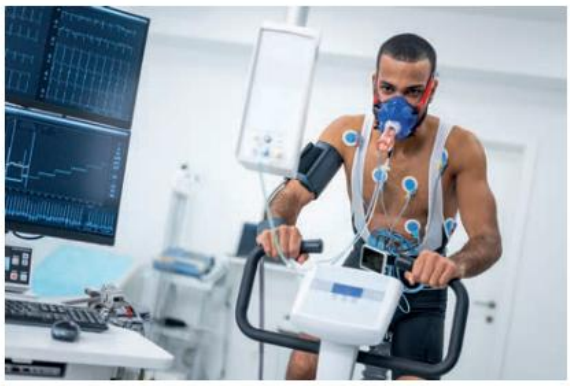


Figure 1.8 Digital measurement tools can capture accurate physiological data in real time.

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Section 1.1 review

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Section 1.1 questions

Remembering

1. **List** three examples of personal protective equipment (PPE).
2. **Recall** the five criteria for a research question to be considered 'investigable'.
3. **Define** 'independent variable', 'dependent variable', 'extraneous variable' and 'controlled variable'.

Understanding

4. **Outline** one advantage of using digital tools, such as data loggers, to capture experimental data.
5. A faulty stopwatch has a stiff 'stop' button and hence regularly overestimates the recorded time by half a second. **Identify** which type of experimental error is represented in this scenario.

Applying

6. **Sequence** these steps of the scientific method in the correct order:
   - do background research
   - communicate your findings
   - observe and ask questions
   - test the hypothesis with an experiment
   - define variables and state a hypothesis
   - analyse the data
   - evaluate the data
   - form a conclusion
   - collect and record the data

Analysing

7. **Contrast** systematic and random errors.

Evaluating

8. An experiment investigating learning examines how a mouse's behaviour changes in response to food rewards. When a mouse correctly travels through a maze, it receives a piece of cheese. The maze is made progressively more complex by adding corners, and the time taken to reach the cheese is recorded by the experimenter using a stopwatch.
   a) **Identify** the independent variable and the dependent variable in this experiment.
   b) **Construct** a hypothesis for this experiment.
   c) **Justify** why conclusions drawn from this experiment are not reliable, given the small sample size.
   d) **Propose** a digital tool that could be used to minimise experimenter error.

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1.2 Drawing conclusions from data

Learning goals

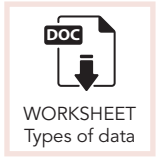
At the end of this section, I will be able to:

1. Classify data types.
2. Calculate descriptive statistics for a dataset.
3. Select and construct appropriate representations of data.
4. Analyse and connect a variety of data and information to identify and explain patterns, trends, relationships and anomalies.

At the conclusion of a scientific investigation, the gathered data must be processed, modelled and analysed to collect evidence to support or refute the hypothesis and generate valid conclusions. The way that data is handled and represented depends on the data type. Calculating descriptive statistics and identifying trends and anomalies offers insight into the relationships between variables and the likelihood of causation.

Types of experimental data

Data that has been generated from your own research is referred to as primary data. You may also access secondary data, which has been collected by other authors. Secondary data includes the data reported by the Census, raw data collected by someone else, or published research summaries.



Did you know? 1.1

The Census

Every five years, the Australian Bureau of Statistics (ABS) conducts its national Census of Population and Housing in Australia. Compulsory paper questionnaires and online forms collect data from every member of the population on topics such as income, ancestry, religion, work, health and education. This gives a snapshot of the social, economic and cultural make-up of Australia and is used to inform government policies. You can access and download deidentified Census secondary data on the ABS website for use in your own research or projects.

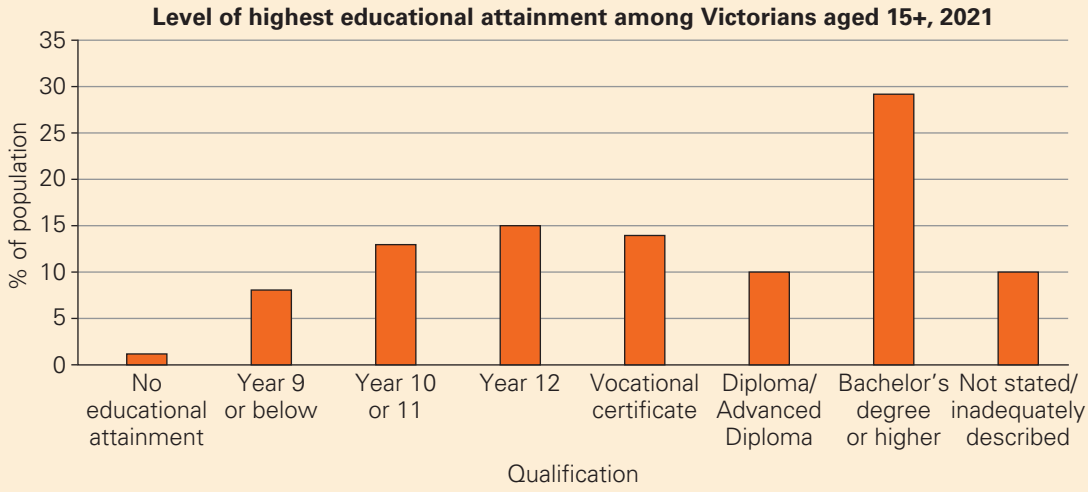


Figure 1.9 The highest level of education attained by the 6 503 491 Victorians aged 15+ who responded to the Census in 2021.

Source of data: Australian Bureau of Statistics.

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continuous data quantitative (numerical) data points that have a value within a range; this type of data is usually measured against a scale that may include decimals or fractions

discrete data quantitative (numerical) data points that tend to have whole numbers; this type of data is usually counted

ordinal data qualitative (categorical) data where the categories have an order

nominal data qualitative (categorical) data where the categories have no clear order

descriptive statistics mathematical tools used to summarise and describe datasets (e.g. measures of centre and spread)

inferential statistics mathematical tools that allow scientists to make claims regarding cause-and-effect relationships between variables by analysing the changes in datasets

***p*-value** a value that determines the statistical significance of results by gauging the level of probability that the difference between two group's results is due to chance

Quantitative data is numerical in nature and can be categorised as continuous or discrete. **Continuous** data is typically measured, and the values fall along a range (e.g. mass in milligrams). **Discrete** data is typically counted and tends to include whole integer values (e.g. the number of seeds that germinated).

Qualitative data is descriptive or categorical in nature. It is often less objective than quantitative data because it relies on the interpretation of the observer. Qualitative data is valuable for describing phenomena that cannot be captured numerically. **Ordinal** data uses categories that have a natural order (e.g. classifying the amount of bubbles produced in a reaction as none, low, moderate or high). **Nominal** data uses mutually exclusive categories that have no natural order (e.g. the classification of red blood cells under the microscope as normal, shrivelled or lysed).

Try this 1.2

Data types

Data can be represented in a variety of ways. Examine the graph below and classify the type of data that was collected.

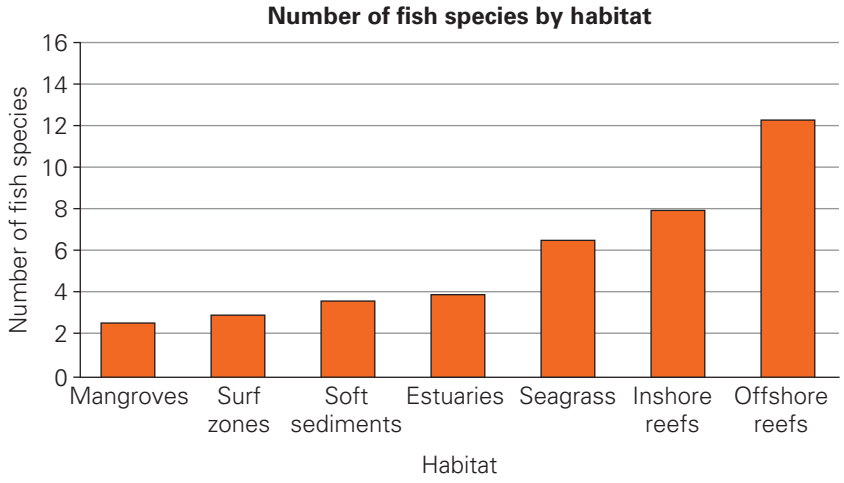


Figure 1.10 Data represented in a column graph

Processing data

Descriptive statistics are used to organise and summarise data. This includes calculating percentages, measures of central tendency and measures of spread. Descriptive statistics only describe the data and do not allow for interpretation of relationships or claims of causation between the variables. Spreadsheet software allows for efficient calculations of descriptive statistics for large datasets.



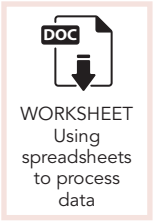
Water only (control group) Water and fertiliser (experimental group)

Inferential statistics allow scientists to infer cause-and-effect relationships between variables. Mathematical calculations can generate a statistic known as the ***p*-value**, which tells us the probability that the difference in two group's results is due to chance. You will see this statistic used widely in professional publications such as scientific journals.

For example, one group of plants were provided with fertiliser in addition to water (experimental group) and one group received water alone (control group). A hypothesis was generated: 'If increased levels of fertiliser are provided, then the growth of the plant will also increase.' After several weeks, their growth was measured and the experimental group demonstrated greater growth.

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But how does the researcher know if this was due to the independent variable, or due to other extraneous variables or even due to chance? Inferential statistics allow the researcher to calculate the statistical significance of the difference. If the generated *p*-value is less than 0.05, then this means there is a less than 5% chance the results are due to chance; that is, there is a 95% chance that the difference is the result of the independent variable (fertiliser). This *p*-value is an accepted cut-off in scientific literature and allows the scientist to confidently conclude that the hypothesis is supported.



WORKSHEET
Using spreadsheets to process data

Measures of central tendency

When conducting experiments with multiple trials, several values are obtained, which then need to be summarised into one representative value. Using descriptive statistics, we can calculate the average to gauge the central value (or 'central tendency') of a dataset. The three commonly used measures of central tendency are the mean, median and mode.

The **mean** is used to measure the centre of a dataset 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. It is found by arranging values in ascending order and then locating the middle data point (or average of the two middle points in the case of a dataset with an even number of values). The median is the value that has an equal number of data points 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 dataset.

mean
the total of a set of values divided by the number of values in that set

outlier
an extreme data point – a number that is very different from the rest of the data collected

median
the middle value of the dataset after all the values have been ranked (sorted in ascending order); there should be as many values below the median as above it

mode
the most frequently occurring value or values in a dataset

Worked example 1.1

Determining the mean, median and mode of a dataset

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, repeating this 10 times. Their results in minutes are: 2, 4, 4, 2, 2, 2, 3, 2, 13, 4.

Determine the mean, median and mode of the dataset.

Working	Explanation
Calculating the mean	
$\frac{(2 + 4 + 4 + 2 + 2 + 2 + 3 + 2 + 13 + 4)}{10} = 3.8$	To calculate the mean, we add all the values. Then we divide that total by the number of values. In this case, there are 10 values and the mean is 3.8.
Determining the median	
2, 2, 2, 2, 2, 3, 4, 4, 4, 13	First, we need to order the values from smallest to largest.
2, 2, 2, 2, **2**, **3**, 4, 4, 4, 13	If there is an odd number of values, then we pick the middle number. In this case, there is an even number of values, so we must find the mean of the two middle numbers.
$\frac{(2 + 3)}{2} = 2.5$	To find the mean of the two middle numbers, we add them together and divide by 2. In this case, the median is 2.5 minutes.
Determining the mode	
2, 2, 2, 2, 2, 3, 4, 4, 4, 13	First, we need to order the values from smallest to largest.
2, **2**, **2**, **2**, **2**, 3, 4, 4, 4, 13	The value '2' occurs more frequently than any other value in this dataset; therefore, the mode is 2 minutes.

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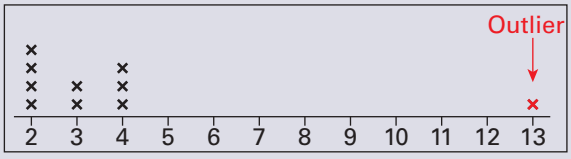
Measures of spread

We can also measure the distribution of the data. This provides information about the spread of a particular variable's values. The simplest way of doing this is to calculate the range, which is the difference between the smallest and largest values. Note that outliers can be excluded from range calculations if you judge them to be the result of an error; however, this is an important point of discussion in your evaluation of the data.

Worked example 1.2

Identifying outliers and determining the range of a dataset

Using the data from Worked example 1.1, determine which data point is a likely outlier, and calculate the range of the data. The results of time taken for water to boil in minutes (ranked) are: 2, 2, 2, 2, 2, 3, 4, 4, 4, 13.

Working	Explanation
Create a line plot of the data:  	Creating a line plot allows us to easily see that 13 minutes is likely to be an outlier. Given it was a measurement of the time taken for water to boil, this is likely to be a result of a procedural or human error.
2, 2, 2, 2, 2, 3, 4, 4, **4** Smallest Largest	Remove the outlier from the dataset, re-rank, and identify the smallest and largest values.
Range = 4 – 2 = 2 minutes	Subtract the smallest value from the largest value.

Range bars can be plotted on graphs to visually represent this information. The larger the range bars, the more variation there is in the variable's values, suggesting that the data is less reliable. 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.

Try this 1.3

Descriptive statistics

Consider the following dataset: 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 program and explore how you can determine the mean, median, mode and range of the data by using formulas and functions within the program.

Representing data

To analyse the trends in data and make meaning of the results, it is important that results are organised in tables and presented in appropriate and meaningful ways. The data type informs the choice of representation: bar and column graphs are appropriate for qualitative data, while histograms, scatterplots and line graphs are useful for quantitative data.

Tables of data

Tables are useful for recording data during an experiment, but also for displaying results, including descriptive statistics such as averages. The independent variable should be listed in the first column,

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with the unit of measurement in the title rather than replicated for each measurement. The dependent variable measurements should be listed in the second and subsequent columns, with or without a final column showing the mean (see Figure 1.11).

Independent variable placed in first column, with one column of dependent variable results for each trial

Clear title

Unit of measurement specified in heading

Table: 'Height of bubbles produced when bicarbonate soda reacts with vinegar, according to the mass of bicarbonate soda'

Mass of bicarb soda (g)	Height of bubbles (mm)			
	Trial 1	Trial 2	Trial 3	Mean (average)
1.5	89	91	90	90
2.0	102	100	104	102
3.0	160	167	168	165

Consistent number of decimal places

Figure 1.11 A table of results clearly communicates the experimental data.

Bar and column graphs

Bar and column graphs have rectangular bars that are proportional in height (or length) to the values they represent. A column graph has vertical bars, and a bar graph has horizontal bars. They are useful for comparing data between different categories or groups, and are suitable for large datasets. They both consist of four parts:

- a title that explains the information being graphed; titles for graphs should be written above the graph
- axes with labels that explain what each side of the graph is showing, including units. In a column graph, the independent variable tends to go on the horizontal axis (the *x*-axis) and the dependent variable goes on the vertical axis (*y*-axis); the opposite is true for a bar graph
- a scale of numbers that increases evenly from bottom to top (or from left to right if the bars are horizontal)
- category labels that explain what each bar is showing.

Figure 1.12a shows an example of a column graph and Figure 1.12b shows the same information presented as a bar graph.

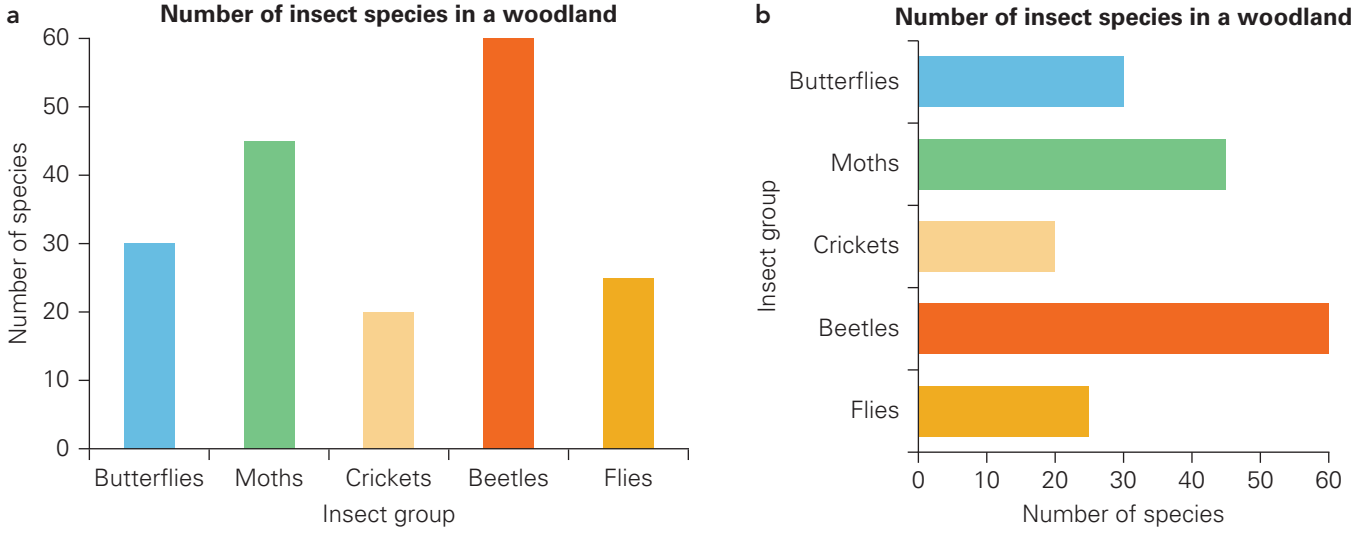


Figure 1.12 Data represented in **(a)** a column graph and **(b)** a bar graph

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Quick check 1.4

1. The information in the table shows the results of an investigation into the number of fish species feeding on ocean plants. **Represent** this data as a column graph.

	Plant types				
	Brown algae	**Red algae**	**Green algae**	**Yellow-green algae**	**Fire algae**
Number of fish species feeding	21	18	24	8	18

2. **Calculate** the mean, median, mode and range of this data.

Histograms

Histograms may resemble a column graph, but they are actually used to plot the frequency of continuous (quantitative) data that is divided into intervals. They are suitable for large sets of data. The range of values of the dependent variable (the measured data) is plotted on the *x*-axis and the frequency is plotted on the *y*-axis, represented by the height of the bars. There are no gaps between the bars.

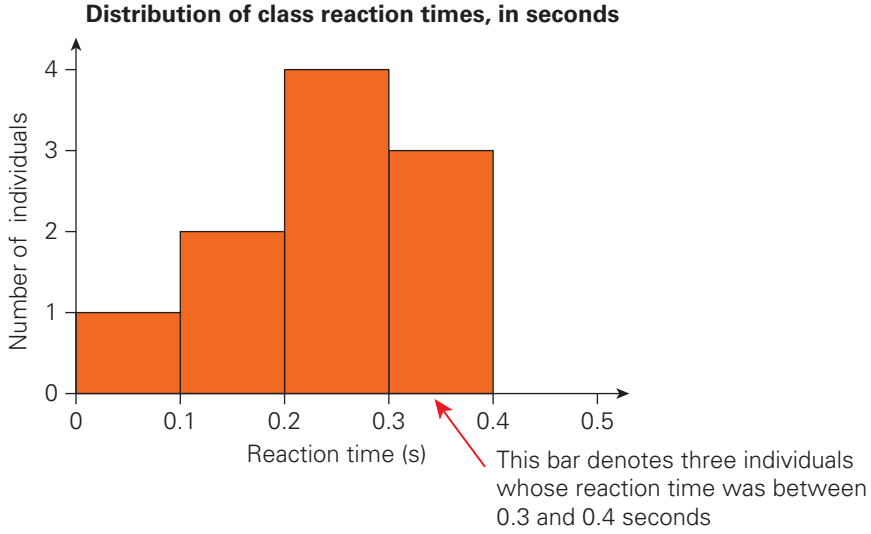


Figure 1.13 Data represented in a histogram

Scatterplots

A scatterplot is used to identify the relationship between two variables. It is suitable for large datasets of discrete or continuous (quantitative) data. The data is displayed on a Cartesian plane, with the independent variable on the *x*-axis (horizontal), and the dependent variable on the *y*-axis (vertical). A dot (or cross) is typically used to denote a data point, and is placed where the *x* and *y* values intersect. For example, if plotting the temperature (dependent variable) at a certain time of day (independent variable), then the measurement of 20°C obtained at 9 am would be represented by a data point drawn at (9, 20), which corresponds to 9 on the *x*-axis (time) and 20 on the *y*-axis (temperature).

origin
the point on a graph where the *x*-axis and *y*-axis intersect (0, 0)

A scatterplot consists of similar parts to the column graph, including a title, and labelled and evenly scaled horizontal and vertical axes. When setting up your scatterplot, it is particularly important to ensure that the axis label scale is appropriate and consistent. The point where the *x* and *y* axes intersect (0, 0) is called the **origin**.

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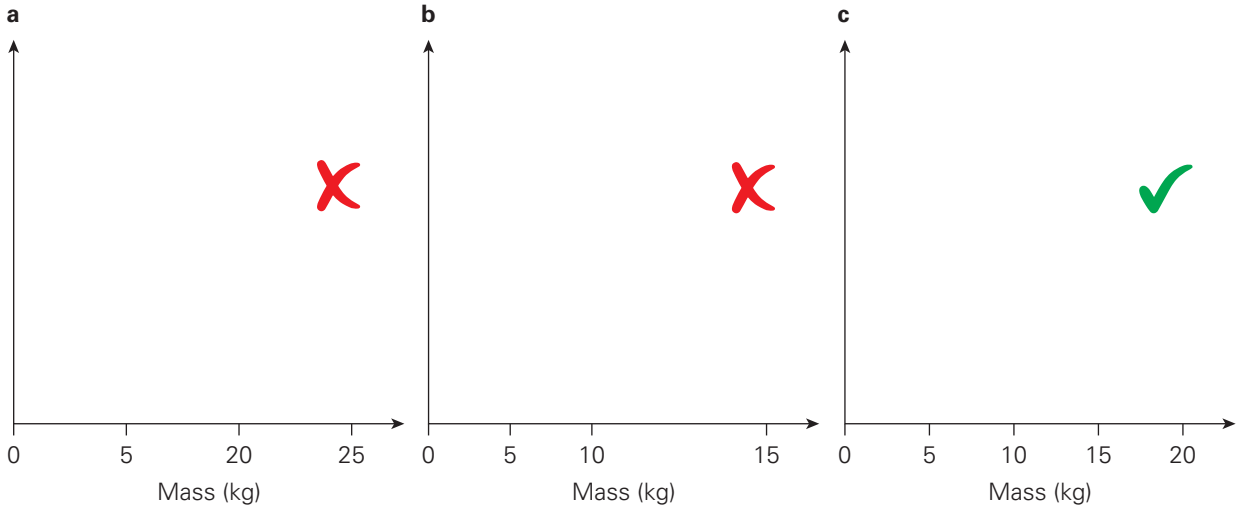


Figure 1.14 The first two scatterplots are not correct because **(a)** the graph does not have evenly increasing increments along the horizontal axis and **(b)** the graph scale is not evenly spaced. **(c)** This scatterplot is correct because the scale is evenly spaced with evenly increasing increments.

When plotting more than one variable (dataset), you can use different colours or shapes to distinguish the datasets (e.g. using circles for males and crosses for females). Once the data points are plotted, they can be further analysed in terms of correlation and line of best fit. The data points are not typically connected with a line *unless* the independent variable is continuous in nature (e.g. time or mass); however, this would then be referred to as a line graph.

Table 1.2 shows the results from an investigation into plant height that took place over 25 days. Only the averages are shown. The data is then shown as a scatterplot in Figure 1.15.

Time (days)	Mean plant height (cm)
1	10.0
5	10.4
10	14.0
15	18.1
20	21.3
25	23.5

Table 1.2 Mean plant height over time

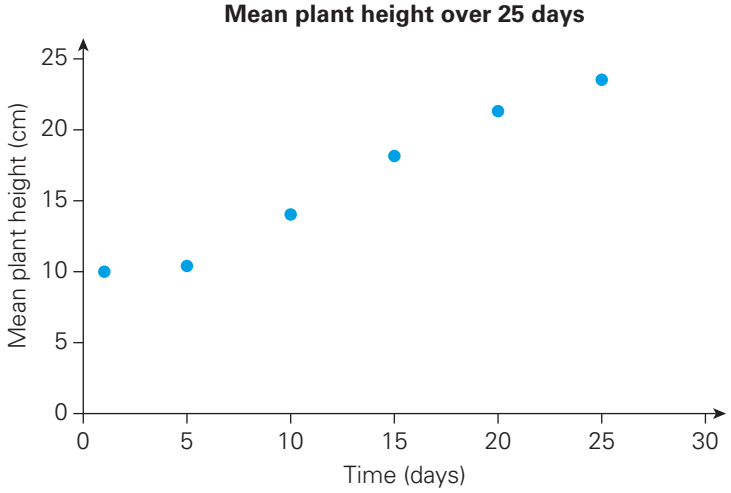


Figure 1.15 Data relating to mean plant height over time, represented in a scatterplot. The independent variable (time in days) is continuous, so it would be appropriate to connect these data points, forming a line graph.

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Quick check 1.5

A study was undertaken on the effect on plant growth in an aquarium of the amount of plant food added. Eight aquariums (A–H) containing aquatic plants were set up in a laboratory. Food was added to each aquarium each day, in the amounts shown in the table below. After 3 weeks, the increase in mass of plants in each aquarium was measured. The results are shown in the table.

Aquarium	Mass of food added each day (g)	Mass increase of plants (g)
A	0.0	1.0
B	0.5	3.0
C	1.0	5.0
D	1.5	9.0
E	2.0	11.0
F	2.5	14.0
G	3.0	15.0
H	3.5	16.0

1. **Identify** the independent variable in this experiment.
2. **Identify** the dependent variable in this experiment.
3. Use this information to **draw** a complete scatterplot of this data. Hint: Your Cartesian plane should take up at least half of an A4 notebook page to allow enough room to plot your points. Using pencil allows any mistakes to be easily corrected.

WORKSHEET
Plotting and analysing data

Analysing data

Once you have graphed your data, you can determine if there are any patterns, trends or relationships.

Line of best fit

It may be difficult to see how the variables relate to each other on a scatterplot, especially when there are many data points. A 'line of best fit', also known as a trend line, can be drawn to represent all the points and highlight a trend (relationship between the *x* and *y* variables).

Your line of best fit is not intended to connect each data point. Rather, the line should aim to 'average' the data by running through the centre of the data, with approximately half the data points above the line and half below. The line may touch some or none of the data points, but it often does not touch all of them unless there is a perfect linear relationship between the variables (i.e. the dependent variable increases/decreases at the exact same rate as the independent variable).

linear
a straight line plotted on a graph

non-linear
a plot on a graph that is not a straight line

exponential
a growth or decline that becomes increasingly rapid with time (or relative to another variable)

Your line of best fit:

- should run as close as possible to as many data points as possible (data points 'hug' the line)
- may be **linear** (straight) or **non-linear** (curved) if that better suits the spread of data points; do not force a straight line over data that is clearly curved or displaying a pattern such as **exponential** growth
- be continuous and drawn as a solid line within the original dataset; if extended beyond the original dataset, it can be dotted/dashed (see the later section on extrapolation in 'Making predictions')
- not be forced through the origin (0, 0), if one is used on the graph.

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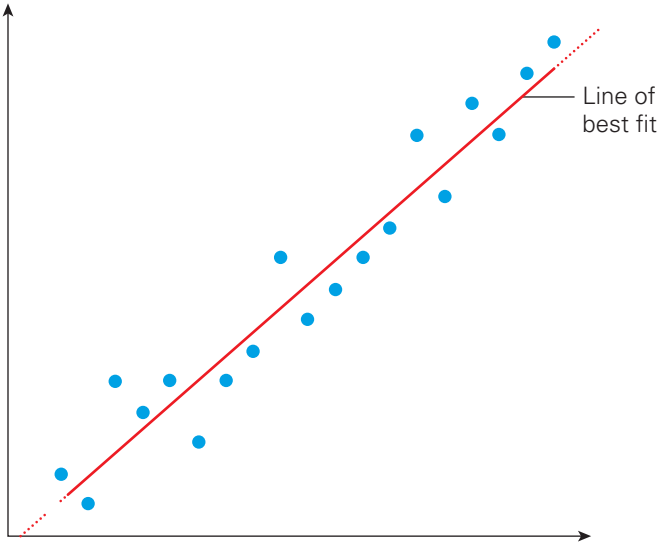


Figure 1.16 A scatterplot with a (linear) line of best fit. Note how the line runs through the middle of the data, with approximately half the points above the line and half the points below.

Relationships between variables

Correlation measures the association between two variables and provides valuable insights into how changes in one variable relate to changes in another (see Figure 1.17). Given that research questions and hypotheses often directly speculate about the effect of the independent variable on the dependent variable, this is an important statistical tool.

correlation
a statistical measurement of the extent to which two variables change in relation to one another

You will recall that when constructing a scatterplot, 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:

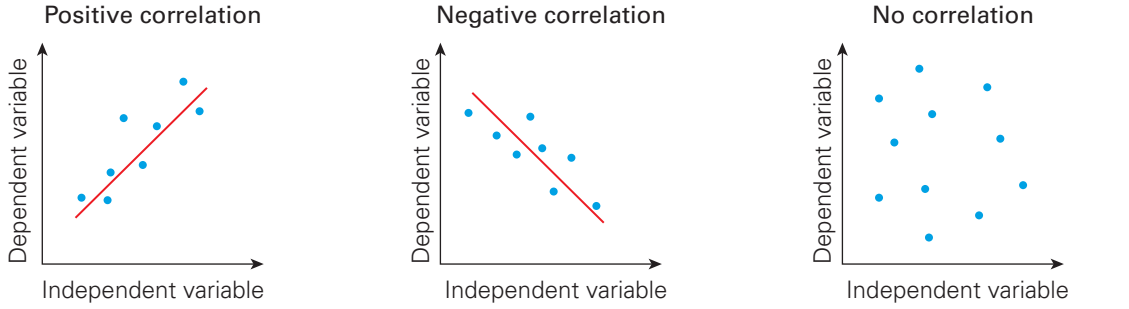


Figure 1.17 The relationship between two variables can be positive or negative, or there may be no correlation.

It is important to note that correlation does not equal causation. A correlation may actually be caused by a third extraneous variable. Avoid using words like 'proves' or 'causes' when discussing the possible relationship between variables. Instead, you can use the following sentence stem to indicate the direction of the relationship:

'As the _____ _____, the _____ _____.'
independent variable | state how it changes | dependent variable | state how it changes

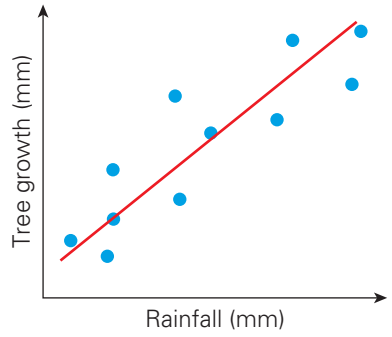
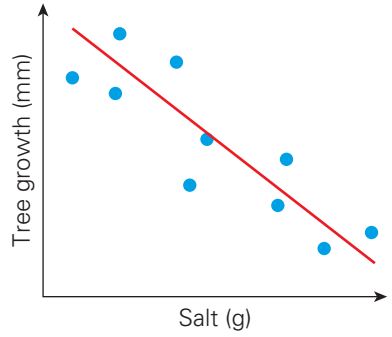
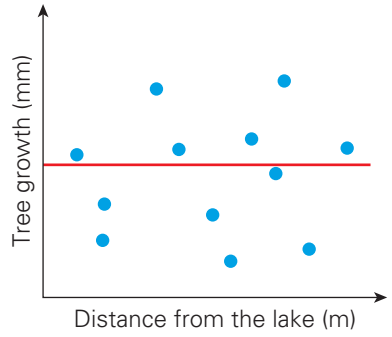
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Try this 1.4

Interpreting correlation

Visually inspect the scatterplots shown below. Use the sentence stem for describing correlation to state the relationship between the variables. An example has been completed for you.

Graph	Direction of correlation	Interpretation
	Positive	As the amount of rainfall (in mm) increases, the tree growth (in mm) also increases.
		
		

You should also comment on the strength of the relationship. Statistical methods are available for quantifying this; however, a visual inspection of the data using a scatterplot allows for a good estimation. The strength of the correlation can be approximated by considering how tightly the data values hug a line of best fit.

If the data values do not appear to follow a linear relationship, the relationship may be non-linear or there may be no relationship between the variables at all (see Figure 1.18). If the relationship appears non-linear, fitting a line of best fit can be difficult. In this case, use a software program such as Microsoft Excel, a website such as Desmos, or a graphics calculator to generate the non-linear equation and plot the curved line of best fit.

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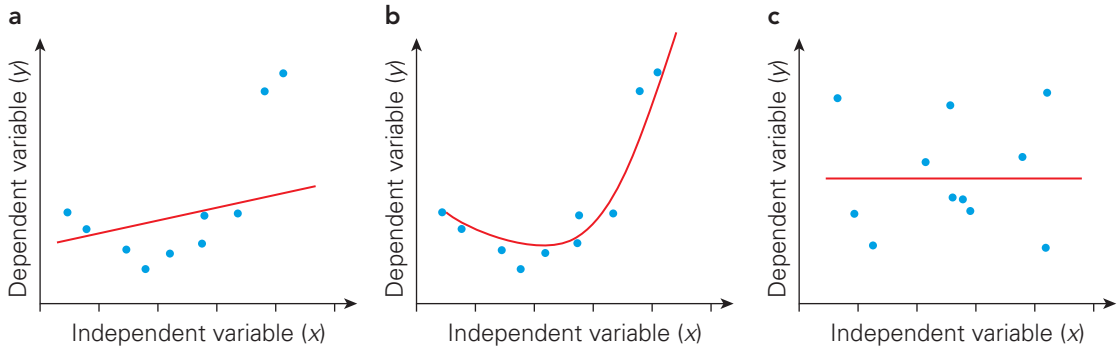


Figure 1.18 When a line of best fit is drawn on a scatterplot, **(a)** the data points do not appear to show a relationship between the variables. However, **(b)** when a curved line of best fit is drawn on the same dataset, the non-linear relationship is evident. The scatterplot in **(c)** shows data points with a random distribution, suggesting there is no correlation (no relationship) between the variables.

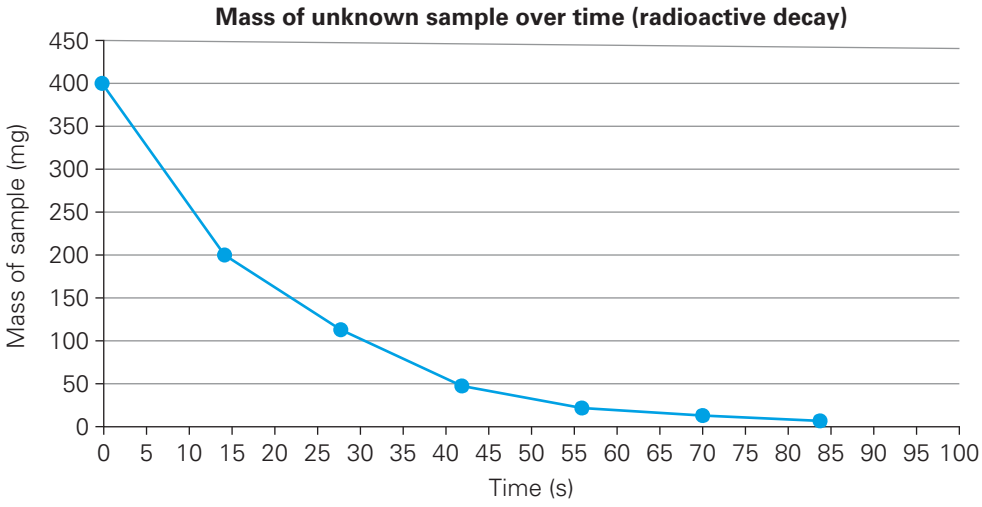
Try this 1.5

Radioactive decay

While oxygen-16 is the most abundant form of oxygen present on Earth, there are also numerous unstable isotopes of oxygen, each of which has a different mass number (due to having a different number of neutrons in the nucleus). A scientific team has an unlabelled pure sample of one of the unstable isotopes of oxygen. This isotope is radioactive, meaning it will decay over time. To establish which isotope they have, the team has taken readings over time of the mass of the sample and established the **half-life**.

half-life
the time taken for half of the atoms in a sample of radioactive material to decay

Isotope	Known half-life (s)
Oxygen-14	70.6
Oxygen-15	122.0
Oxygen-19	26.5
Oxygen-20	13.5
Oxygen-21	3.4



a) **State** the type of graph that has been used.
b) **Describe** the relationship between mass and time.
c) **Identify** the half-life of the sample in seconds.
d) With reference to the table of values, **propose** which isotope the sample was.

Making predictions

A line of best fit can be used to make predictions inside the existing dataset. This is known as **interpolation** and can be done graphically (with the aid of a ruler), or it can be calculated mathematically if you have determined the equation of the line of best fit using graphing software. Interpolation is useful for finding missing data points – you can use the other data to predict the dependent variable value for an independent variable value that you did not test.

interpolation
using a line of best fit to make predictions within an existing dataset; predictions tend to be reliable

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extrapolation extending a trend, pattern or relationship observed in a limited range of data to estimate values beyond that range; predictions can lack reliability

Extrapolation is the process of estimating a value outside the range of the data by extending a trend or pattern from the observed data. This is shown graphically by extending the line of best fit with dots/dashes (see Figure 1.19). Such predictions are less reliable as they are beyond the original dataset and therefore assume the relationship continues. The larger your dataset (more points on the scatterplot) or the greater the correlation (more closely the points hug the line), the more confident you can be in the accuracy of an extrapolated prediction. Making predictions a long way outside your original dataset further reduces the accuracy.

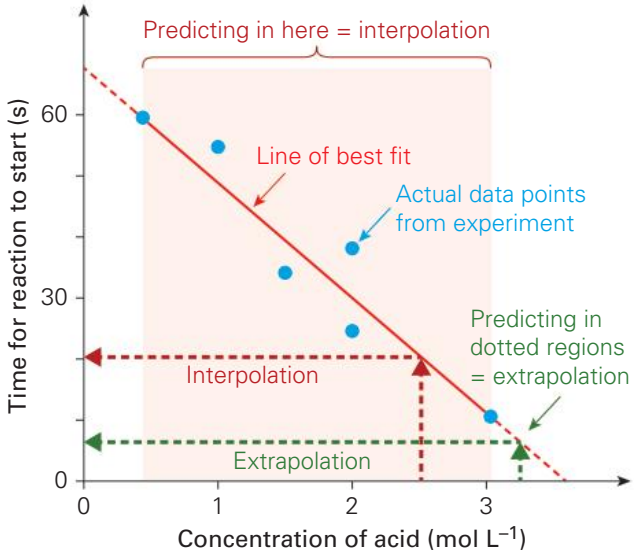


Figure 1.19 A scatterplot showing a line of best fit. Predicting the time taken for the reaction to start with an acid concentration of 2.5 mol L^{-1} (shown in dark red) would be considered interpolation, and the prediction should be reliable. Predicting outside the original dataset using the dashed region of the line of best fit is extrapolation. This gives a less reliable prediction. An example would be predicting the time taken for an acid concentration above 3 mol L^{-1} (shown in green).

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Section 1.2 review

Online quiz | Section questions | Teachers can assign tasks and track results

Section 1.2 questions

Remembering

1. **Determine** the mean, median, mode and range of the following dataset:
   10.2, 21.0, 18.5, 18.6, 10.2, 10.4, 16.7, 17.5
2. **State** whether interpolation or extrapolation is more reliable.

Understanding

3. **Describe** the type of data that would best be represented in a bar or column graph.
4. **Describe** one difference between a histogram and a column graph.

Applying

5. **Classify** this experimental data as continuous, discrete, ordinal or nominal:
   a) the colour of a solution after a chemical reaction
   b) the duration of a pendulum swing in seconds.

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6. **Construct** a scatterplot of the following data from an experiment that investigated the stretch in a spring with increasing masses added.

Mass added (g)	Spring stretch (mm)
0	0
10	5
20	12
30	15
40	20
50	21
60	24
70	30
80	35
90	41

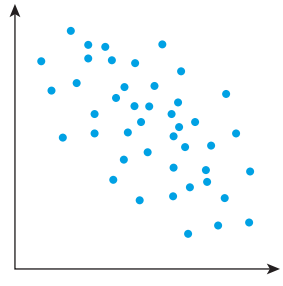
7. **Construct** an appropriate graph for the following data relating to the temperature of water with each minute of heating.

Time (min)	Temperature (°C)
0	0
1	3
2	3
3	15
4	17
5	18
6	18
7	20
8	22
9	30

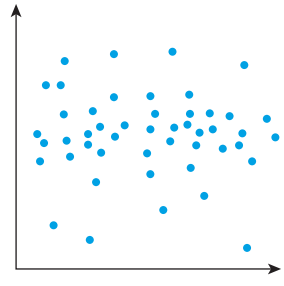
Analysing

8. **Compare** the use of descriptive and inferential statistics.
9. **State** whether a correlation exists between the variables shown on the following scatterplots; **classify** the direction of the correlation if one exists.

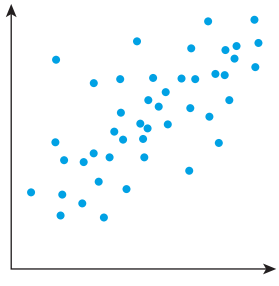
a)



b)



c)



Evaluating

10. **Propose** a time when it would not be appropriate to represent data on a scatterplot where the *x* and *y* axes intersect at (0, 0).

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1.3 Communicating conclusions

Learning goal

At the end of this section, I will be able to:

1. Communicate research findings effectively based on analysis of evidence.

The aim of scientific research is to validate knowledge and generate new understandings. However, it is essential that we critically reflect on the scientific process and consider the validity of our data before forming conclusions that may be inherently biased or based on assumptions.

As a student, you will present your research findings in structured practical reports. Professional scientists need to tailor their communication methods and styles to reach broad audiences and share their reasoned conclusions. They must also consider the work of the scientists who have come before them, including the invaluable contributions of Aboriginal and Torres Strait Islander people, ensuring their engagement is respectful, collaborative and **culturally responsive**.

culturally responsive learning from and connecting respectfully with Aboriginal and Torres Strait Islander people from different language groups and communities; building strong, meaningful and collaborative relationships that value their knowledge and cultures

Practical reports

As part of your secondary school science studies, you will undertake experiments and research and present your findings in practical reports and scientific posters. These differ in terms of detail and depth, but both are formal ways of reporting your findings and must use appropriate scientific language and accepted conventions, such as acronyms and units of measurement.

Practical reports feature structured headings that align with the steps in the scientific method, as outlined in Figure 1.20.

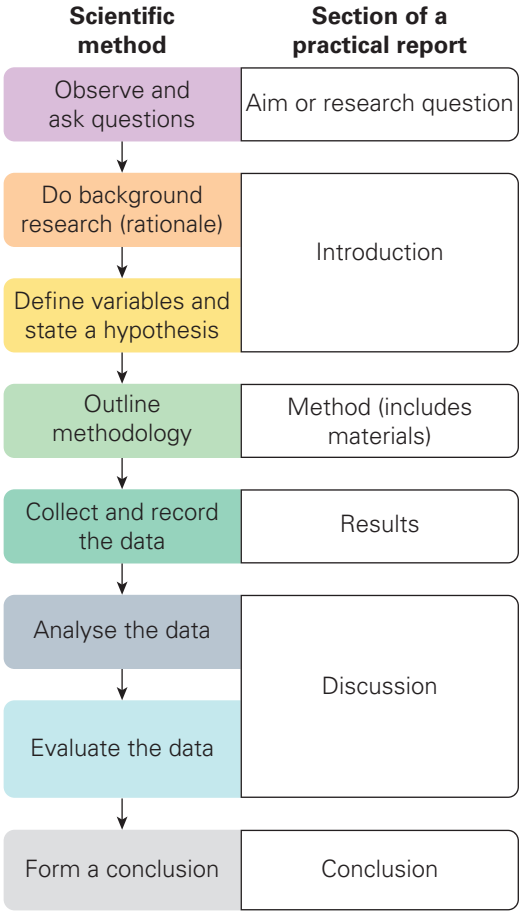
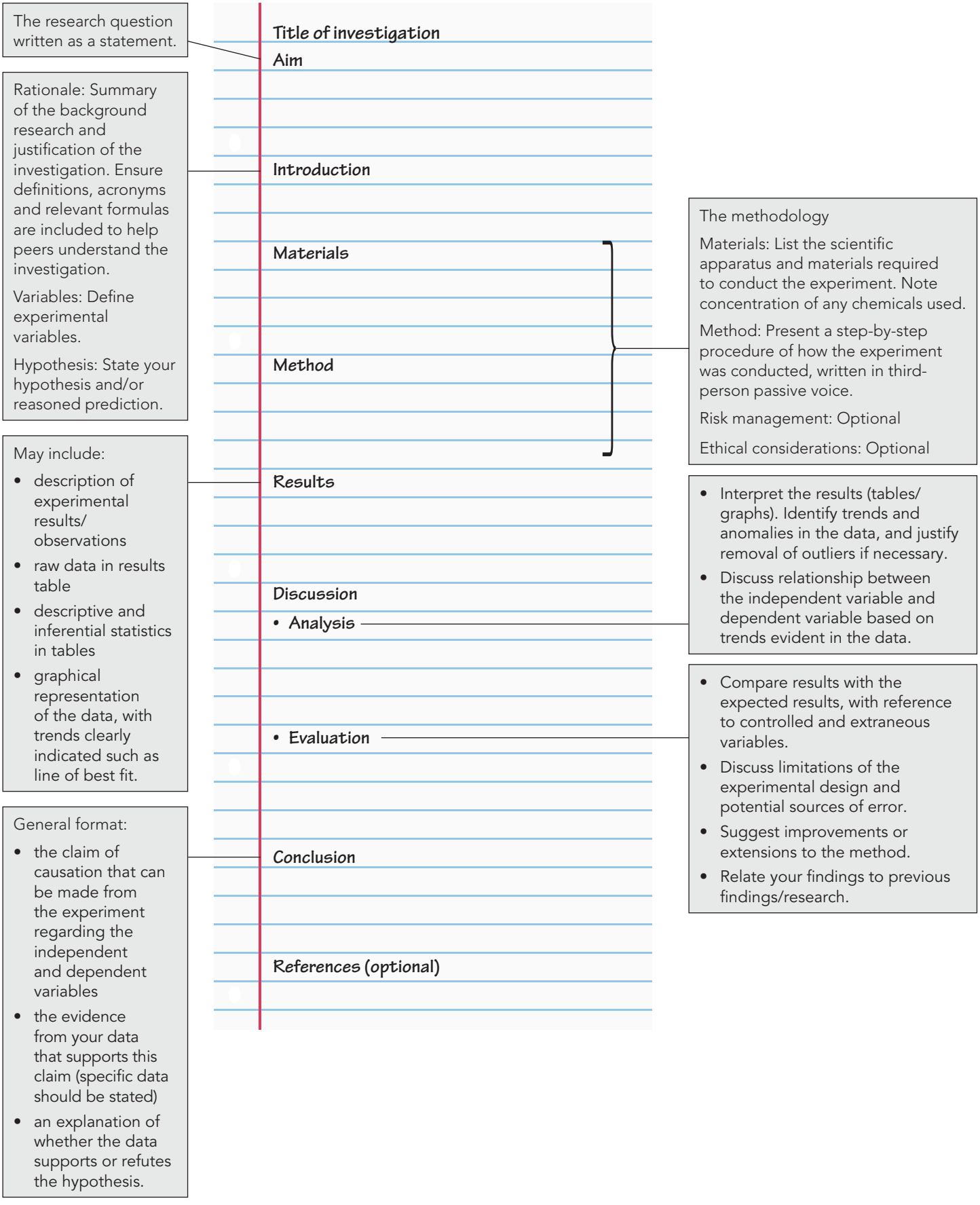


Figure 1.20 Steps of the scientific method matched to sections of a practical report

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A guide on structuring a practical report follows:



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Framing your discussion

The discussion section of a practical report or scientific poster typically includes a section dedicated to the analysis of the data and a section for an evaluation.

Analysis

The analysis of the results should make reference to the tables of raw data and representative graphs:

- Trends should be highlighted, with any possible correlations described in terms of their direction and strength.
- The relationship between the independent variable and the dependent variable should be discussed, based on these trends.
- Any anomalies in the data should be indicated, and if outliers have been removed from the data analysis process, this needs to be justified. Consider if the outlier represented a human error or an instrument error.

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. Consider the possibility of random errors.
- how your results compare to expected results and previous research. Consider how well extraneous variables were controlled, and the possibility of systematic errors.
- the accuracy of your data. How closely does the line of best fit align with your data? Are the error bars large or small?

In terms of the methodology, you should discuss:

- any limitations or potential sources of error in the experimental design and how these could be improved in the future
- any problems you encountered and the impact they had on the results
- how any problems could be resolved in the future
- any extensions to the method for future use, or recommendations for future research.

An example discussion

The discussion in the following example relates to an experiment investigating how the acceleration of a model car was affected by the angle of the ramp it travelled down. Results were as shown below.

	Time (s) from release to end of ramp			
Angle of ramp (°)	**Trial 1**	**Trial 2**	**Trial 3**	**Mean time**
15	0.92	0.91	0.98	0.94
30	0.70	0.72	0.71	0.71
45	0.59	0.61	0.75	0.60
60	0.53	0.53	0.52	0.53

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Student work: Discussion	Criteria met
Analysis	
The data indicates a strong correlation between the angle of the ramp and the acceleration of the model car. As the angle of the ramp increased, acceleration also increased, which is reflected in the decreasing times for the car to travel down the length of the ramp.	Trend identified.
At a ramp angle of 15°, the car took 0.94 seconds (on average) to reach the end of the ramp, but this decreased steadily to only 0.53 seconds when the angle of the ramp was raised to 60°. This supports the hypothesis.	Supporting experimental data referred to, and anomalies identified. Reference made to whether hypothesis is supported.
There is a potential outlier for Trial 3 at a ramp angle of 45°. This data point was removed from the calculation of the mean time for this ramp angle, as it was assumed to have resulted from personal or instrument error.	
Evaluation	
The results aligned with those of other groups. While every effort was made to carefully release the car without administering a pushing force, this may not have been adequately controlled from group to group or between trials. All other variables, such as ramp surface and the condition of the model car, were adequately controlled.	Results compared with expected results; reference made to controlled variables.
A potential limitation in the experimental design was the use of manual stopwatches for recording the elapsed time. Group members may have been inconsistent in recording the 'end' time based on when the front of the car exited the ramp or when the back of the car exited the ramp.	Limitations of experimental design noted.
Differences in reaction speed may also account for variation in the trial times. This potential source of random error could be minimised by recording the trials using a camera and pausing the video to obtain a more accurate measurement of the time. This would improve the accuracy of the obtained data, and therefore the reliability.	Potential source of error identified, impact on results noted and future improvements suggested.

Forming a conclusion

The conclusion section of your practical report or scientific poster is where you answer the original research question and state whether your hypothesis was supported or refuted. You should start with a general statement of your findings, but then justify and support this with actual data from your results. You could 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 the trends present: the experiment must be thoroughly planned and well executed in order to yield valid data to base the conclusions upon. This is especially critical when the investigation aims to support or refute a claim.

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An example conclusion

The conclusion in this example relates to the same experiment mentioned earlier, which investigated the relationship between ramp angle and acceleration. This conclusion follows the framework below.

Student work: Conclusion	Conclusion framework
From this experiment, we can conclude that as the angle of the ramp increases, the acceleration of the model car also increases. The data showed a reduction in the time taken for the car to travel along the ramp, from 0.94 seconds at a ramp angle of 15° to 0.53 seconds at a ramp angle of 60°. This indicates greater acceleration with larger ramp angles.	Claim made regarding your experimental findings. Claim supported by referring to your experimental observations/data. Explanation made of how the data supports your claim.

WORKSHEET Evaluating scientific claims

Did you know? 1.2

A flaw in the experimental design

Research that involves human subjects is fraught with danger in terms of adequately controlling extraneous variables. There are so many factors that influence the way our bodies work and our thoughts and behaviour. How scientists recruit study participants can also be problematic, especially if the results are then to be generalised to a broader population under the assumption that the sample was representative.

A 2010 article published in the journal *Behavioural and Brain Sciences* claimed that a significant portion of psychology literature focuses on WEIRD participants – Western, Educated, Industrialised, Rich and Democratic – yet this group was 'among the least representative' of all humans.



Figure 1.21 Humans are a diverse bunch! Poorly designed experiments that feature human participants may lead to flawed conclusions.

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Acknowledging and communicating Traditional knowledge

Aboriginal and Torres Strait Islander Peoples' knowledges are deeply grounded in their custodianship of Country and have been developed for at least 65 000 years through careful observation and robust experimentation. Contemporary science uses systematic methods of observation, experimentation and analysis to develop an understanding of the natural world.

Acknowledging and identifying the relationship between Aboriginal and Torres Strait Islander Peoples' knowledges and contemporary science promotes a more accurate, holistic and inclusive and collaborative approach to knowledge generation. This is known as working 'both ways' or combining Traditional knowledge with Western scientific methods. When working 'both ways', it is important to recognise the value and contributions of both approaches.

When communicating Aboriginal and Torres Strait Islander knowledge, it is important to be culturally responsive and respectful, maintain cultural protocols, and avoid racist narratives, language or images. You should seek permission from the relevant Aboriginal and Torres Strait Islander Peoples before engaging with or communicating about their knowledge. Avoid stereotypes and use appropriate language. This includes being aware of the differences between different nations and languages and using the correct terminology when discussing specific cultural practices or beliefs.

Did you know? 1.3

Spinifex gel

Spinifex grass, which covers almost one-third of Australia, has long been harvested for its durable, fine nanofibers, which can be used to strengthen rubber and latex products. However, researchers have now developed a medical gel from the grass that could potentially be more effective in treating ailments such as arthritis, as well as assisting with the delivery of other drugs in both medical and cosmetic applications.



Figure 1.22 (a) Spinifex grass contains resins that are used to manufacture **(b)** a thick gel.

The Indigenous-owned Bulugudu organisation is the majority shareholder of Trioda Wilingi, a bioscience company based in Brisbane and affiliated with the University of Queensland. The company has secured investment from its shareholders to advance the development of medical gels using spinifex grass. The grass is harvested and processed at a laboratory in Camooweal, in the north-west region of Queensland. Only two machines of their kind are currently available in Australia to extract resins from the grass before it is transported to Brisbane for manufacturing.

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Explore! 1.1

Traditional knowledge

Aboriginal and Torres Strait Islander Peoples have a rich history of medicinal knowledge and practices that have been developed and refined over tens of thousands of years. Their understanding of physiology and the environment continues to contribute significantly to the advancement of modern medicine.

The Wiradjuri people of central New South Wales have a history of treating respiratory illnesses by constructing steam pits heated by fire, lined with eucalyptus leaves and overlaid with possum rugs. This practice triggered Western scientists to further investigate the medicinal qualities of *Eucalyptus*, and they relied on Aboriginal Peoples' knowledge about how to formulate the plant for effective use. Modern research has shown that eucalyptus oil has antiviral and antibacterial qualities, and it is now manufactured for commercial use in the same way that the Wiradjuri people have been using it for thousands of years.

As two other examples:

- The use of emu oil as a topical anti-inflammatory has been adapted from Aboriginal knowledge.
- The Kakadu plum, which has the highest concentration of vitamin C of any fruit in the world, has been used to treat the disease scurvy. Its antioxidant properties have also been studied for their potential in cancer treatment. Aboriginal people now harvest and share the fruit for medicinal uses to the world.

Research some other plants that different groups of Aboriginal and Torres Strait Islander people use as medicine. Explore whether their use has been adapted by Western science. Kangaroo apple and banksia flowers are a good place to start.



Figure 1.23 Some Aboriginal and Torres Strait Islander Peoples use eucalyptus oil to treat respiratory infections.

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Section 1.3 review

Online quiz

Section questions

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Section 1.3 questions

Remembering

1. **Describe** the process of working 'both ways'.

Understanding

2. **Outline** the three key things to include in the conclusion of a practical report.

Applying

3. **Explain** how the analysis and evaluation sections of the discussion differ.

Analysing

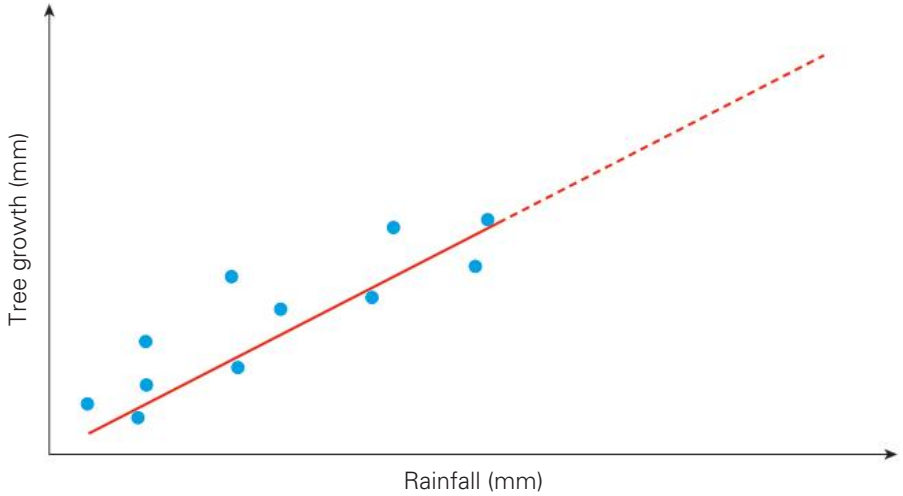
4. A marine biologist counted the number of fish eggs present in coastal rockpools that were at varying distances from the shoreline. She recorded the raw data in a table.

Temperature of water (°C) in rockpool	Number of fish eggs present
16	20
17	3
18	60
19	81
20	98
21	119
22	140

Suggest whether the outlier is the result of a random or systematic error.

Evaluating

5. 'Trees that receive greater rainfall will always grow taller.' **Evaluate** the credibility of this conclusion with reference to the student's experimental data, shown below.



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Chapter review

Chapter checklist

Success criteria		Linked question
1.1	I can recall the steps of the scientific method.	2
1.1	I can develop an investigable research question.	5
1.1	I can identify the independent, dependent, controlled and extraneous variables in a scientific investigation.	12a, 14
1.1	I can construct a hypothesis to test an identified relationship.	9
1.1	I can plan and conduct a safe and valid experiment.	4, 10
1.1	I can discuss how to minimise errors through the use of technology.	8
1.2	I can classify data types.	6
1.2	I can calculate descriptive statistics for a dataset.	12d, 12e
1.2	I can select and construct appropriate representations of data.	1, 7, 11a, 12f
1.2	I can analyse and connect a variety of data and information to identify and explain patterns, trends, relationships and anomalies.	3, 11b, 11c, 11d, 12b, 12d
1.3	I can communicate research findings effectively based on analysis of evidence.	13

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **State** the type of data that can be represented in a scatterplot.
2. **List** the numbered steps in the scientific method.

Understanding

3. **State** the purpose of extrapolation.
4. **List** three risk management responsibilities that might be assigned to the lead scientist in a research team.
5. **Outline** the five criteria that can be used to evaluate if a question is 'investigable'.
6. **Classify** the following according to data type (ordinal, nominal, discrete or continuous):
   a) number of bacteria in the growth medium
   b) size of balloon (deflated, partially inflated, fully inflated)
   c) gender of offspring
   d) volume (mL).

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Applying

7. **Decide** on the appropriate graph to use and **construct** one for the following data. It was obtained from a survey of the methods used to heat houses in a neighbourhood.

Heating type	Number of households
Gas	25
Electric	20
Wood	8
Reverse-cycle air conditioning	22
Kerosene	5
Heat pumps	5

8. A data logger and probe are used in an experiment to track temperature changes over a 24-hour period, with readings taken every 1 minute. **Explain** how this digital tool reduces the chance of random errors, but how it could introduce a source of systematic error if it were poorly calibrated.
9. **Construct** a hypothesis regarding the speed a sound wave travels through materials of different density (solids, liquids and gases).

Analysing

10. **Reflect** on why an appropriate sample size is important in any scientific investigation.
11. A pathologist wanted to know the effect of adding an unknown substance X to bacteria. She conducted an experiment comparing bacterial colonies where the substance had been added and where it had not been added. She counted the number of bacterial colonies over a number of hours. The results are shown in the following table.

Time (hours)	Number of bacterial colonies	
	Substance X added	Nothing added
0	120	120
1	96	121
2	92	122
3	83	123
4	64	123
5	58	120
6	45	124
7	45	125
8	25	126
9	12	130

a) **Construct** a graph of the data points and draw a line of best fit for each dataset.
b) **Describe** the two results in terms of correlation.
c) **Determine** the relationship between substance X and bacterial colony growth.
d) Using extrapolation, **predict** the number of bacterial colonies after 10 hours if no substance X is added.

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12. The table below shows the effect of changing the pH of a pond on the number of insect larvae in the pond.

pH of water	Number of insect larvae		
	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 insect larvae growth.
c) **Identify** an outlier in the data.
d) **Calculate** the mean and median number of insect larvae in a pond with a pH of 7.5.
e) **Calculate** the range of the number of insect larvae in a pond with a pH of 6.5.
f) **Construct** a graph of the number of insect larvae in trial pond 1 against the pH of water. Label the axes correctly and write an appropriate title.

Evaluating

13. **Justify** how a scientific conclusion can be supported by evidence.

14. 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: Gretchen Reynolds, 'Even a 10-minute walk may be good for the brain', *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) Exercise undertaken
e) Exercise duration



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Data questions

A Victorian scientist designed an experiment to show how the temperature at which water boils changes at different heights above sea level. The scientist did this by boiling water while on a hike up Mount Arthur, in Victoria's Alpine National Park. The mountain is 1657 m high. The scientist used the same volume of water in the same beaker, the same heating apparatus and the same thermometer to measure the temperature. The results are presented in Figure 1.24.

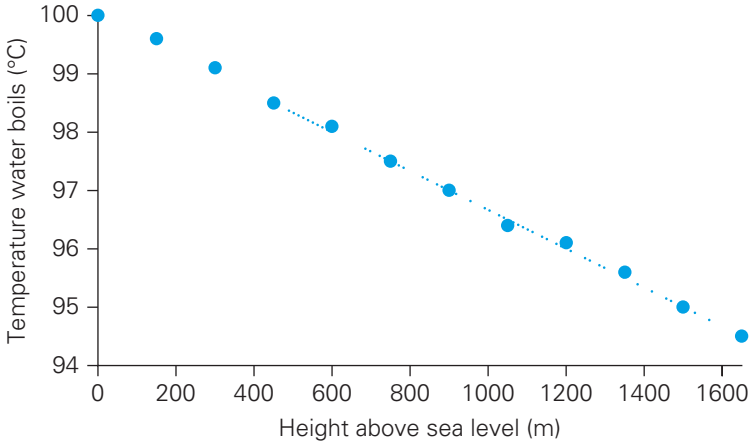


Figure 1.24 The different temperatures at which water boils at different heights above sea level on Mount Arthur

Applying

1. **Identify** two controlled variables in this experiment.
2. Use the graph to **determine** the independent variable in the experiment.
3. **Calculate** the range of the data presented.

Analysing

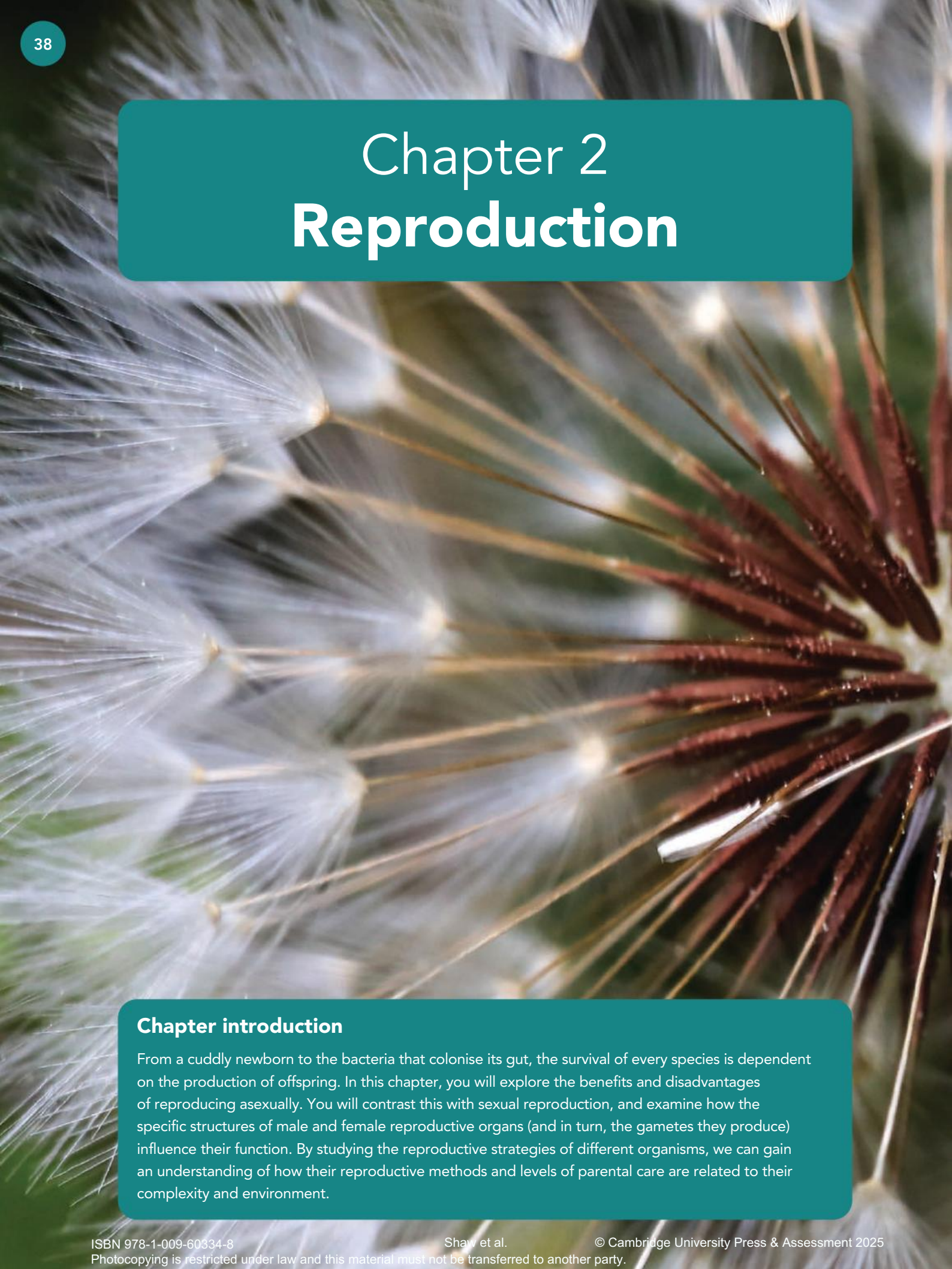
4. **Identify** the trend in the temperature at which water boils, as height above sea level changes.
5. From the trend line, use interpolation to **infer** the temperature at which water would boil at 700 m above sea level on Mount Arthur.

Evaluating

6. **Inspect** the data and conclude if there are any outliers that should have been removed from the dataset prior to plotting the trend line.
7. **Justify** whether the linear trend line is an appropriate model for the data.
8. **Extrapolate** to estimate the height above sea level that would allow water to boil at 94 °C.
9. Mountains in the Alps in Europe can be twice the height above sea level of Mount Arthur. **Predict** the temperature that water would boil at on a 3300-m-high peak in the Alps.

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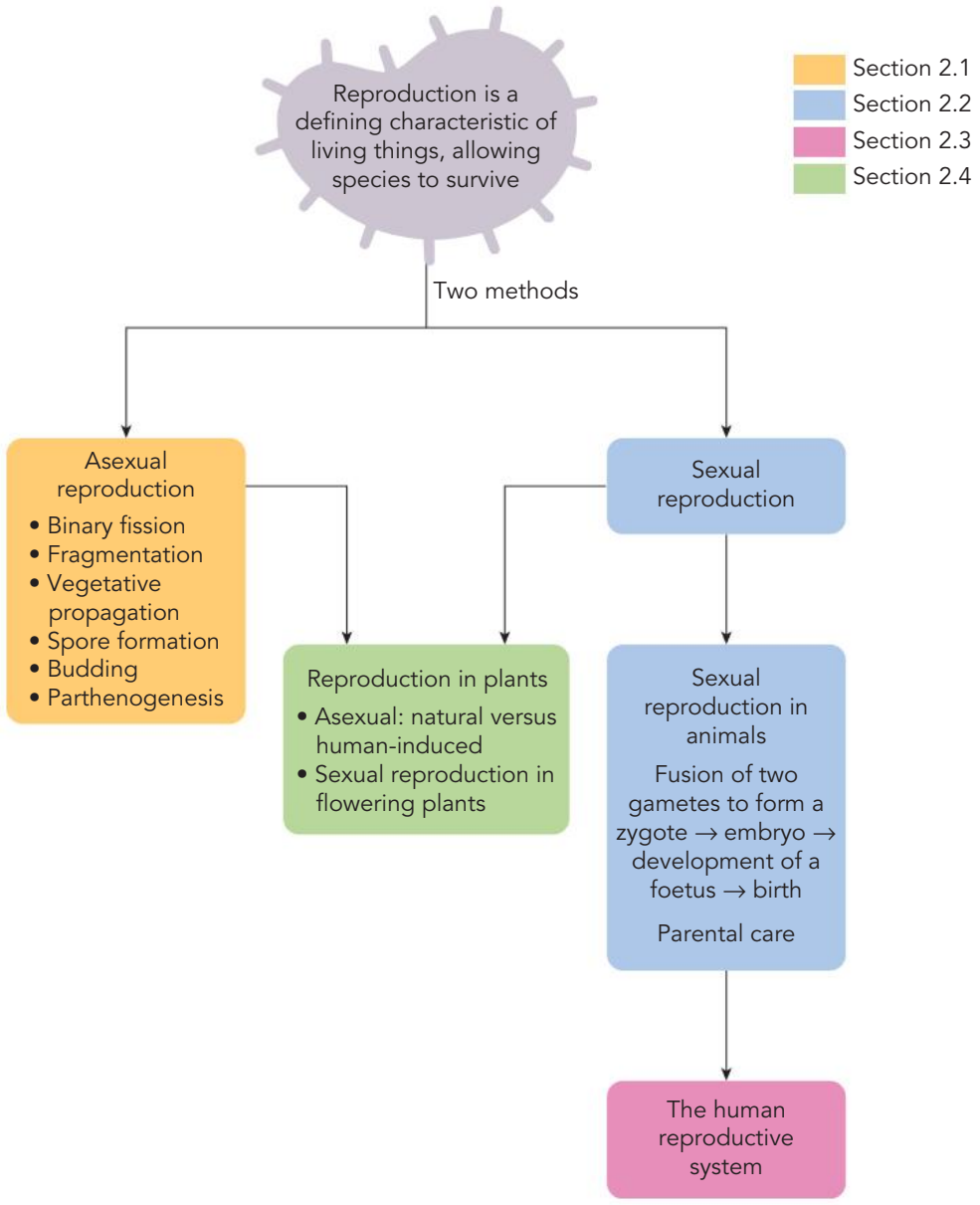
Chapter 2
Reproduction

Chapter introduction

From a cuddly newborn to the bacteria that colonise its gut, the survival of every species is dependent on the production of offspring. In this chapter, you will explore the benefits and disadvantages of reproducing asexually. You will contrast this with sexual reproduction, and examine how the specific structures of male and female reproductive organs (and in turn, the gametes they produce) influence their function. By studying the reproductive strategies of different organisms, we can gain an understanding of how their reproductive methods and levels of parental care are related to their complexity and environment.

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Concept map



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Curriculum content

the structures of reproductive cells and organs in plants and animals are related to their functions; processes of sexual and asexual reproduction enable survival of a species (VC2S10U01)	
• examining how the reproductive organ structures work collectively in males and females as systems	2.3
• explaining how the forms of male and female gametes relate to their specific functions	2.3
• identifying and comparing sexual and asexual reproductive strategies in plants	2.4
• exploring how sexual reproduction produces a greater rate of variation among offspring compared with asexual reproduction	2.2
• examining how the reproductive strategies of multicellular animals are related to their environments and the complexity of the organisms	2.1, 2.2
• examining how the number of offspring produced by animals is related to the amount of parental care	2.2
the use of scientific knowledge to address socio-scientific issues and shape a more sustainable future for humans and the environment may have diverse projected outcomes that affect the extent to which scientific knowledge and practices are adopted more broadly by society (VC2S10H03)	
• researching citizen science projects related to public health and examining why people would choose to be involved	2.4

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Glossary terms

Asexual reproduction	Gonad	Puberty
Binary fission	Hormone	Scrotum
Budding	Internal fertilisation	Secondary sexual characteristic
Cloaca	Menstrual cycle	Seed
Cross-pollination	Menstruation	Seed dispersal
Differentiation	Mitosis	Self-pollination
Embryo	Nectar	Sexual reproduction
Embryo sac	Ovulation	Sperm
External fertilisation	Ovule	Spore
Fertilisation	Ovum	Testes
Fragmentation	Parthenogenesis	Trait
Gamete	Pollen	Vegetative propagation
Gestation	Pollination	Zygote

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2.1 Asexual reproduction

Learning goal

At the end of this section, I will be able to:

1. Describe the six methods used by animals, plants and microbes to asexually reproduce.

WORKSHEET Asexual reproduction

Reproduction is the biological process by which living things produce offspring. There are two main types of reproduction: sexual and asexual. **Sexual reproduction** involves two parent organisms, and results in offspring with genetic variation. Humans and most other animals reproduce through sexual reproduction, creating diversity in their offspring.

In contrast, **asexual reproduction** involves only one parent organism and results in offspring that are genetically identical to the parent. This type of reproduction is common in single-celled organisms, such as bacteria and amoebae, but can also be undertaken by plants and animals under certain circumstances. Asexual reproduction is a highly efficient way of reproducing because it does not require the involvement of another organism, and every organism is capable of reproducing.

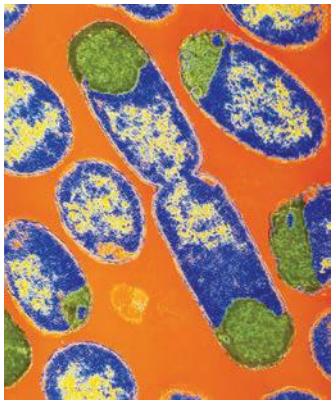


Figure 2.1 A stained transmission electron micrograph of the bacterium *Escherichia coli*, undergoing binary fission, a type of asexual reproduction in which a cell splits into two identical individuals

sexual reproduction a method of reproduction that involves two parent organisms and results in genetic variation in the offspring

asexual reproduction a method of reproduction in which a single parent produces offspring genetically identical to itself

trait a characteristic belonging to an individual; under genetic control (although the environment may have an influence)

Types of asexual reproduction

There are biological advantages to asexual reproduction, particularly for organisms that are geographically isolated or have limited mobility. It can be beneficial because:

- the process requires less energy than sexual reproduction and is typically faster, leading to rapid population growth
- the organism expends less energy and does not waste time on trying to find a suitable mate
- offspring are clones of the parent organism, so beneficial **traits** can be passed on.

If the parent organism is well adapted to the environment, then passing on successful traits to the next generation of genetically identical organisms is a good thing. However, there are also disadvantages to asexual reproduction. If environmental conditions change or a disease is introduced that the organisms are susceptible to, the lack of genetic variation places the species at risk of extinction. Conversely, the rapid population growth often associated with asexual reproduction can lead to overcrowding and competition.

Did you know? 2.1

The Irish Potato Famine (1845–49)

In Ireland, during the harsh economic climate of the mid-nineteenth century, potatoes accounted for up to 80% of a typical person's daily energy intake. Over-reliance on growing several high-yielding potato varieties greatly reduced the genetic variation present in the crops, and left them susceptible to late blight, a disease caused by a water-borne mould. Over the period 1845–49, blighted potato crops rotted in the field, leading to widespread starvation in Ireland and the deaths of over one million people.



Figure 2.2 A rotting potato infected with late blight

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The six types of asexual reproduction discussed below all involve the replication and division of a single parent cell into two genetically identical copies. The mechanisms of growth vary and are tailored to suit the structure of the organism and the environmental conditions it exists within.

Binary fission

binary fission a type of asexual reproduction in which the cell divides, creating two identical cells; the most common form of reproduction in prokaryotes, such as bacteria

fragmentation a type of asexual reproduction in which a parent organism splits into multiple fragments, each of which can potentially develop into an independent individual

vegetative propagation a form of asexual reproduction in which only one plant is involved

Binary fission is a type of asexual reproduction and is used by many single-celled organisms, such as bacteria and protozoans. In binary fission, the genetic material within the parent cell is replicated, and then the cell elongates and constricts at the centre. This causes the cell to divide into two genetically identical daughter cells, each containing a copy of the genetic material (see Figure 2.3). Binary fission is a rapid process and enables the organism to produce large numbers of offspring quickly.

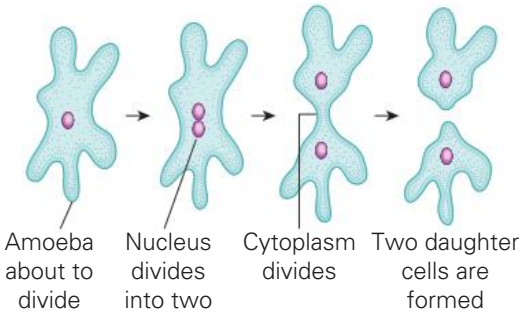


Figure 2.3 Binary fission in an amoeba (a unicellular organism)

Fragmentation

Fragmentation is a form of asexual reproduction in which an organism splits into several fragments, each of which can grow into a new individual. This mechanism of reproduction is observed in certain multicellular organisms such as flatworms and sea anemones.

In fragmentation, the parent organism breaks into two or more fragments, each of which contains a portion of the parent's body, including its organs and tissues. These fragments can then regenerate missing parts and develop into complete, independent individuals over time.



Figure 2.4 Fragmentation in a flatworm

Vegetative propagation

Plants may reproduce asexually via a process called **vegetative propagation** (also called vegetative reproduction), which involves the growth of specialised tissue, such as runners, tubers or bulbs, from the roots or shoots of the plant. These growths can potentially break off from the parent plant and develop into an independent, but genetically identical, organism. In this sense, it is similar to fragmentation. If you have ever taken a cutting from a plant and grown it in a new location, this is a form of vegetative propagation. This is explored in further detail in Section 2.4.

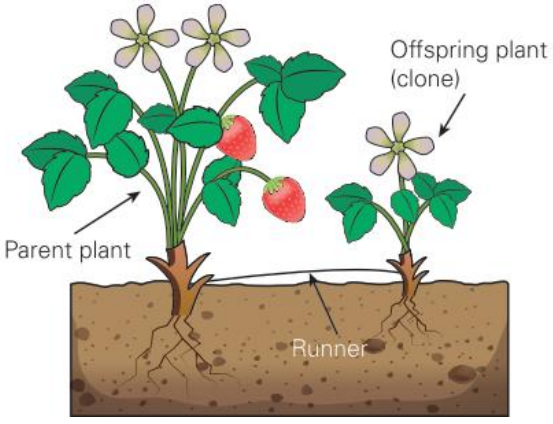


Figure 2.5 A strawberry plant reproduces asexually by growing a runner. When the runners contacts the ground, root development is switched on and a new genetically identical strawberry plant grows.

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Spore formation

Fungi and some plants, such as ferns, produce single-celled **spores**, which are released into the environment. The spore is a clump of unspecialised cells surrounded by a protective coating. These spores are carried by the wind to a new location. If conditions at the new location are favourable, the spores germinate and grow into new individuals that are genetically identical to the parent. Note that spores can be formed by sexual or asexual reproduction.



Figure 2.6 Spores under a fern leaf



Figure 2.7 Spore formation can provide a means of survival in harsh environments. For example, a fungus can produce spores that remain dormant until conditions become favourable for growth.

spore
a reproductive body, produced by fungi and some plants, that develops into a new individual

budding
a type of asexual reproduction, used by organisms such as yeast and hydra; it involves the daughter offspring growing off the side of the parent and then dropping off

Budding

Budding is a type of asexual reproduction in which a new genetically identical individual grows as an outgrowth or bud from the parent organism. This process is commonly observed in simple organisms such as hydra (tiny freshwater organisms) and yeast.

In budding, the new individual develops as a smaller version of the parent organism and remains attached to it until it is fully formed. The bud grows until it reaches a certain size, then detaches from the parent organism to become a separate individual (see Figure 2.9).

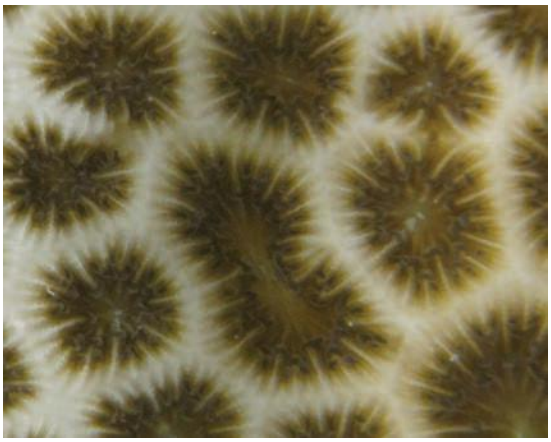


Figure 2.8 Corals reproduce asexually by fragmentation or budding. In the centre, a *Leptastrea purpurea* coral polyp has produced a large bud, which will split off.

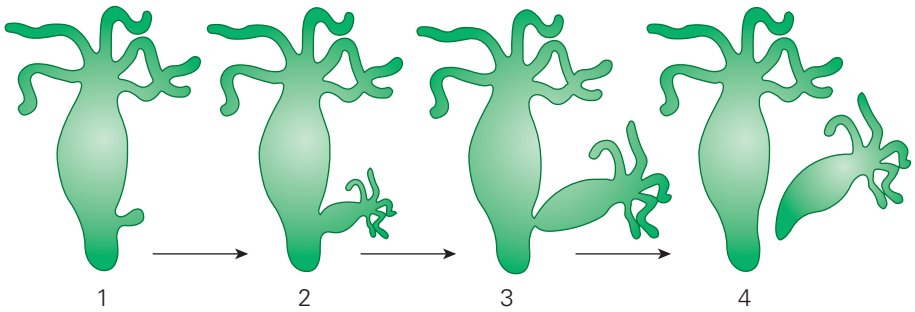


Figure 2.9 Budding in a hydra – a daughter offspring grows off the side of the parent and drops off

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Parthenogenesis

parthenogenesis a type of asexual reproduction in which an egg develops into an embryo without being fertilised by a male gamete

Parthenogenesis comes from the Greek words for 'virgin birth' and is a form of asexual reproduction in which an egg develops into an embryo without being fertilised by a male gamete. Most animals that reproduce by parthenogenesis are invertebrates, such as bees, wasps, ants and aphids. These species can switch between sexual and asexual reproduction. However, parthenogenesis has also been documented in more than 80 vertebrate species, with about half of these being lizards or fish.

Egg cells contain half of the mother's genetic material, but when they are formed, a smaller cell is produced as a by-product that also contains some of the mother's genetic material. In one form of parthenogenesis, the gamete and smaller by-product cell merge. This slightly shuffles the genes, so the offspring are similar, but not genetically identical, to the mother.



Figure 2.10 The New Mexico whiptail (*Aspidoscelis neomexicanus*) is a female-only species of lizard.

Did you know? 2.2

Parthenogenesis and sex of offspring

Offspring produced by parthenogenesis in species that have the XY sex-determination system usually have two X chromosomes, resulting in a female offspring. In species such as birds or Komodo dragons that have the ZW sex-determination system, the ZW mother is capable of reproducing via parthenogenesis and creating either ZZ (male) eggs or ZW (female) eggs. The female eggs are not viable; hence, all the Komodo dragon hatchlings born this way will be exclusively male.



Figure 2.11 Parthenogenesis in Komodo dragons results in male offspring, who therefore cannot be genetic clones of their mother!

Occasionally, certain animals such as aphids can give birth to male offspring that are fertile and genetically identical to their mother, except for the absence of a second X chromosome. Although these males are typically capable of reproducing, their sperm only contains X chromosomes, resulting in the production of exclusively female offspring.

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Section 2.1 review

Online quiz

Section questions

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Section 2.1 questions

Remembering

1. **List** the six forms of asexual reproduction, and give an example of an organism that reproduces by each method.
2. **Recall** how many parent organisms are required for asexual reproduction.

Understanding

3. **Explain** why it could be advantageous for an organism to reproduce asexually.
4. **Explain** how a flatworm that has been surgically cut in half can regenerate into two organisms.

Applying

5. A bacterial cell undergoes binary fission every 20 minutes. After an hour, **calculate** how many cells would be present in the Petri dish.
6. **Outline** the effects that reproducing asexually has on the genetic variation in a population.

Analysing

7. While exploring a rockpool, a child comes across two sea stars (as shown) and exclaims, 'A Mum and a baby!' **Deduce** which type of asexual reproduction has occurred based on the appearance of the sea stars.



Evaluating

8. **Propose** why organisms produced from asexual reproduction are referred to as clones.
9. A fellow student suggests that asexual reproduction is only used by very basic organisms, such as bacteria and single-celled parasites. **Justify** why this student is incorrect by referring to some multicellular organisms and the types of asexual reproduction they employ.
10. A new species of lizard is discovered, and a zoologist captures a female of the species. One year later, the lizard lays eggs that hatch into many female lizards. **Determine** the method of reproduction she has used.

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2.2 Sexual reproduction in animals

WORKSHEET Sexual reproduction

Learning goals

At the end of this section, I will be able to:

1. Describe how sexual reproduction creates a greater rate of variation among offspring than asexual reproduction does.
2. Describe how the reproductive strategies of multicellular animals are related to their environment and the complexity of the organism.
3. Describe how the number of offspring produced by animals is related to the amount of parental care.

gamete
a sex cell (egg or sperm); it contains half the genetic material required to make an organism

gonad
the reproductive organ where gametes are produced; testis in males and ovary in females

fertilisation
the fusion of the male and female gametes (sperm and egg)

zygote
a fertilised egg cell

embryo
a fertilised egg cell in the early stages of growth and differentiation; in humans, 2–8 weeks after fertilisation

You will recall that sexual reproduction combines the genetic input from two parents to create a new, unique organism that is not identical to either parent. This is the method used by humans, most animals and many plants. While sexual reproduction costs the organism time and energy, the benefit is that it creates diversity in the population.

The process of sexual reproduction

Sexual reproduction involves the fusion of two **gametes** (sex cells containing half the normal amount of genetic information) – one from each parent. Gametes are specialised cells produced by the **gonads**, which are the reproductive organs. In males, the gonads are the testes, while in females, they are the ovaries.

During sexual reproduction, the male gamete, or sperm cell, and the female gamete, or egg cell, unite in a process known as **fertilisation** to form a **zygote** (see Figure 2.12). The zygote contains the complete set of genetic material necessary to form a new organism of the same species (in humans, 23 chromosomes from the egg cell and 23 chromosomes from the sperm cell). The zygote then undergoes cell division and develops into an **embryo** (see Figure 2.13).



Figure 2.12 A zygote results from the fusion of an egg cell and a sperm cell.

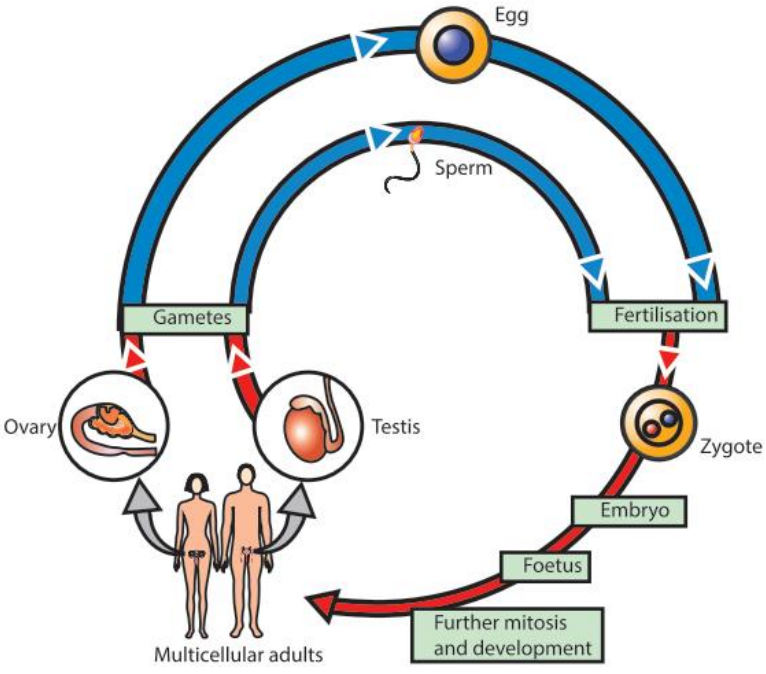


Figure 2.13 The human reproductive cycle

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Figure 2.14 Sexual reproduction creates variation in the offspring, as the genetic material from two different parents is combined in unique ways.

Quick check 2.1

1. **Define**:
   - **a)** sexual reproduction
   - **b)** gametes
   - **c)** gonads
   - **d)** zygote
   - **e)** embryo.
2. **Compare** and **contrast** sexual and asexual reproduction.
3. **Recall** the number of parents involved in asexual and sexual reproduction.
4. **Name** the female gonads and gametes and the male gonads and gametes.

VIDEO
Asexual and sexual reproduction

Did you know? 2.3

Courtship rituals

Attracting a mate is essential in sexual reproduction. Many animals, such as birds, use elaborate and impressive courtship rituals to signal to the opposite sex that they are ready to mate. Rituals include:

- behavioural adaptations, such as special mating calls (songs) and dances
- physical adaptations, such as special feathers and colour patches
- physiological adaptations, such as releasing hormones called pheromones to attract a mate.

Bowerbirds are known for their unique and elaborate mating rituals. One aspect of these rituals is the use of colour to attract mates. Male bowerbirds create intricate displays called bowers, which they decorate with various objects such as leaves, flowers and feathers. One popular decoration is the colour blue, which is known to be attractive to female bowerbirds. Male bowerbirds will gather blue objects such as flowers, feathers and even bottle tops and wrappers to decorate their bowers, in the hopes of catching the attention of a female.

In general, more complex organisms tend to have more intricate and varied reproductive strategies, which may involve specific courtship behaviours and elaborate mating displays. These strategies are often shaped by the selective pressures of the environment, such as competition for mates and access to resources.



Figure 2.15 The satin bowerbird is native to Australia; like other bowerbirds, it uses the colour blue to attract potential mates.

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Fertilisation methods

internal fertilisation a method of fertilisation in which male gametes are delivered into the female reproductive system and fertilisation takes place inside the female

external fertilisation a method of fertilisation in which gametes are released into the environment and fertilisation occurs outside the body

Fertilisation can occur inside an organism or in the external environment. **Internal fertilisation** is the method of fertilisation in which male gametes are delivered into the female reproductive system and fertilisation takes place inside the female. This is the method of fertilisation of most animals living in a terrestrial environment, because it protects the gametes and zygote from drying out.



Figure 2.16 Internal fertilisation allows reproduction to take place on land without gametes drying out.



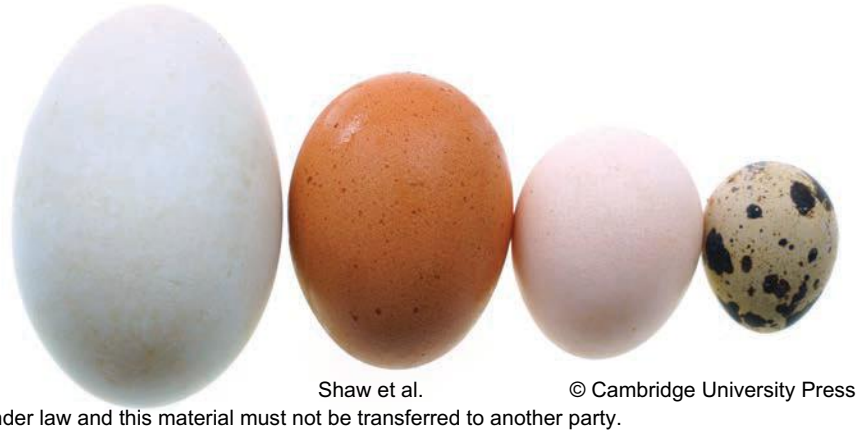
Figure 2.17 A school of fish and a cloud of gametes that have been released in external fertilisation

External fertilisation typically occurs outside the parent animals and is commonly observed in organisms that live in an aquatic or semi-aquatic environment, such as amphibians and fish. This method of fertilisation requires eggs and sperm to be expelled from the organisms' bodies, to then be united in water.

One potential problem with external fertilisation is that the eggs and sperm may not meet, due to either being eaten by predators or unfavourable environmental conditions, such as strong currents. Consequently, organisms that rely on this method of fertilisation have evolved to produce large quantities of eggs and sperm cells, which are released simultaneously and near each other.

Quick check 2.2

1. **Define**:
   a) internal fertilisation
   b) external fertilisation.
2. **State** the type of fertilisation that occurs in mammals.
3. **Describe** some advantages of internal fertilisation and some disadvantages of external fertilisation.



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Explore! 2.1

Assisted reproduction to save endangered species

In 2023, scientists achieved a world-first successful embryo transfer in a southern white rhino. Although this technique is widely used in humans and domestic animals, it was the first time it had been used in rhinos. The transfer relied on the development of completely new methods, protocols and equipment specifically designed to implant an embryo through the digestive tract of the two-tonne rhino. The embryo was created using an egg from a female southern white rhino from a zoo in Belgium. The egg was then fertilised in a laboratory with sperm from a male southern white rhino in Austria, and implanted into a surrogate female in Kenya. Tragically, this surrogate female died from an unrelated infection, but the foetus had been developing well until that point.

This has given scientists hope that the technology could be applied in a bid to save the closely related northern white rhino, a sub-species that is considered functionally extinct since only two infertile females remain alive. Prior to the deaths of the last male northern white rhinos, sperm was collected and used to create 30 embryos. However, due to the age and health of the two remaining females (who are kept under tight security at a facility in Kenya), the northern white rhino embryos would need to be implanted into the womb of a southern white rhino surrogate. The team from Biorescue, a German group aimed at fighting species extinction, are confident that transferring the embryo into a different sub-species will work.

Yet researchers admit that even if successful, this technique alone will not be sufficient to save the species. Since the 30 frozen embryos were all created from the eggs of one of the living females, there would not be enough genetic diversity to produce a viable population. The team is also exploring experimental techniques, such as producing northern white rhino sperm from stem cells and gene editing, to create more diversity in the embryos and save the northern white rhino.



Figure 2.18 A veterinarian examines a southern white rhino, Lulu, during her 16–18-month pregnancy. She later gave birth to the first rhino calf born via artificial insemination.

Consider the ethical concerns around using these advanced reproductive techniques to save the northern white rhino. For example, some people would argue that we are using the technology to fix an undesirable outcome of human activity (species extinction) when we should be addressing the underlying causes, such as habitat loss and hunting.

1. Do humans have the right (or the responsibility) to intervene and save this species, or should we accept the end of the evolutionary line for the northern white rhino?
2. If saving the species is dependent on gene editing (changing the species genetically) are we really conserving the same species at all?
3. Would the same efforts be made for a species that was not so widely known and popular?

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Gestation

gestation the pregnancy period, when offspring are developing inside the mother

Gestation refers to the period during which offspring develop inside the mother's body until they can survive outside the body. This is commonly known as 'pregnancy'. Gestation typically lasts about 280 days (approximately 9 months) in humans, but varies among different mammalian species. More complex organisms tend to have longer gestation times.



Figure 2.19 A heavily pregnant elephant. Elephants have a gestation period of nearly two years!

Did you know? 2.4

Mouse plagues

Mice are prolific breeders, with a gestation period of 19–21 days. A female mouse can produce 5–10 litters a year, with each litter ranging from 3–14 pups. On average, a litter contains 6–8 pups, resulting in a potential output of at least 32–56 pups annually from a single female mouse.

Moreover, mice have a rapid reproductive cycle, with the mother capable of mating again immediately after giving birth. The offspring can start reproducing as early as 6 weeks old and can have up to 10 litters a year themselves. One mathematician estimated that in a perfect world for mice, just two initial mice could result in a total of five million mice being produced in a year.

This quick gestation time plays a significant role in creating mouse plagues; that is, an explosion in the mouse population. This phenomenon only occurs in China and Australia and can have a devastating impact on agriculture, natural ecosystems and public health.



Figure 2.20 Periods of flooding often trigger mouse plagues in Australia.

Stages of embryonic development in humans

In humans, the time from fertilisation to birth is about 38 to 40 weeks. The baby's due date is calculated based on the first day of the last known menstrual period (see Section 2.3), but it is not always accurate. All babies develop via the same sequence of developmental stages; however, only 5% are actually born on their due date.

Egg to zygote

The unfertilised egg is released from the ovary and travels along the fallopian tube towards the uterus (see Figure 2.21). There is a 12–24-hour period in which the egg can unite with a sperm cell and become fertilised after it has been released. Once fertilised, the egg is referred to as a zygote.

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Zygote to embryo

After fertilisation, the zygote starts to divide via a process called **mitosis** and splits into two cells, which further divide repeatedly and form a ball of cells. This ball of cells takes about five days to travel through the fallopian tube before finally implanting into the lining of the uterus. The cells within the ball continue to divide and begin to specialise, forming an embryo.

mitosis
a process in which a single eukaryotic cell divides into two identical daughter cells

differentiation
the process by which cells become specialised

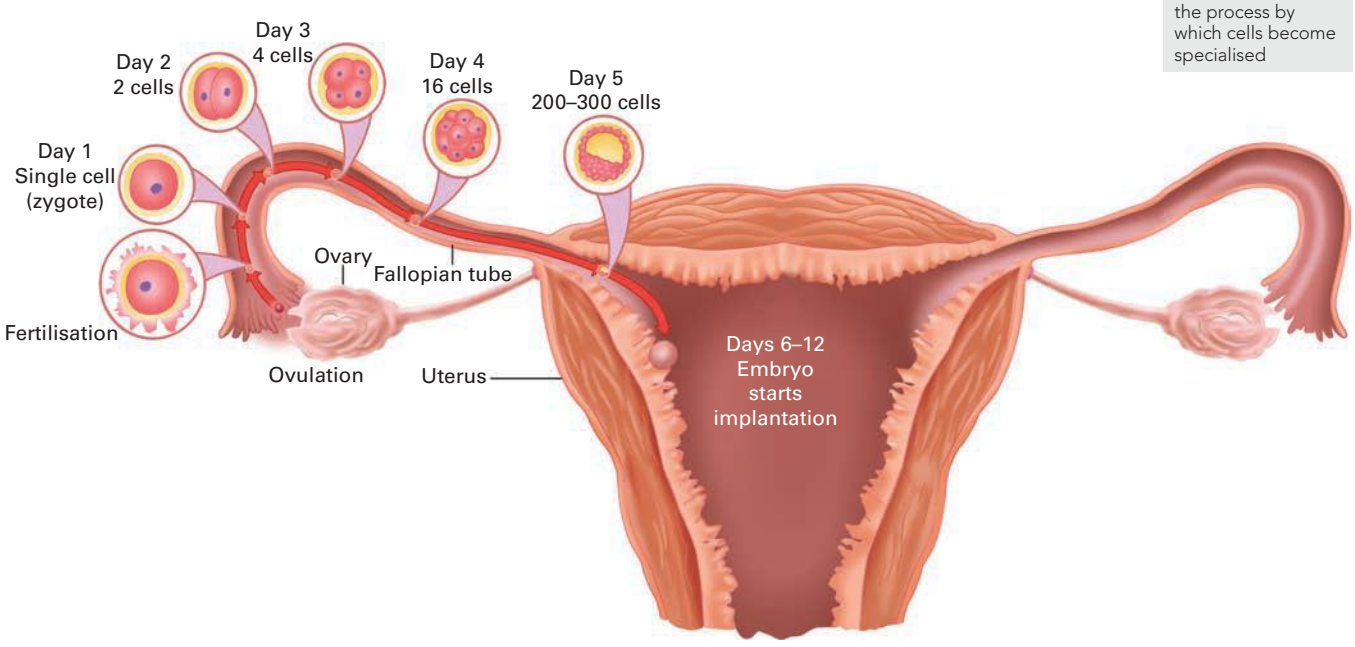


Figure 2.21 The stages of embryonic development in the female reproductive system

Embryonic stage

During the embryonic stage, which spans from week 2 to week 8, the cells of the developing embryo divide extensively and undergo **differentiation** into various types of cells, including neurons, liver cells and skin cells. This period of differentiation is a crucial phase in human development. During this time, the embryo is highly vulnerable to the negative effects of alcohol, disease and drugs, which can cause birth defects, such as limb abnormalities, or hinder the proper growth of the brain. Although all major organs are formed by the eighth week, they are not yet fully developed at this stage.

Foetal stage

From approximately week 8 until birth, the foetal stage of development takes place. This is characterised by a period of accelerated growth, during which the organs become fully developed and functional. During this stage of development, the foetus is still susceptible to the effects of alcohol, disease and drugs.



Figure 2.22 A 9-week-old human foetus

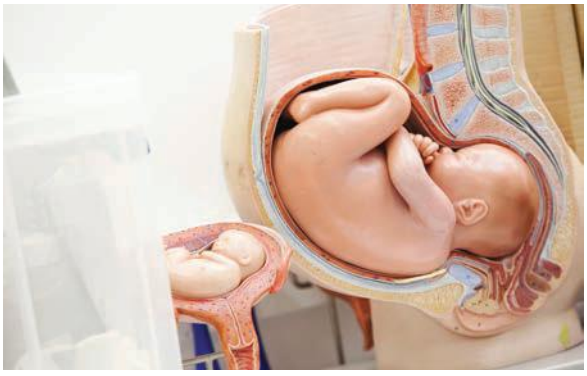


Figure 2.23 A model of a foetus that is nearly full term and ready to be born

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Explore! 2.2

Investigating gestation and development

How much time does it take different animals to develop from an embryo to infant form? Conduct some research to answer the question and then copy and complete the following table.

Animal	Gestation period	Time until they can walk/move	Time relying on parent for food	Average lifespan
Human	280 days			
Dog				
Giraffe				
Choose your own animal				

VIDEO Microscopic view of an IVF procedure

Explore! 2.3

Ivy AI

Australia has developed an artificial intelligence system that is used to predict the likelihood of a viable pregnancy from transfer of a single embryo to a woman undergoing in-vitro fertilisation (IVF). IVF is a fertility treatment procedure where eggs are removed from a woman's ovaries, fertilised with sperm in a laboratory, and then transferred back into the woman's uterus to try to achieve a successful pregnancy.

The artificial intelligence system is called 'Ivy' and it uses data from previous IVF cycles to predict the probability of a successful pregnancy based on various factors, such as a woman's age and body mass index (BMI) and the quality of the embryo. Ivy AI was trained on data from more than 24 000 IVF cycles, and it uses machine learning algorithms to analyse and identify patterns in the data.

The system provides a personalised prediction of the likelihood of pregnancy for each patient, which can help doctors and patients make more informed decisions about how many embryos to transfer. The goal is to maximise the chances of a successful pregnancy while minimising the risk of multiple pregnancies, which can be associated with complications for both the mother and the babies.

The use of Ivy has reduced the number of multiple pregnancies and led to a higher success rate for single embryo transfers. This not only improves the chances of a healthy pregnancy but also reduces the costs associated with multiple cycles of IVF.

Conduct some research to determine how assisted reproductive technologies have become widely used since their initial development.

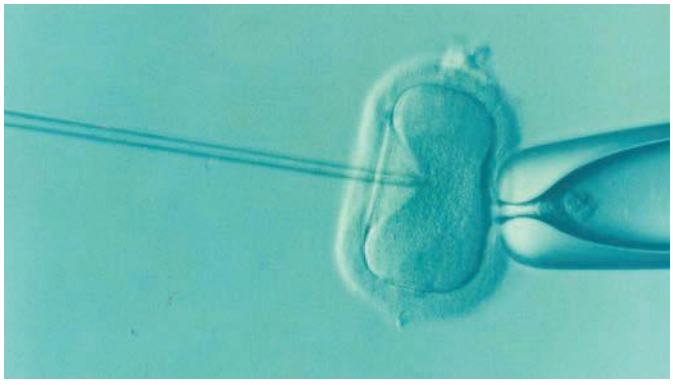


Figure 2.24 Intracytoplasmic sperm injection is a fertility treatment procedure where a single sperm is directly injected into an egg to help with fertilisation. It can be used when conventional IVF has failed.

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Quick check 2.3

1. **Define** 'gestation'.
2. **Recall** the length of the gestation period in humans.
3. Copy and complete the following table to **summarise** the stages of embryonic development in humans.

Stage	Duration	Description
Egg to zygote		
Zygote to embryo		
Embryonic stage		
Foetal stage		

Birth

The onset of birth remains somewhat of a mystery. A complex cascade of hormones and interactions between mother and baby results in the beginning of labour, which can last from a few hours to several days. During labour, the cervix thins and dilates, and the uterus contracts to facilitate the delivery of the baby through the vagina, usually head first. Complications can occur due to the positioning of the baby or medical issues. For example, a baby may present as 'breech', which means it is positioned to come through the vagina feet first. In medical emergencies, a surgical procedure known as a caesarean section (C-section) may be required. This involves making an incision across the mother's abdomen and removing the baby in an operating theatre.



Figure 2.25 A newborn baby's umbilical cord is cut, severing the circulatory connection with the mother. A screaming baby is a healthy breathing baby!

During gestation, babies receive nutrients and oxygenated blood from the maternal placenta, via the umbilical cord. This is also how wastes are removed from the foetal bloodstream. When the baby emerges and takes their first breath, their respiratory system takes over, and previously fluid-filled lungs begin to exchange gases and absorb oxygen into the bloodstream. The umbilical cord is typically clamped and cut once it is no longer pulsing and has gone pale. The final stage of labour involves the mother delivering the placenta.

Development

Like humans, most other mammals undergo internal development, where offspring develop within the uterus and receive direct nourishment from the mother via the umbilical cord. Baby mammals tend to be born generally resembling the adult organism, only smaller. However, two sub-classes of mammals undergo a different pattern of development.

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Monotremes, such as the platypus, are egg-laying mammals. Marsupials, such as kangaroos, give birth to extremely underdeveloped young, which must make their way through the mother's fur from the vagina to the pouch, where they attach to a nipple and continue to develop (see Figures 2.26 and 2.30). Offspring of birds, reptiles, amphibians and insects typically undergo external development outside the mother's body. They develop within a waterproof egg and hatch when they are developed enough to survive in their environment.



Figure 2.26 A baby kangaroo is called a joey. After being born, the joey wriggles its way into its mother's pouch to feed.



Figure 2.27 Internal fertilisation in most reptiles is followed by external embryo development.

Did you know? 2.5

Breast crawl

A defining characteristic of mammals is that they feed their offspring milk. Newborns placed skin-to-skin on their mother's chest will instinctively crawl upwards and root around with their mouths to locate the nipple, looking for their first breastfeed. The golden-yellow early milk they receive is called colostrum. It is produced in small quantities but is rich in nutrients, antibodies and growth factors to help colonise the baby's gut with beneficial bacteria and build their immune system.



Figure 2.28 A newborn baby enjoys their first feed

Parenting

Throughout your life, you have been nurtured by adults. But not all living beings provide parental care to their offspring. Many organisms do not look after their young after laying eggs. For instance, after laying their eggs on the beach, female turtles return to the ocean and do not provide any further care to the eggs or hatchlings. The eggs are left to develop on their own in the sand, and once the hatchlings emerge, they must fend for themselves and make their way to the ocean to start their lives.



Figure 2.29 Organisms that do not provide parental care frequently produce a large quantity of eggs, which increases the likelihood of some offspring surviving predators, disease and competition and reaching adulthood. Approximately one in 1000 turtle hatchlings survives to adulthood.

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The amount of parental care provided by animals is generally inversely related to the number of offspring they produce. Species that produce few offspring typically invest a lot of time and resources into each offspring, providing extensive parental care to ensure their survival. In contrast, species that produce many offspring, such as the turtle, generally provide minimal parental care because the sheer number of offspring increases the chance that some offspring will survive.



Figure 2.30 A kangaroo mother's pouch provides a safe environment for her offspring.

Explore! 2.4

Dr Helen Mayo

Dr Helen Mayo was an Australian doctor and social reformer who dedicated her life to improving the health and welfare of women and children. She was the second woman to gain a medical degree from the University of Adelaide, but she is best known for her work in reducing infant mortality rates in South Australia in the early twentieth century. The practices adopted by society based on Dr Mayo's research and recommendations caused the infant mortality rate to decline rapidly. Dr Mayo's work had a lasting impact on public health in Australia, and her recommendations for improving infant care and nutrition are still widely used today.

Conduct some research to discover the recommendations that Dr Mayo made that led to a significant reduction in infant mortality rates in South Australia.



Figure 2.31 Dr Helen Mayo's research helped reduce infant mortality rates in Australia.

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Did you know? 2.6

Octopus fertilisation

While octopuses do not undergo pregnancy, they do lay eggs, albeit in an unusual manner. During mating, male octopuses use specialised arms known as hectocotyli to transfer packets of sperm to the female. The female can retain the sperm for later use when fertilising her approximately 200 000 eggs. After fertilisation, she proceeds to lay the eggs, either suspending them near her den or attaching them to the sea floor. Unusually for an animal that lays so many eggs, the female displays intense care towards her eggs, continually fanning water over them to provide aeration and protect them from harm.



Figure 2.32 An octopus guarding her egg mass

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Section 2.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 2.2 questions

Remembering

1. **Recall** the two types of reproduction.
2. **State** the two cells that are required for sexual reproduction.
3. **Define** 'gamete'.
4. **Recall** where gametes are made.

Understanding

5. **Explain** why an aquatic animal can use external fertilisation more easily than a land-dwelling animal can.
6. **Summarise** the benefits of internal fertilisation.

Applying

7. **Explain** why it could be advantageous for an organism to reproduce sexually.
8. **Describe** the differences between internal fertilisation and external fertilisation.

Analysing

9. **Distinguish** between sexual reproduction and asexual reproduction.
10. **Connect** methods of fertilisation with methods of embryo development, in relation to where they take place – internally or externally. Include examples. Consider why for an animal a particular method of fertilisation might not go with a particular method of embryo development.

Evaluating

11. **Construct** a short timeline of the human gestation period. Ensure you include the terms 'egg', 'zygote', 'embryo' and 'foetus'.
12. Many courtship displays demonstrate a male individual's strength through physical feats, or their health through the vibrancy of their colourings. **Discuss** why this would be useful information for the female.

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2.3 The human reproductive system

Learning goals

At the end of this section, I will be able to:

1. Examine how the male and female reproductive organ structures work collectively as a system.
2. Describe how the forms of male and female gametes relate to their specific functions.

WORKSHEET Human reproductive organs

As previously discussed, humans rely on internal fertilisation to sexually reproduce. Male and female reproductive organs are structured in a way that facilitates this process. While these organs share similarities (such as the production of gametes in the gonads), their physical structures and hormonal systems are vastly different.

ovum egg, or female gamete

puberty the time of transition from juvenile form to adult form

NOTE

It is important to note that this chapter uses the terms 'male' and 'female' to indicate biological sex. This is different from, and independent of, gender, which refers to the socially constructed roles, behaviours, expressions and identities of people, which can vary widely.

Female reproductive system

The female reproductive system supports the production and transport of eggs, as well as the growth and development of a fertilised egg **ovum** into a foetus during pregnancy (see Figure 2.33).

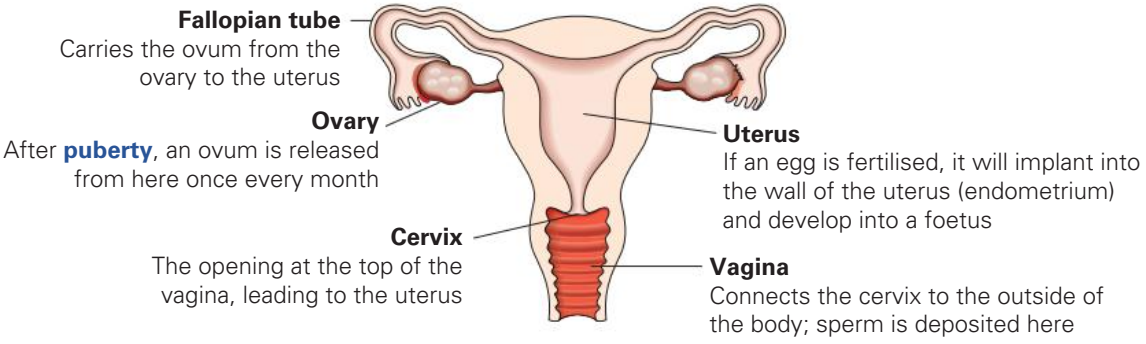


Figure 2.33 The female reproductive system

Male reproductive system

The male reproductive system consists of several organs and structures that work together to produce, store and transport sperm (see Figure 2.34).

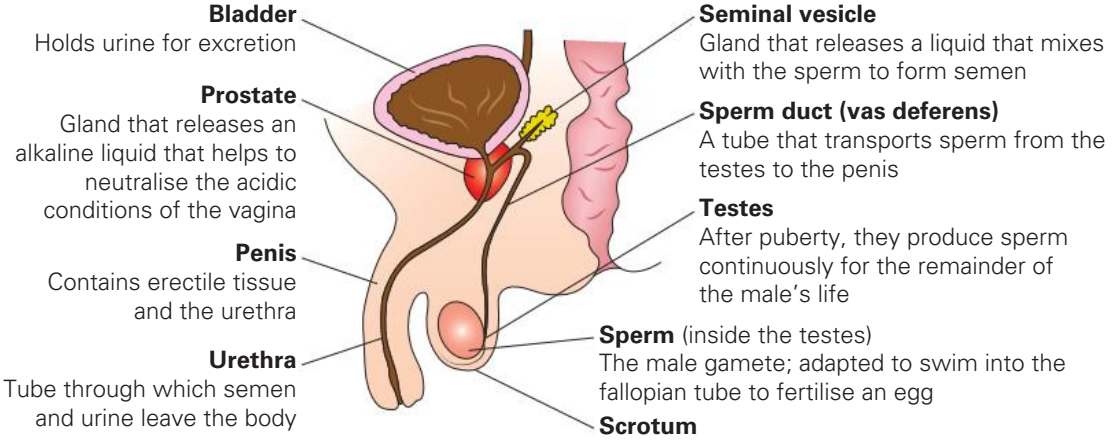


Figure 2.34 The male reproductive system

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Female and male gametes

The forms of female and male gametes are adapted to their specific functions. They both contain half the amount of genetic material as body cells. This is important for sexual reproduction, as when a sperm and egg meet during fertilisation, the resulting zygote will have the normal number of chromosomes.

An egg or ovum is large and immobile. The larger size allows for the storage of nutrients and proteins required for the early stages of embryonic development. An egg also has a protective coat to prevent multiple sperm from fertilising it. At birth, females typically have from one million to two million eggs stored in their ovaries, enclosed in small sacs called follicles. However, many of these eggs will naturally deteriorate before they reach puberty.

ovulation
the release of an ovum (egg) from the ovary into the fallopian tube

menstruation
the cyclical shedding of the uterine lining; also known as the menstrual period

sperm
the male gamete

testes
the male reproductive glands that produce sperm

scrotum
a sac that encloses the testes

Once they reach this stage, one egg is released from the ovaries into the fallopian tube each month in a process known as **ovulation**. If this egg remains unfertilised, the uterine lining is shed, along with the remains of the egg, resulting in **menstruation**.

After reaching puberty, males begin to generate **sperm** in their **testes**, which are held in a sac known as the **scrotum**, located outside the body. This area remains approximately 2–3°C cooler than core body temperature; this temperature is best suited for efficient sperm production.

Sperm are smaller and more streamlined in shape than eggs. The streamlined shape of a sperm enables it to move quickly and efficiently through the female reproductive tract to reach the egg. It also has a long, whip-like tail or flagellum that enables it to swim (see Figure 2.35b). The midpiece of the sperm contains many mitochondria, which provide energy for the sperm to swim. The sperm also has a sac of enzymes in its head, which helps it to penetrate the egg membrane. Unlike eggs, sperm are continuously produced in large quantities throughout a male's life.

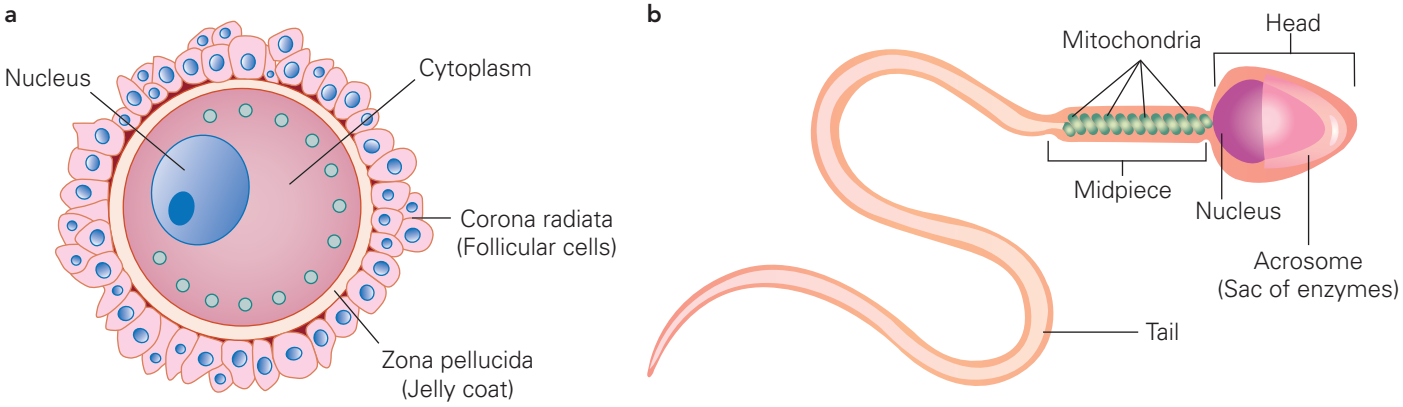


Figure 2.35 (a) An ovum, or human egg cell, is surrounded by a jelly coat that acts as a barrier to sperm entry, and follicular cells, which provide support and nourishment. **(b)** The human sperm cell has adapted for quick movement towards the egg.

Quick check 2.4

1. **Identify** where eggs are released from and what structure they are released into.
2. **Describe** what happens when an egg is released but not fertilised.
3. **Recall** what the vas deferens is.
4. Draw up a table to **summarise** the parts of the female and male reproductive systems and their function.

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Try this 2.1

Modelling fertilisation

Construct a model or a diagram showing the structures of the female reproductive system and the process of fertilisation (from ovulation until the zygote implants in the uterine wall).

Puberty

During their early stages of life, all animals undergo a process of transformation from their juvenile form to their adult form, which is facilitated by various **hormones** that control and regulate different processes in the body. This process is commonly referred to as puberty.

hormone a chemical messenger secreted by endocrine glands that controls and regulates different processes in the body

secondary sexual characteristic any physical characteristic developing at puberty that helps distinguish between the sexes but is not directly involved in reproduction

In humans, puberty generally occurs later than in other animals. Females usually go through puberty at 9–14 years, whereas males go through puberty at 12–16 years. The timing of puberty varies among individuals, and this variation is normal. In both sexes, the production rate of growth hormone (GH) doubles during puberty, causing individuals to grow taller.

The hypothalamus, a part of the brain, produces gonadotropin-releasing hormone (GnRH), which stimulates the pituitary gland to release two important hormones called luteinising hormone (LH) and follicle-stimulating hormone (FSH).

In females, LH and FSH produced in response to the production of GnRH are responsible for triggering the production of oestrogen and progesterone in the ovaries. Oestrogen is the primary female sex hormone and is responsible for the development of **secondary sexual characteristics** such as breasts, wider hips, and pubic and underarm hair (see Figure 2.36).

In males, LH and FSH are responsible for triggering the production of testosterone in the testes. Testosterone is the primary male sex hormone and is responsible for the development of secondary sexual characteristics such as facial and body hair, a deeper voice and larger muscles. The increase in testosterone levels during puberty also leads to the enlargement of the testes, scrotum and penis.

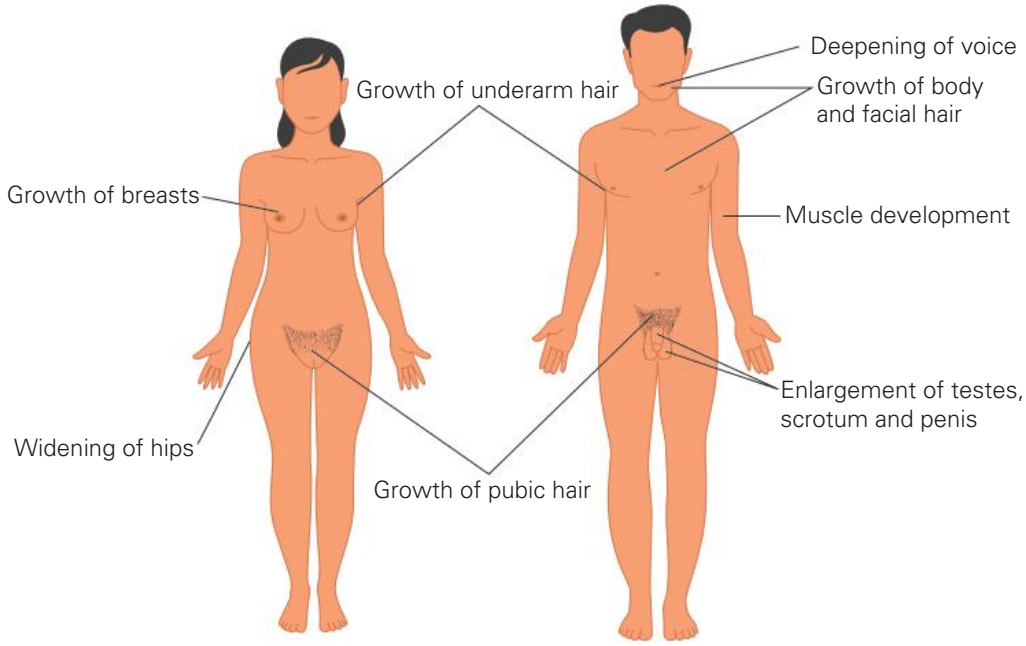


Figure 2.36 Secondary sexual characteristics in puberty

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Did you know? 2.7

Other effects of hormones

During puberty, hormonal changes in the body can lead to body odour and acne. Body odour is caused by the apocrine sweat glands, which are in the armpits and groin. These glands produce a thick, oily sweat that can have a strong odour when it mixes with bacteria on the skin's surface. During puberty, hormones stimulate the apocrine sweat glands to produce more sweat, leading to increased body odour.

Hormones also stimulate the sebaceous glands in the skin's pores to produce more sebum, an oily substance that helps keep the skin moisturised. However, excessive production of sebum can clog the pores and cause acne as a result.



Figure 2.37 Some unpleasant side effects of puberty are body odour and acne.

Menstrual cycle

menstrual cycle a cycle controlled by hormones to prepare a female body for fertilisation of an egg; if fertilisation does not occur, menstruation will follow

Hormones also control the **menstrual cycle**, which usually lasts about 28 days (see Figure 2.38).

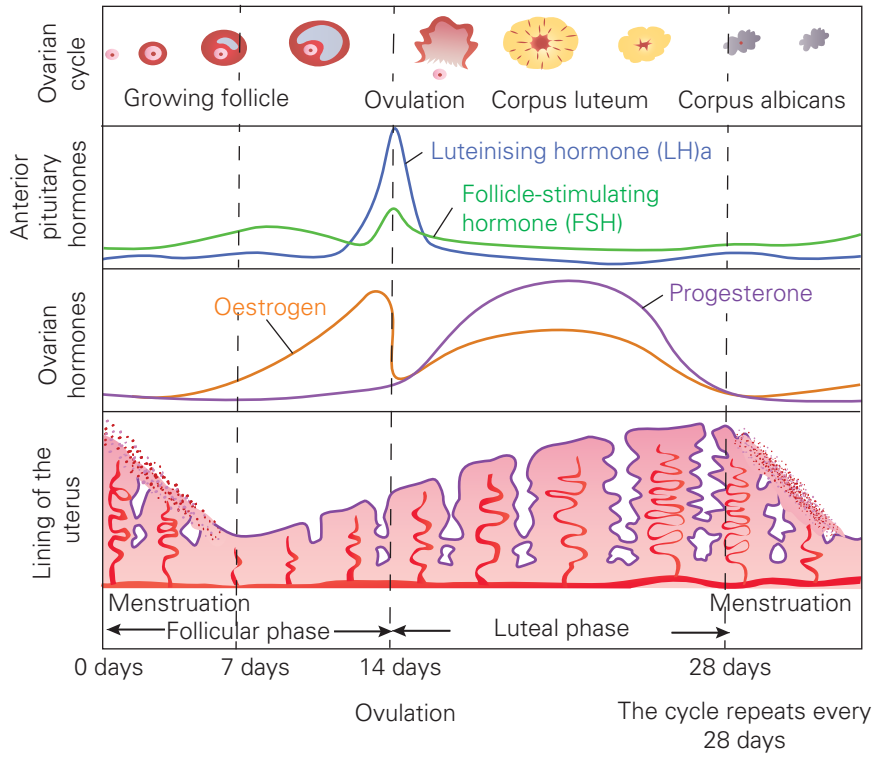


Figure 2.38 The link between the different hormones in the female reproductive system and the action of the follicles. After the follicle releases an egg, it is known as the *corpus luteum*.

1. The pituitary gland in the brain releases FSH.
2. FSH causes one of the eggs in an ovary to mature. It also stimulates the ovaries to make oestrogen.
3. Oestrogen stimulates the pituitary gland to release LH.

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4. LH triggers the release of an egg (ovulation).
5. Oestrogen also inhibits further production of FSH (stopping other eggs from maturing). It also repairs the uterine lining (endometrium).
6. Once the egg has been released, progesterone is produced by the empty follicle (called the *corpus luteum* or yellow body). This maintains the uterus lining and inhibits LH.
   a) If pregnancy occurs, the follicle continues to produce progesterone and a placenta is formed.
   b) If pregnancy does not occur, then the *corpus luteum* stops secreting progesterone and decays into the *corpus albicans* (whitening body). As a result, the progesterone and oestrogen levels drop towards the end of the menstrual cycle, the uterine lining breaks down and menstruation occurs.

Did you know? 2.8

Cloaca: One opening for everything!

Humans have separate openings for different bodily functions: an anus and a urethra to excrete waste, and, in females, a vagina for reproduction. But not all animals are like that. In fact, it is much more common to have a single opening that does all of the above. This organ is called the **cloaca** and it is found in amphibians, reptiles, birds, some fish and even monotremes. This is why it can sometimes be tricky to distinguish between the sexes of certain animals. For example, birds mate by pressing their cloacas together in a process known as a 'cloacal kiss', where muscular undulations move the sperm from the male to the female.

cloaca
a hole used for defecating, urinating and reproduction that is present in some amphibians, reptiles, birds, fish and monotremes



Figure 2.39 A turtle laying an egg through its cloaca



Figure 2.40 A kākā with its cloaca visible

Quick check 2.5

1. **Define** 'puberty'.
2. **Name** the hormones involved in puberty for males and **explain** what their roles are.
3. **Name** the hormones involved in puberty for females and **explain** what their roles are.
4. **Draw** a flow chart to summarise the female menstrual cycle. Use Figure 2.38 to help you.

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Did you know? 2.9

Early puberty

Research has confirmed that the average age of puberty has been decreasing, with females experiencing puberty about three months earlier per decade since the 1970s. A similar but less pronounced trend has been observed in males. The cause remains unclear, with no specific risk factor or combination of factors explaining the change. Researchers are exploring potential factors such as obesity and certain chemicals such as BPA and phthalates. Additionally, doctors worldwide reported a surge in early puberty cases during the COVID-19 pandemic, suggesting stress may play a role.



Figure 2.41 Phthalates are a group of chemicals that are commonly used as plasticisers to make plastic products more flexible and durable. They are also used in personal care products. However, phthalates have been associated with various health risks, including hormone disruption that may lead to early puberty.

Go online to access the interactive section review and more!

Section 2.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 2.3 questions

Remembering

1. **Recall** where the female and male gametes are produced.
2. **Name** three signs of puberty for males and three signs of puberty for females.
3. **Recall** what the onset of puberty indicates.
4. **State** the location of the cervix.
5. **State** the function of the testicles.

Understanding

6. **Describe** the cloaca.

Applying

7. Refer to the graph of the menstrual cycle in Figure 2.38. **Identify** the:
   a) hormones that peak just before ovulation (when the egg is released)
   b) hormone that is at its greatest concentration when the uterine wall is at its thickest.

Analysing

8. **Classify** the following structures as belonging to the female reproductive system, the male reproductive system or both: fallopian tube, penis, gonads, prostate gland, scrotum, ovary, vas deferens, cervix.

Evaluating

9. **Determine** why a person who has blocked fallopian tubes might find it difficult to become pregnant.
10. As a male ages, their prostate can increase in size. **Propose** a reason why this could affect urination.

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2.4 Plant reproduction

Learning goal

At the end of this section, I will be able to:

1. Identify and compare sexual and asexual reproductive strategies in plants.

WORKSHEET
Asexual plant reproduction

Plants can reproduce both asexually and sexually. Sexual reproduction in plants, as in animals, involves the fusion of gametes, resulting in a zygote and embryo. This process leads to genetic diversity, which can increase the chances of survival in changing environments.

Although asexual reproduction does not contribute to variation in the population, it offers plants several benefits: it is a quick process, requires less energy and enables plants to produce offspring in environments that are unfavourable for sexual reproduction. A plant may also reproduce asexually to take advantage of good conditions, such as following heavy rainfall, or to regenerate quickly after a fire.



Figure 2.42 Plants are a very diverse kingdom, including non-flowering plants such as **(a)** moss, **(b)** ferns and **(c)** conifers, as well as **(d)** flowering plants.

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Asexual reproduction in plants

Moss and ferns reproduce asexually via spore formation, in a similar fashion to fungi. Conifers and flowering plants use vegetative propagation to reproduce asexually. Vegetative propagation can occur naturally or through human manipulation. Both methods are summarised in Tables 2.1 and 2.2.

Natural methods of vegetative propagation	Definition	Examples
Bulb	• Underground stem for food storage • Food is stored in large leaves • Each bulb develops into a new plant	Onions, hyacinths, daffodils  **Figure 2.43** An onion bulb with leaves and roots
Runner	• A stem that grows on top of and across the ground, from an existing stem • New plants grow from the runners	Strawberries, some grasses  **Figure 2.44** Strawberry leaves and runner
Tuber	• Underground stem that contains stored food • The eyes of a potato can develop into new plants	Potatoes, sweet potatoes  **Figure 2.45** A potato with eyes beginning to sprout
Rhizome	• Long modified stem that grows horizontally under the ground • New plants grow from the rhizome	Long grasses, ferns, irises, ginger, asparagus  **Figure 2.46** A ginger rhizome with sprout

Table 2.1 Natural methods of asexual reproduction in plants

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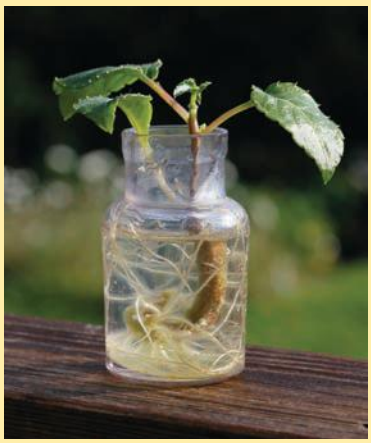
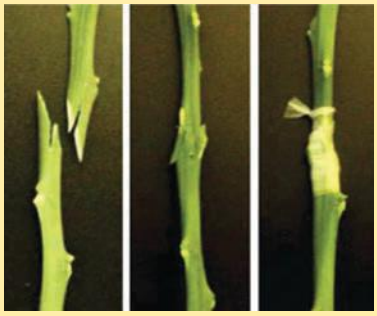
Human-induced methods of vegetative propagation	Definition	Examples	
Cutting	• Taking pieces of a root or stem • Each piece grows into a new plant	Bananas, roses, sugar cane	 **Figure 2.47** A cutting growing roots in water
Grafting	• Connecting part of a plant to another plant, combining the two plants	Citrus, grapes, apples, stone fruit, roses	 **Figure 2.48** Two pieces of stem are tied in place and will eventually grow into one stem

Table 2.2 Human-induced methods of asexual reproduction in plants





Figure 2.49 Some trees can have multiple fruits grafted onto the same tree. For example, plums, nectarines and peaches can be grafted together.



Figure 2.50 Growing new plants from cuttings is a way of making clones.

Quick check 2.6

1. **Define**:
   a) asexual reproduction
   b) sexual reproduction.
2. **State** two advantages of asexual reproduction in plants.
3. **Define** 'rhizome'.
4. **Name** one plant that can be grown from a cutting.

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Practical 2.1

Asexual reproduction in plants

Aim

To model the process of asexual reproduction, using potato tubers

Materials

- potatoes with eyes that are already starting to grow
- cotton wool
- Petri dish
- windowsill
- water
- knife
- chopping board

Method

1. Place the cotton wool in the Petri dish.
2. Add enough water to make the cotton wool damp but not wet.
3. Cut the potato into 3 cm pieces with one eye on each piece.
4. Press a piece of potato into the wet cotton wool with the eye on top.
5. Re-water the cotton wool every few days to prevent it from drying out completely.
6. Once the stem begins to grow, measure and record the growth each day over 2 weeks.

Results

Use your data and the data from two other groups in your class to calculate the average stem growth each day. Use the average data to produce a line graph.

Remember:

- Place the independent variable on the horizontal axis.
- Place the dependent variable on the vertical axis.
- Label both axes.
- Write a title.
- Use more than 75% of your graph paper.
- Use equal spaces between each number plotted.

Copy and complete the following table in your science book.

Table showing stem length over time

Day	Stem length (mm)			
	Group 1	Group 2	Group 3	Mean
1				
2				
3				
4				
5				
6				
7				
8				

continued …

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Discussion: Analysis

1. Describe the trend you see in your graph.
2. Explain why you calculated an average using other groups' data as well as your own.

Discussion: Evaluation

1. Suggest another plant that could be used for a similar activity.
2. Propose an independent variable that you could add to this activity to turn it into a different experiment.

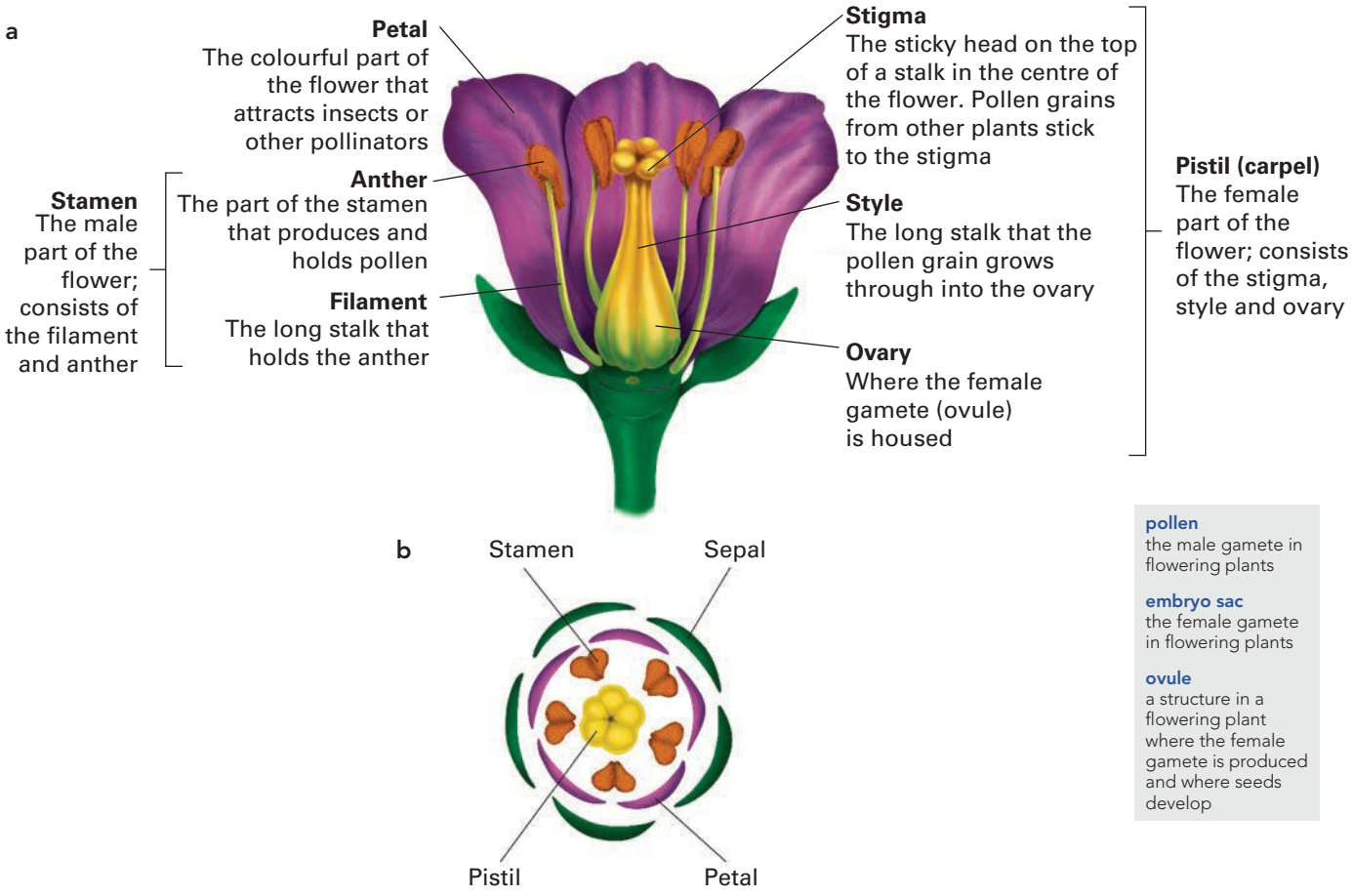
Conclusion

1. Make a claim regarding potatoes and their mode of reproduction.
2. Support your claim by referring to your experimental observations, and include potential sources of error.
3. Explain how the data supports your claim.

Sexual reproduction in plants

WORKSHEET
Sexual plant reproduction

If you sit near a patch of flowers on a summer's day, you may see a bee or a butterfly visiting the flowers. Many flowers rely on these insects to help them reproduce by sexual reproduction. The flower is the sexual organ of the plant. The **pollen** it produces is the male gamete (similar to sperm), while the female gamete, known as the **embryo sac**, is inside the **ovule**. The parts of a flower are shown in Figure 2.51.



pollen
the male gamete in flowering plants

embryo sac
the female gamete in flowering plants

ovule
a structure in a flowering plant where the female gamete is produced and where seeds develop

Figure 2.51 (a) A vertical section showing the reproductive parts of a flower. **(b)** A cross-section of the reproductive parts.

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pollination
the process by which pollen, containing the male reproductive cells of a plant, is transferred from the male part of a flower to the female part of a flower

nectar
a sweet liquid produced by flowers to attract pollinators

Pollination is the fertilisation process in which the pollen from one flower reaches the ovule of another flower. Bees and other insects are attracted to brightly coloured and scented flowers. As a bee feeds on the sweet **nectar** of the flowers, they pick up pollen on their bodies (see Figure 2.52). When the bee moves to the next flower, some of the pollen on the bee sticks to the stigma of the new flower, and the pollen grain then grows down the style to the embryo sac in the ovule. This is where fertilisation occurs and seeds develop.



Figure 2.52 A bee with a large yellow pollen sac on its leg

WIDGET
Sexual and asexual reproduction

VIDEO
Pollination methods

Making thinking visible 2.1

Compass points: Robot pollinators

In recent years, there has been global decline in the population of pollinators, such as bees, butterflies, birds and bats, which are crucial to the reproduction of many crops and wild plants. This decline is mainly attributed to habitat loss, pesticide use, climate change and diseases, and has significant implications for food security, ecological balance and biodiversity.

The RoboBee, the world's tiniest flying robot insect, was unveiled by US researchers in 2013, after 12 years of experimentation in the laboratory. RoboBee was designed to address the current pollinator crisis. However, there was a slight issue with the robot bees: they required an exceptionally lengthy extension cord to venture out into the field.

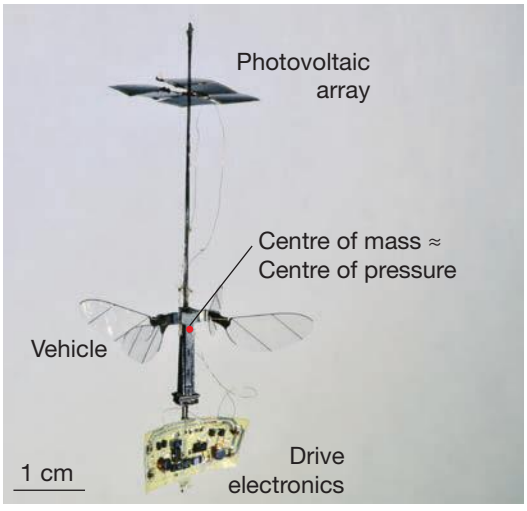


Figure 2.53 The 2019 untethered prototype of the RoboBee, with an additional set of wings

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A new version of the RoboBee was introduced in 2019, featuring an additional set of wings to allow the removal of the power cord and soft 'muscles' to prevent the robot from disintegrating when crashing into crops (see Figure 2.53).

In 2017, Dr Eijiro Miyako, a materials chemist at Japan's National Institute of Advanced Industrial Science and Technology, transformed a toy drone into a fast but somewhat hazardous pollinating robot. To achieve this, he attached a patch of horsehair to the drone and coated it with an ionic liquid gel, resulting in a sticky surface that could collect and transport pollen between plants.

However, the drone faced two immediate issues. First, it damaged the flowers. Second, it required a human operator to control it, which, given the significant number of bees required for pollinating, would be very expensive for farmers when hiring people to pilot the drones.

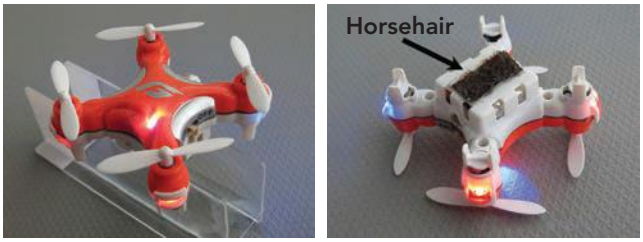


Figure 2.54 Dr Miyako's horsehair drone

Dr Miyako and his team then attempted a different approach by using a drone equipped with a bubble gun that released soapy bubbles filled with pollen. In lab experiments, the researchers tested the technique on pear flowers, and the results were promising. The bubbles ruptured on contact with the pistil, allowing the pollen to adhere and form pollen tubes, which helped in fertilisation. However, excessive bubbles stunted pollen growth, possibly because of the soap's properties. The team is working on developing an environmentally friendly soap bubble solution that biodegrades more quickly, potentially leading to an even more effective and sustainable pollination method. However, this approach is not suitable for use on windy days!



Figure 2.55 Dr Miyako's bubble gun pollinating drone

Complete the Compass points activity about robot pollinators:

1. E = Excited: What *excites* you about RoboBee and robot pollinators? What are the potential benefits?
2. W = Worries: What *worries* you about this idea? What are the potential drawbacks?
3. N = Need for information: What other details or facts *do you need* to evaluate this idea?
4. S = Suggestion for progress: What is your current *viewpoint or proposal* about robot pollinators? How can you continue to assess this concept?

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

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Explore! 2.5

Pollination

Pollination is an important process that allows plants to reproduce. After fertilisation, the ovary swells and grows into a fruit. There are different methods by which pollen can be transported from one flower to another to allow pollination to occur; for example, wind, insects, birds and animals.

self-pollination pollination that occurs when pollen is transferred from the same flower or from another flower on the same plant

cross-pollination pollination that occurs when pollen is transferred from a flower on one plant to a flower on another plant

When male gametes fertilise female gametes on the same plant, it is called **self-pollination**. When pollen from one plant fertilises the ovule of another plant, it is called **cross-pollination**. Cross-pollination results in genetically diverse offspring that increase variation in the species, making it better able to survive changes in the environment.

1. Draw up a table with two columns. In the first column, list the four methods of moving pollen from one flower to another. Then conduct some research on the types of flowers that use each method of pollination. In the second column, summarise what you have found out about the characteristics (shape, colour and size) of these different types of flowers, including their stamens and pistils.
2. What are the advantages and disadvantages of self-pollination? Conduct some research to find out how plants prevent self-pollination occurring.



Figure 2.56 These flowers are pollinated by different methods. Can you identify what the methods are?

Did you know? 2.10

Palynology

Pollen grains come in many shapes and sizes, depending on the plant that produces them. This is why pollen from certain plants can trigger an allergic reaction in some people, while other pollen has no effect. Palynology is the name for the study of pollen grains. Palynologists study pollen samples found in such places as archaeological digs and crime scenes. Palynology suggests that Australia's oldest flowering plants are approximately 126 million years old, and they resembled modern magnolias, buttercups and laurels.

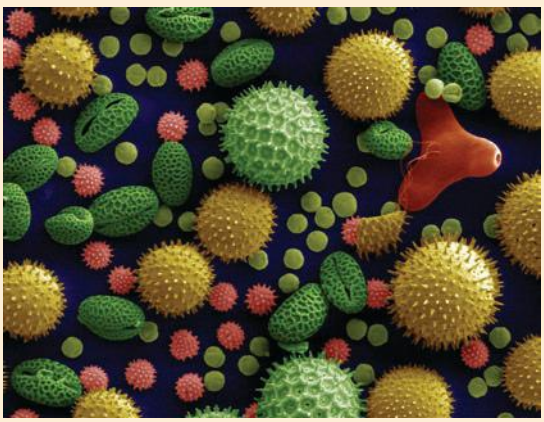


Figure 2.57 There are many types of pollen in the air.

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Humans are attracted to flowers because of their beautiful and varied colours and scents, but there is much more to flowers than the colours we can see. Unlike us, many insects can perceive wavelengths beyond the visible spectrum. When flowers are viewed under ultraviolet light, distinct patterns resembling landing strips or bullseye targets become apparent. You can see these patterns in Figure 2.58. These patterns serve as a guide for insects, directing them precisely to the nectar source.



Figure 2.58 Flowers with **(a)** a bullseye pattern and **(b)** a landing strip pattern

Quick check 2.7

1. **Name** the male gamete and the female gamete of plants.
2. Bees and insects can transfer pollen from one flower to another flower. **Name** some other ways that pollen can be transferred.
3. Draw up a table to **summarise** the parts of the flower and their role in sexual reproduction.

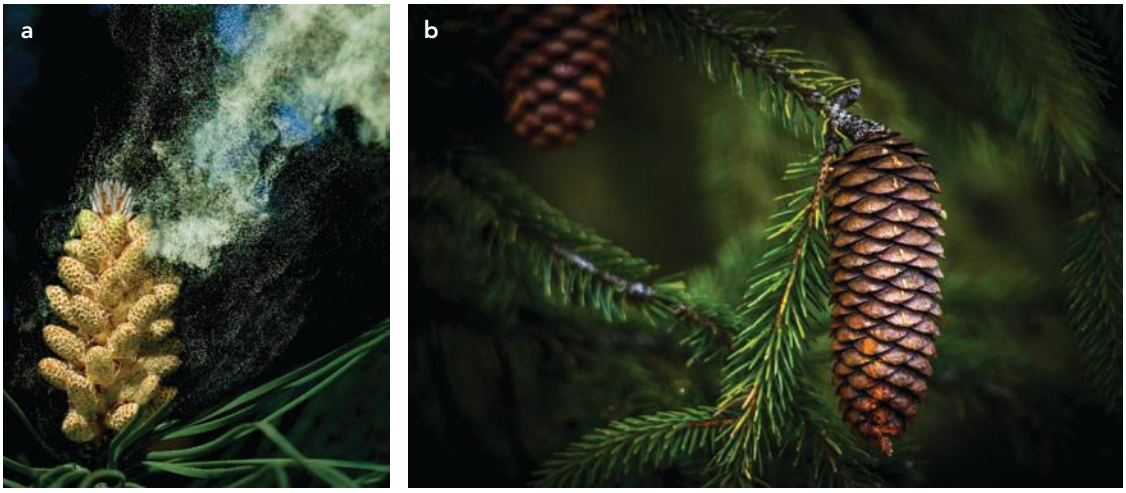


Figure 2.59 Conifers such as pine trees have separate **(a)** male and **(b)** female cones on the same tree. They do not have flowers. They are wind pollinated – male cones release pollen to the wind. When ready, the female cones open and the pollen is blown inside to fertilise the female gametes, which develop into seeds. To reduce self-pollination, female cones are on the higher branches and male cones are on the lower branches.

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Practical 2.2

Flower dissection

Be careful
Be very careful when handling the razor blade.

Aim
To identify the parts of a flower, and link their structure to their role in reproduction

Materials
- variety of flowers for dissection
- hand lens
- stereomicroscope
- tweezers
- single-sided razor blade
- chopping board

Method
1. Refer to Figure 2.51 to help you to identify the parts of your flower. Draw a diagram of your first flower. Note the number of petals and sepals, and label these on your diagram.
2. Holding the flower carefully with tweezers on the chopping board, cut the flower in half vertically. This means you should now be looking at a vertical section of the flower, similar to the top picture in Figure 2.51.
3. Draw a diagram of the flower and label all the parts you can recognise. Add 'M' next to the male parts of the flower and 'F' next to the female parts of the flower.
4. Gently remove the sepals and petals by pulling them down towards the stem. Use a microscope to look at the tip of the petal at low magnification. Record your observations of the petal's texture in your results.
5. Remove the flower's stamens by breaking or gently cutting them off the stem. Examine the pollen with your microscope. Record your observations of the pollen's shape and texture in your results.
6. Gently remove all parts except the pistil, so that it remains alone on the stem. Carefully cut the pistil in half lengthwise and use your hand lens to look at the inside. Record your observations of the style, ovary and ovules in your results.
7. Repeat steps 1–6 with the other flowers.

Results
Your results should consist of:
- labelled diagrams of the whole flowers and vertical sections of the flowers
- observations made during the dissection.

Discussion: Analysis
1. Consider the different flowers you looked at. List the similarities and differences between them.
2. Explain why these differences between flowers might exist.
3. Use a flow chart to summarise the process of sexual reproduction in plants. Use the names of the parts of flowers that are involved and their role in reproduction.

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Explore! 2.6

Citizen science

Bees pollinate most of our crops, but bee numbers are decreasing rapidly. Bees can fly between flowers at about 25 kilometres per hour and visit up to 5000 flowers in 1 day. In fact, bees are so important that artificial hives are moved all around the country to help pollinate new crops.

With the bee industry facing challenges such as invasive pests and extreme weather, bee experts are urging citizen scientists to help count various species of insects to assess the health of pollinators. The Australian Pollinator Count is a long-term citizen science project to monitor the status of pollinator populations, including more than 2000 species of bees, along with thousands of species of flies, butterflies, moths and wasps.

Suggest why people want to be involved in citizen science projects.



Figure 2.60 The Australian Pollinator Count takes place every year around November, and anyone can get involved!

Did you know? 2.11

FlyGro

When managing an avocado and lychee farm in Mareeba, in Far North Queensland, James Wheildon began exploring the use of flies for pollination. Flies are just as efficient at pollinating as bees, and are ideal because they visit flowers year-round, seek sugar from nectar and easily pick up pollen. Wheildon became known as the 'fly guy' after locals advised him to use dead animals to attract flies for pollination. However, he found the method was not practical because the dead animals did not last long and were a health risk. As a result, he developed FlyGro, a product that would attract flies for pollination. When water is added to FlyGro, it starts to ferment and emits a gas that attracts flies, dramatically boosting numbers and therefore pollination.



Figure 2.61 A fly pollinating a flower

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VIDEO
Seed dispersal methods

seed
a plant embryo enclosed in a protective coating

seed dispersal
the spread of seeds away from the parent plant

Seed dispersal

After fertilisation in conifers and flowering plants, the embryo develops inside a **seed** or nut. In flowering plants, the seeds are usually inside a fruit, which develops from the ovary after flowering. The everyday use of the term 'fruit' usually refers to an edible product such as apples, lemons, grapes and nectarines, but in plant science, the term 'fruit' refers to any seed-containing structure that develops from the ovary of a flowering plant. This includes bean pods, wheat grains and corn kernels.

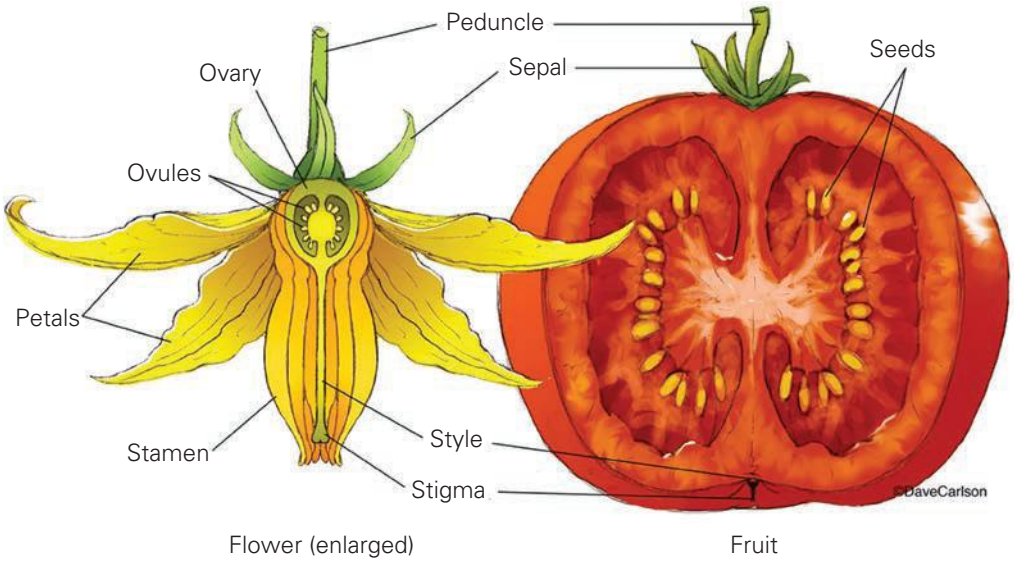


Figure 2.62 A tomato plant flower showing how the ovary develops into the fruit

Pine trees and other conifers produce cones (see Figure 2.63), which are specialised structures that hold and protect the seeds. The cones can vary in size and shape, and they can remain on the tree for several years before they mature and release the seeds. When the cones are mature, they open to release the seeds, which are usually small and winged to aid in dispersal by the wind.

Seeds are often eaten by birds and mammals, so plants produce large numbers of seeds to increase the chance of survival. Even then, the seeds may land in inhospitable areas where they lack the resources to grow, such as enough soil, sunlight or water. Because adult plants require a lot of space and similar resources, it would not be advantageous for seeds to be dropped and germinate immediately next to their parent plants. Therefore, many plants have developed creative methods of **seed dispersal** to spread the seeds further away and improve the chances of survival.



Figure 2.63 A pine cone ready to drop its seeds

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Seed explosions

A group of plants known as impatiens use ballistic force to disperse their seeds (although they do not typically travel far). At the slightest touch, the ripe seed pod bursts open, flinging its seeds in multiple directions (see Figure 2.64).

Hitching a ride on the outside

Certain plants produce seed pods with spikes, thorns or hooks that can become caught in animal fur (or on human clothing) and carried to a new location (see Figure 2.65). When the animal scratches at the itchy sensation, the seed pods can detach and fall to the ground.



Figure 2.64 A Himalayan balsam seed pod exploding. This species is a member of the genus *Impatiens*.



Figure 2.65 Burrs caught on a dog's fur. They are transported by the dog until the dog scratches them off, typically in a new location.

Hitching a ride on the inside

Some plants have extra sweet fruit, which encourages animals to eat them, and the seeds they contain (see Figure 2.66). These seeds have a tough coat so that they will not be digested. The seeds eventually pass intact through the animal, becoming deposited in a new location, where they may begin to grow.



Figure 2.66 Animals ingest seeds in fruit and then defecate the seeds in a new location.

Shooting the breeze

Wind is not only a method of pollination, but can also be used for dispersing seeds. Some plants, such as the dandelion, produce seeds with specialised parachute-like tuft called a pappus, which is easily caught in the breeze (see Figure 2.67). The seeds are very light, allowing them to travel long distances before coming to rest. A dandelion head is not one flower; it has many florets. Each head can produce around 500 seeds, making dandelions very efficient at dispersing seeds and a very hardy weed.



Figure 2.67 Dandelion seeds flying away on the breeze

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Floating away

A coconut is one giant seed. It is hollow, so it can float (see Figure 2.68). This is how coconuts can move between islands and possibly even across oceans.



Figure 2.68 A floating coconut. Wild coconuts are typically found in coastal areas because their floating seeds are well suited to dispersal over water.

Quick check 2.8

1. Draw a table to **summarise** the different ways in which seeds can disperse. Include examples where appropriate.

Explore! 2.7

Saving seeds

The Royal Botanic Gardens in Kew, England, is leading a seed conservation program to preserve rare and threatened wild plants. Kew's 2020 report on the State of the World's Plants and Fungi indicates that 40% of the world's plants are at risk of extinction due to the deterioration of natural ecosystems, changes in land use, and the unpredictable effects of climate change.



Figure 2.69 The Millennium Seed Bank holds the Guinness World Records title as the largest seed bank in the world, and has a bomb-proof and flood-proof building.

On 1 March 2023, the Millennium Seed Bank announced it had successfully stored more than 2.4 billion individual seeds of 40 020 various species of wild plants. Dubbed the 'Noah's Ark for plants' by experts, the Millennium Seed Bank is the most prominent global storage facility for wild seeds.

Research the Australian Seed Bank Partnership and the work that is being done to conserve Australia's native plant diversity.

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Investigation 2.1

Seed germination

Aim

To design an experiment to test the conditions necessary for a seed to germinate, using the materials provided. You may investigate other factors that contribute to the plant's germination (e.g. light levels, water, nutrients and heat).

Materials

- Petri dish or glass jar
- paper towel
- seeds
- sugar
- salt
- water
- black paper
- heat lamp
- cotton wool
- fertiliser

Method

1. Write a rationale about the factors that affect seed germination.
2. Write a specific and relevant research question for your investigation.
3. Choose a suitable independent variable to test.
4. Identify the dependent and controlled variables.
5. Write a hypothesis for your investigation.
6. Write a risk assessment for your investigation.
7. Construct a detailed method to explain the procedure you will follow in your experiment. Include all of the instruments and exact measurements you will use. Set the method out in step-by-step form. Include the number of repeats you expect to conduct. Do not forget to mention how the data will be recorded. Remember, another scientist should be able to read this procedure and replicate your experiment exactly, so be detailed in your instructions.
8. After confirming with your teacher that your method is satisfactory, carry out your investigation.

Results

1. Draw a results table for your experiment.
2. Produce a suitable graph for your experiment.

Discussion: Analysis

1. Describe any patterns, trends or relationships in your results.
2. Explain any trends you have identified.

Discussion: Evaluation

1. Identify any limitations in your investigation.
2. Propose another independent variable that could have been tested to expand on your results.
3. Suggest some improvements for this experiment.

Conclusion

1. Make a claim regarding seeds and germination conditions.
2. Support your claim by referring to your experimental data, and include potential sources of error.
3. State whether your hypothesis was supported or not supported by the data.

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Go online to access the interactive section review and more!

Section 2.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 2.4 questions

Remembering

1. **State** four methods of asexual reproduction that occur naturally in plants.
2. **State** the purpose of the petals of a flower.
3. **Define** 'pistil'.

Understanding

4. **Explain** why some flowering plants' ovaries develop into fleshy fruit.
5. **Explain** how seed dispersal by wind is effective.

Applying

6. **Describe** some ways in which a plant can be pollinated.

Analysing

7. **Compare** a peach with a pine cone.
8. **Distinguish** between self-pollination and cross-pollination.

Evaluating

9. Hay fever is caused by pollen irritating the nasal passageways. Hana lived in Korea for 15 years and never experienced hay fever. Since moving to Australia, Hana has had hay fever every summer. **Propose** a reason for this.
10. A new volcanic island forms in the middle of the Pacific Ocean. **Predict** the first type of plants that will grow on the island. **Justify** your answer based on the plant's method of seed dispersal.



Figure 2.70 An island formed by a volcanic eruption

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Chapter review

Chapter checklist

Success criteria		Linked questions
2.1	I can describe the six methods used by animals, plants and microbes to asexually reproduce.	1, 14
2.2	I can describe how sexual reproduction creates a greater rate of variation among offspring than asexual reproduction does.	7, 11, 17
2.2	I can describe how the reproductive strategies of multicellular animals are related to their environment and the complexity of the organism.	4, 5, 8, 12
2.2	I can describe how the number of offspring produced by animals is related to amount of parental care.	10
2.3	I can examine how the male and female reproductive organ structures work collectively as a system.	2, 13, 16
2.3	I can describe how the forms of male and female gametes relate to their specific functions.	9
2.4	I can identify and compare sexual and asexual reproductive strategies in plants.	3, 6, 11, 15, 18

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Remembering

1. **Recall** the type of asexual reproduction used by:
   a) an amoeba
   b) a flatworm
   c) a strawberry plant
   d) ginger.
2. **State** the function of the following structures in the human reproductive system:
   a) ovary
   b) scrotum
   c) fallopian tube
   d) prostate
   e) uterus.
3. **Name** the parts of a flower that have the following functions:
   a) attracts pollinators
   b) the site of seed development
   c) produces the male gametes
   d) produces the female gametes
   e) site where the male gamete sticks to the female part of the plant.
4. **State** the two methods of fertilisation in animals. For each method, **name** one animal that uses it.

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Understanding

5. **Explain** why internal fertilisation exists in some animals rather than external fertilisation.
6. **Explain** four different ways that seeds might be dispersed.
7. **Describe** how sexual reproduction results in a greater rate of variation among offspring than asexual reproduction.

Applying

8. **Describe** how the reproductive strategies of multicellular animals are related to their environment.
9. **Explain** how a sperm's structure is related to its function.
10. **Describe** how the number of offspring produced by animals is related to the amount of parental care they are likely to receive.

Analysing

11. **Contrast** sexual reproduction and asexual reproduction to show the advantages and disadvantages of each method.
12. **Distinguish** between external development and internal development of offspring, naming an example organism for each.
13. **Compare** the changes in secondary sexual characteristics during puberty in females versus males by using a Venn diagram.

Evaluating

14. If a female reptile with XX sex chromosomes reproduces by parthenogenesis because of a lack of male mates in the area, what can you **predict** about the offspring?
15. **Construct** a comic strip or diagram to model how sexual reproduction occurs in a flowering plant. Ensure the reproductive organs are labelled appropriately.
16. **Construct** a timeline of the human gestation period, indicating the name of the structure at each stage and the timeframes involved.
17. A biologist is investigating a species of frog that lives in an environment that is changing rapidly. **Propose** why sexual reproduction would be a better strategy for this species of frog.
18. The flowers of certain orchids closely resemble the shape of a female wasp (see Figure 2.71). **Justify** a reason for this adaptation.



Figure 2.71 *Drakea*, or hammer orchids, are pollinated by specific species of thynnid wasp, so their flowers have adapted to look like the females of those wasp species.

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Data questions

Meera wanted to find out the effect of substance A and substance B on hydra budding. She conducted an experiment for 6 days with three identical samples of hydra. She gave the same amount of food to each sample every day. She also daily added 1 drop of substance A to sample A, and 1 drop of substance B to sample B. The control was given no added substances.

The graph in Figure 2.72 shows her results.

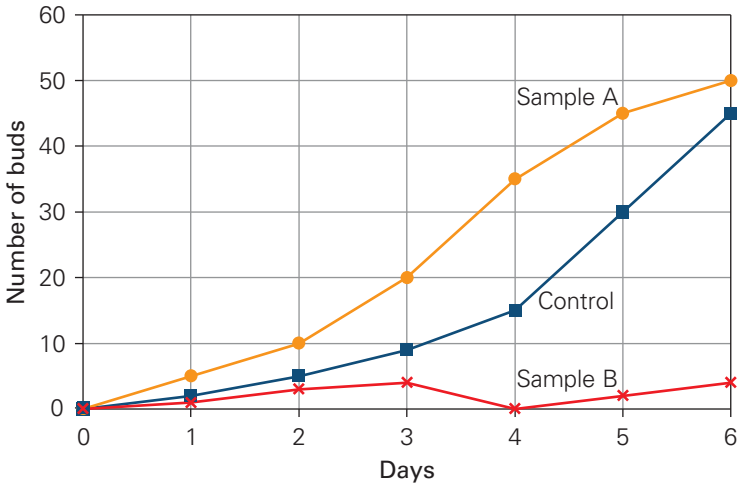


Figure 2.72 The number of hydra buds in the samples each day

Applying

1. **Identify** the sample that had the highest number of buds at the end of the 6 days.
2. **Identify** the sample that had at least 1 day with no buds.
3. **Determine** how many days it took for each sample to reach more than 10 buds.
4. **Calculate** the difference in the number of buds between sample A and sample B on day 5.

Analysing

5. **Contrast** the patterns for the three samples.
6. **Identify** whether the number of buds in the control sample shows a linear or an exponential growth pattern, giving reasons for your choice.

Evaluating

7. **Deduce** which substance, A or B, is a growth activator (i.e. helps growth) and which is a growth inhibitor (i.e. prevents growth).
8. **Compare** the control sample with sample A after day 4. What evidence is there to suggest that sample A was getting crowded?
9. **Predict** how many buds there would be for each sample if Meera extended the experiment to the seventh day.

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STEM activity: Artificial bees to save the planet

Background information

While introduced honey bees are used commercially to pollinate crops, Australia's native bees (of which there are over 1700 species) also have a role to play in ensuring food security.

Bees have evolved specialised skills for transferring pollen that suit the plants they feed on. Blue banded bees use a strategy known as buzz pollination, in which they grab hold of the flower and move their flight muscles rapidly to dislodge pollen from the anthers. Other species of bee have specialised bristles on their forelegs to rake the pollen out.

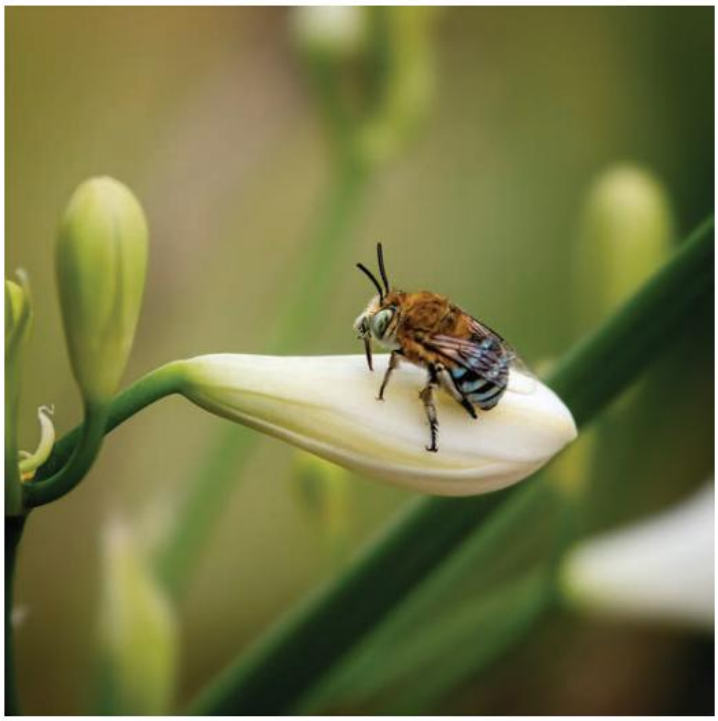


Figure 2.73 *Amegilla cingulata*, also known as the blue-banded bee, is considered a 'safe' bee.

DESIGN BRIEF

Design a pollen distribution prototype robot or machine that could be used in areas with declining bee populations.

Activity instructions

In groups, you will research bees and pollination. Then, you will design and create a scale drawing of a pollen distribution prototype. You won't need to build this, so be creative and incorporate as many types of technology as possible.

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Research and feasibility

1. Conduct some research on how bees support the reproduction of plants. You may want to print out an image of a bee and annotate its features.
2. Discuss how a pollen distribution prototype could be built to mimic the behaviours of bees.
3. Conduct some research on different types of technology that are used in robotics and flight.

Design and sustainability

4. As individuals, sketch your own ideas, and then present them to the group. Discuss the key connections between how bees distribute pollen and your prototype. Discuss the best aspects of each person's sketch.
5. As a group, sketch a design and annotate its key features, incorporating sustainable ideas. This means making sure that your prototype can be reused easily. Discuss in your group the size of your prototype and the materials or manufacturing that would be required.

Create

6. As a group, create a scale drawing of your group's prototype to present to the class. You will need to agree on a scale and a size. Your scale drawing should include colours and annotations.

Evaluate and modify

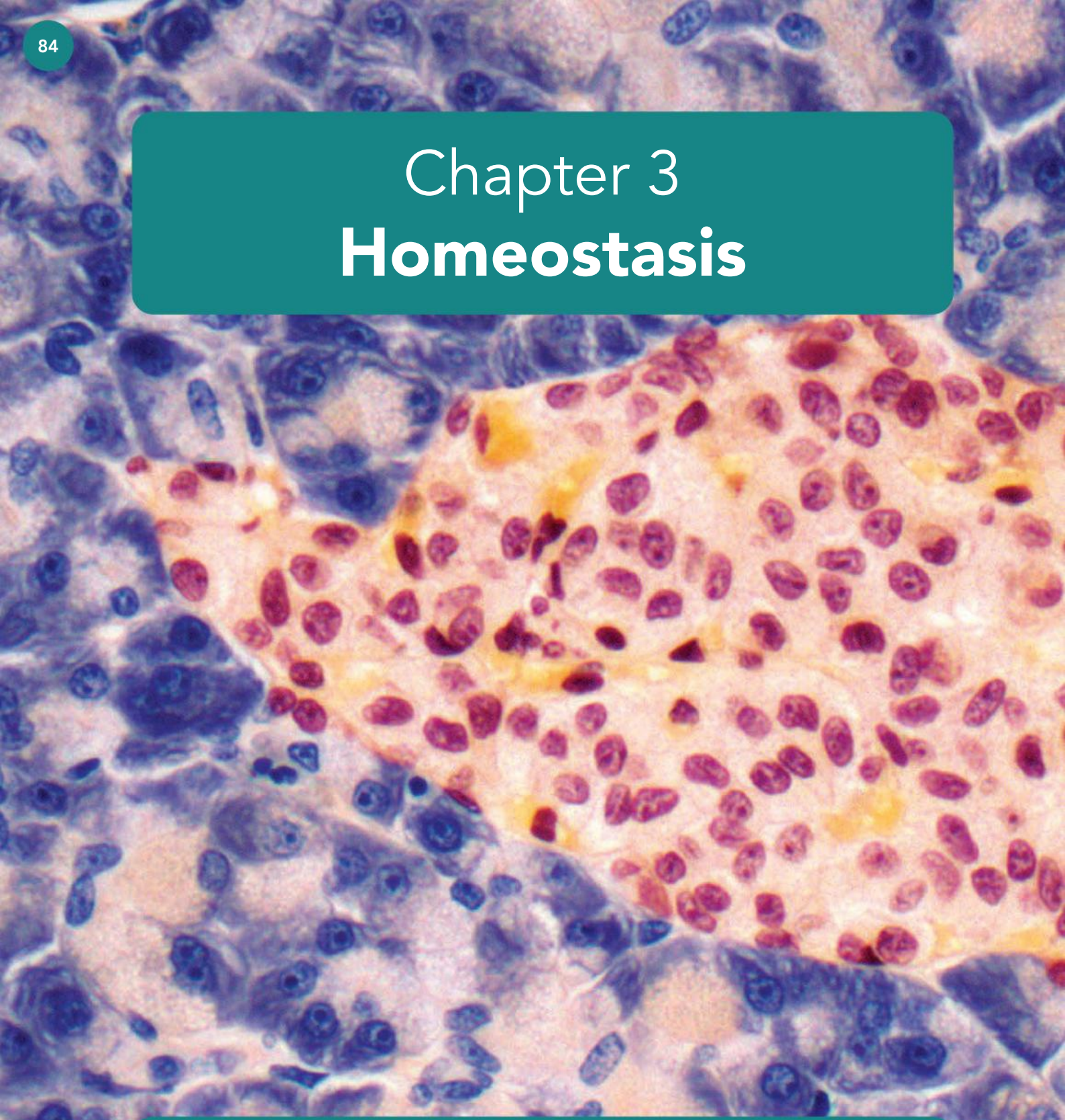
7. Present your prototype design to the class in a 1-minute demonstration of your scale diagram.
8. Discuss with the class your ideas for the design and sustainability of the prototype.
9. Evaluate the issues arising from a human solution to an environmental problem.



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Chapter 3
Homeostasis



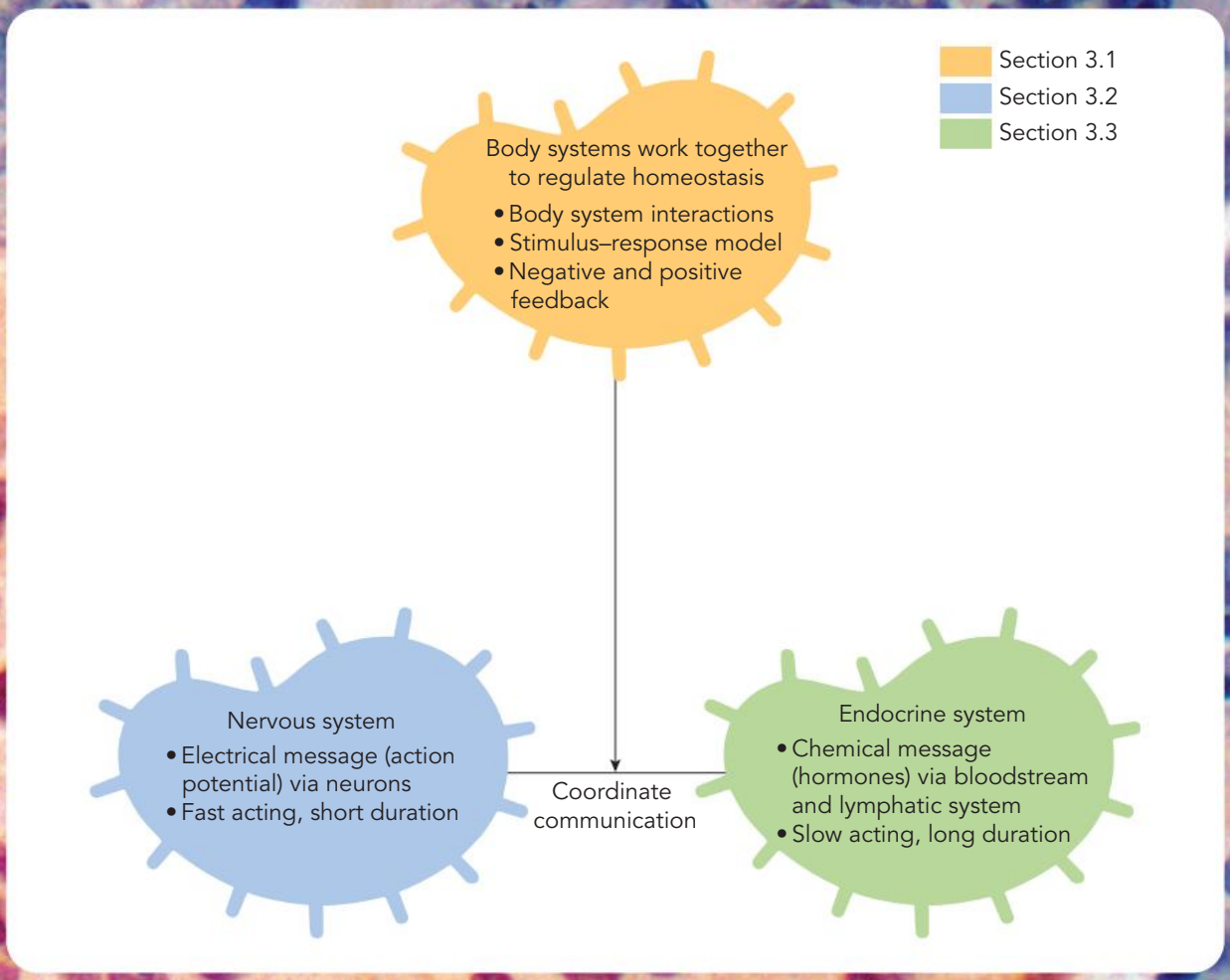
Introduction

The human body is a complex, multicellular organism that must detect and appropriately respond to changes in the external and internal environment. Body systems, such as the nervous and endocrine systems, must work collaboratively to detect stimuli, process this information and coordinate a response. In this chapter you will learn about negative feedback, which is a critical mechanism that helps to achieve homeostasis – the maintenance of the body's internal environment within a narrow range of conditions, despite fluctuations in the external environment. Humans depend on this to keep us alive.

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Concept map



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Curriculum content

the nervous and endocrine systems work together to regulate and coordinate the body's response to stimuli, ensuring homeostasis, including through negative feedback mechanisms (VC2S10U02)	
• exploring the body's observable responses to external stimuli (such as changes in light or temperature, and presence of danger or pathogens) or internal stimuli (such as dehydration and hunger)	3.1
• using models, flow diagrams and virtual simulations to investigate and represent the relationships between body systems that are necessary to coordinate a response to a stimulus	3.1
• comparing the roles and functions of electrical impulses and hormones in the body's responses to external stimuli	3.2, 3.3
• modelling how the process of regulation is monitored and adjusted by connections between the receptor, command centre and effector	3.1
• examining how negative feedback mechanisms serve to maintain balance in internal systems, such as those for body temperature, blood sugar, iron levels and extracellular pH, and how an understanding of feedback mechanisms has enabled the development of pharmaceuticals (such as insulin for type 1 diabetes) and products to maintain or enhance performance (such as electrolyte solutions)	3.1, 3.3
• examining the effects of a condition such as diabetes-induced blindness or hypothermia on a feedback system	3.3
communicating and justifying scientific ideas, findings and arguments for diverse audiences involves the selection of appropriate presentation formats, content, scientific vocabulary, conventions, models and other representations, and may include the use of digital tools (VC2S10I08)	
• developing an interactive presentation that shows feedback loops in human body systems	3.3

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Glossary terms

Action potential	Hypothalamus	Positive feedback
Autonomic nervous system	Insulin	Receptor
Cellular respiration	Interneuron	Reflex action
Control centre	Motor neuron	Response
Effector	Negative feedback	Sensory neuron
Endocrine system	Nervous system	Somatic nervous system
Excretion	Neuron	Stimulus
Glucagon	Neurotransmitter	Synapse
Homeostasis	Osmoregulation	Target cell
Hormone	Pathogen	

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3.1 Body systems working together

Learning goals

At the end of this section, I will be able to:

1. Describe how the body responds to external or internal stimuli.
2. Describe the relationships between body systems that are necessary to coordinate a response to stimuli.
3. Explain how the process of regulation is monitored and adjusted by connections between the receptor, command centre and effector.
4. Describe how positive feedback mechanisms maintain the direction of a stimulus and accelerate its effect.



WORKSHEET
Homeostasis

Coordination: It's a team effort!

Within the human body, 11 major organ systems interact with each other to enable humans to grow, maintain life and reproduce. Each system depends on other systems to keep the body functioning at an optimal level, and each is made up of organs with highly specific functions (see Figure 3.1). The systems are:

- circulatory (sometimes called cardiovascular)
- endocrine
- skeletal
- reproductive (male and female)
- digestive
- excretory
- nervous
- muscular
- immune
- integumentary (skin and outer body coverings)
- respiratory.

Every multicellular organism depends on its body systems working together. The body does an amazing job of maintaining a stable internal environment, despite considerable changes in the external environment. This process is known as **homeostasis**.

homeostasis
the process by which an organism maintains a stable internal environment despite changes in the external environment

hormone
a chemical messenger secreted by endocrine glands that controls and regulates different processes in the body

Body systems working together

Messaging

The nervous system and endocrine system work together to control and coordinate the body's activities. The nervous system sends electrical signals called nerve impulses to different parts of the body, whereas the endocrine system releases **hormones** into the bloodstream. Hormones act as messengers, travelling through the bloodstream to target organs and tissues. Some of the bodily functions regulated by these systems are heart rate, blood pressure and body temperature. You will learn more about the nervous and endocrine systems later in this chapter.

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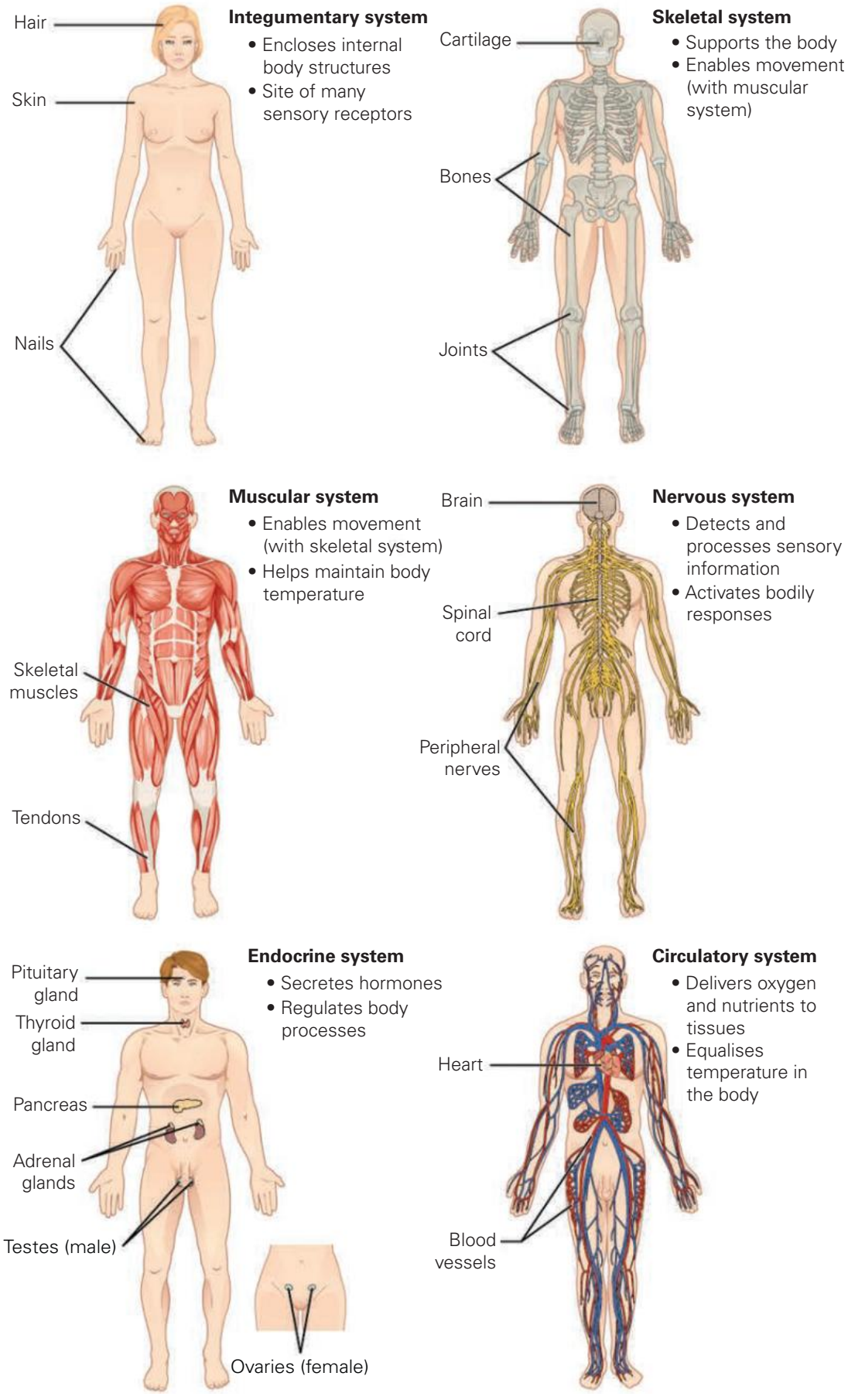
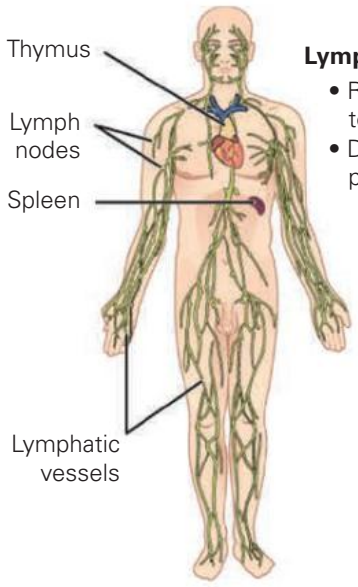
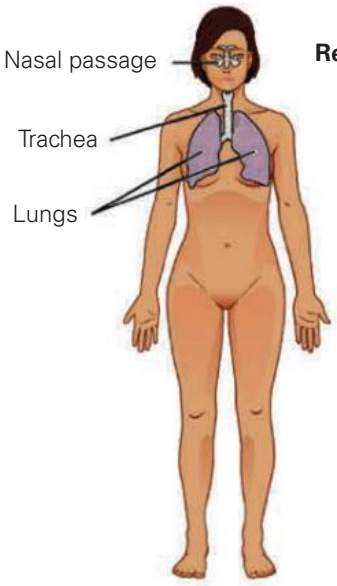


Figure 3.1 The different body systems work together to maintain homeostasis.

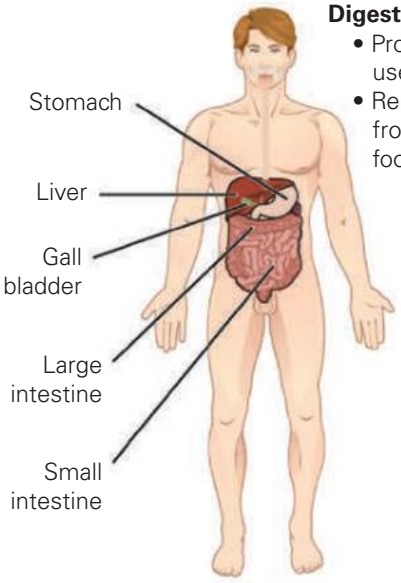
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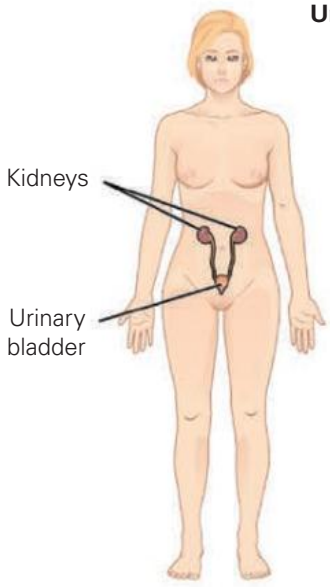
Lymphatic system
- Returns fluid to blood
- Defends against pathogens



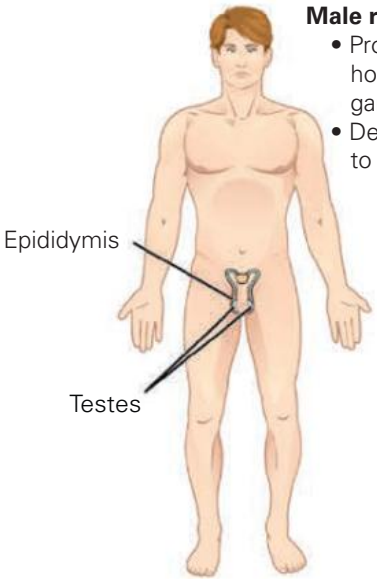
Respiratory system
- Removes carbon dioxide from the body
- Delivers oxygen to blood



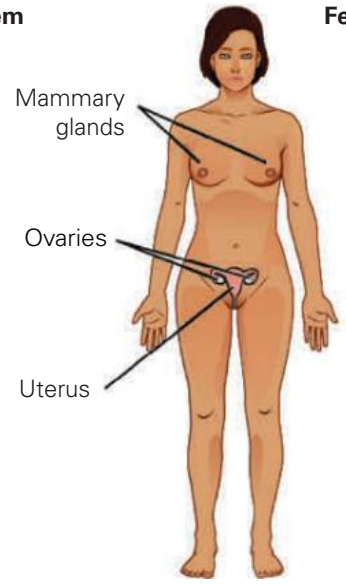
Digestive system
- Processes food for use by the body
- Removes wastes from undigested food



Urinary system
- Controls water balance in the body
- Removes wastes from blood and excretes them



Male reproductive system
- Produces sex hormones and gametes
- Delivers gametes to female



Female reproductive system
- Produces sex hormones and gametes
- Supports embryo/foetus until birth
- Produces milk for infant

Figure 3.1 *(continued)*

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Oxygenation

The muscular system and circulatory system work together to maintain blood flow and oxygenation. The circulatory system consists of the heart, blood vessels and blood. The heart pumps blood through the blood vessels, which transport oxygen and nutrients to the body's tissues. The muscular system helps to maintain blood flow by contracting and relaxing the muscles surrounding blood vessels. This helps to regulate blood pressure and maintain a steady flow of blood to the body's tissues.

The respiratory system and circulatory system work together to provide the body with oxygen. The respiratory system includes the lungs and airways. Oxygen is absorbed across the internal surface of the lungs and transported to the body's tissues by the circulatory system.

Waste removal

The circulatory system transports wastes such as carbon dioxide away from body cells and to the lungs. Here, the gases are exchanged in the lungs and exhaled. The digestive system and excretory system work together to maintain nutrient balance and remove waste products. The digestive system breaks down food into nutrients that can be absorbed by the body. The nutrients are then transported by the circulatory system to the body's tissues. The excretory system removes waste products from the body, including excess water, salts and urea. This is called **excretion**.

excretion
the process of eliminating waste products, excess water and other unnecessary substances from the body

stimulus (plural: stimuli)
a change in the environment that is detected by the human body

receptor
a specialised structure that allows the body to detect and respond to stimuli

effector
a muscle, gland or organ that carries out a response or action in response to a stimulus

Quick check 3.1

1. **Define** 'homeostasis'.
2. **Explain** why homeostasis is important for your survival.
3. **Explain** how the circulatory and respiratory systems work together to achieve oxygenation.

Stimulus–response model

To achieve homeostasis, the body needs to respond to changes within the body's internal and external environment. A **stimulus** is any change in the environment that can be detected by the human body. The change can be physical or chemical. Stimuli include changes in temperature, light, sound, pressure and chemicals in the air or food.

Changes in the environment are detected by **receptors** within the body. If a response is required, certain actions are brought about by **effectors** within the body to bring the body back to its 'normal' or optimum level.



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When a receptor is activated, it sends a signal to the **control centre**, which is often the brain or spinal cord, to process the information and determine the appropriate response. The control centre then sends signals to the effectors, which are the organs, tissues and cells that carry out the necessary actions to produce a **response** to the stimulus. The five-step stimulus–response model is shown in Figure 3.2.

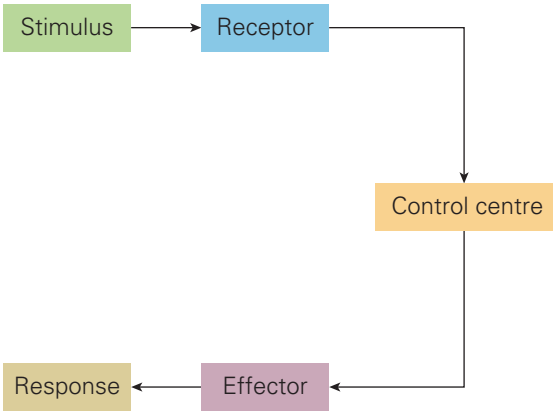
control centre often the brain or spinal cord, which receives signals from receptors and sends out signals to effectors to produce a response to a stimulus

response the reaction to a stimulus

Receptors

Receptors are specialised structures throughout the human body that allow it to detect and respond to various stimuli. They occur in all types of tissue, from the skin to the internal organs. There are many types of receptors, each specialised to detect a specific type of stimulus (see Figure 3.3). The different receptors are described in Table 3.1.

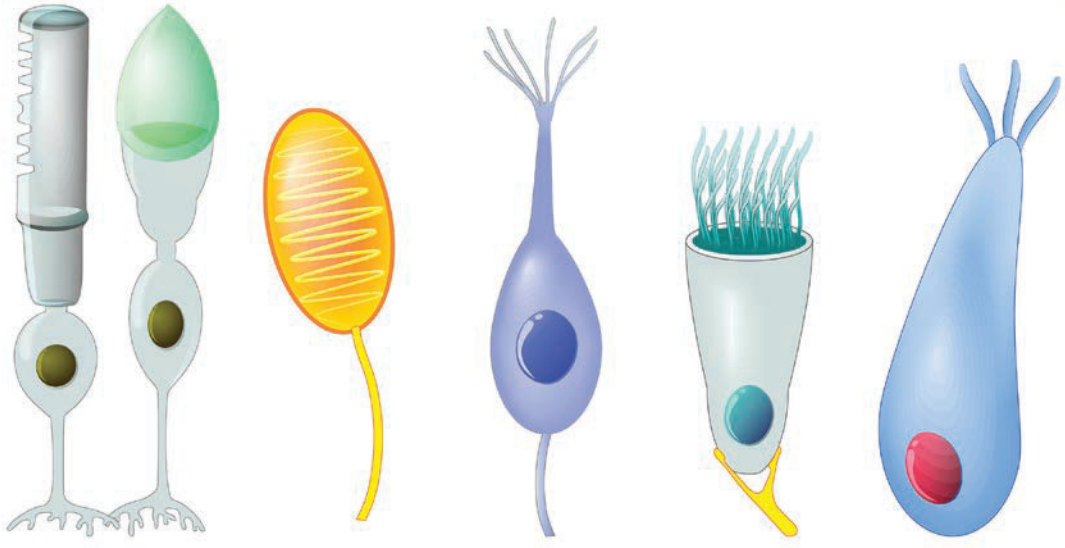
a



b

Stage	Description
Stimulus	A change in the internal or external environment that triggers a response
Receptor	Specialised cells that detect the change and transmit a signal to the control centre
Control centre	The structure (often in the brain, but sometimes in an organ) that received the signal and coordinates the response
Effector	The organ or muscle that carries out the response
Response	A change that occurs in the body as a result of the stimulus

Figure 3.2 (a) A flow chart outlining the stimulus–response model and **(b)** a description of the stages



Vision
Photoreceptors detect light.

Touch
Mechanoreceptors detect mechanical forces such as pressure or movement. Thermoreceptors detect temperature changes. Nociceptors detect damage to body tissues, causing pain perception.

Smell
Olfactory chemoreceptors detect chemical stimuli.

Hearing
Mechanoreceptors detect mechanical forces from the vibrations in the eardrum.

Taste
Gustatory chemoreceptors detect chemical stimuli.

Figure 3.3 The different sensory receptors associated with your five senses. Their shape is closely associated with their specialised functions.

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Receptor type	Location	Stimulus
Chemoreceptor	Blood vessels, brain	Changes in blood chemistry (e.g. oxygen, carbon dioxide, pH levels)
Mechanoreceptor	Skin, muscles, joints, inner ear	Physical distortion or deformation (e.g. touch, pressure, stretching, sound)
Photoreceptor	Retina of eye	Light energy
Thermoreceptor	Skin, brain	Changes in temperature (e.g. heat or cold)
Olfactory receptor	Nose	Chemicals in air (odours)
Gustatory receptor	Taste buds on tongue	Chemicals in food and drink (taste)
Nociceptor	Skin, muscles, joints, organs	Tissue damage or potentially harmful stimuli (e.g. heat, cold, pressure, chemicals)

Table 3.1 A summary of receptors in the body

Making thinking visible 3.1

See, feel, think, wonder: Taste buds

The tongue is a complex organ that contains various types of papillae, which house specialised sensory receptors known as taste buds. Papillae are small, raised structures on the surface of the tongue, and they can be different shapes and sizes.

Taste buds play a crucial role in our sense of taste. The human tongue can contain thousands of taste buds, which detect different types of taste such as sweet, sour, salty, bitter and umami (savoury). Each taste bud is made up of groups of specialised cells called taste receptor cells, which are stimulated by different chemicals in the food we eat.

When a taste receptor cell is activated, it sends a signal to the brain, which then translates the information into the sensation of taste. The location and number of taste buds varies from person to person, which can influence individual preferences for different types of food.

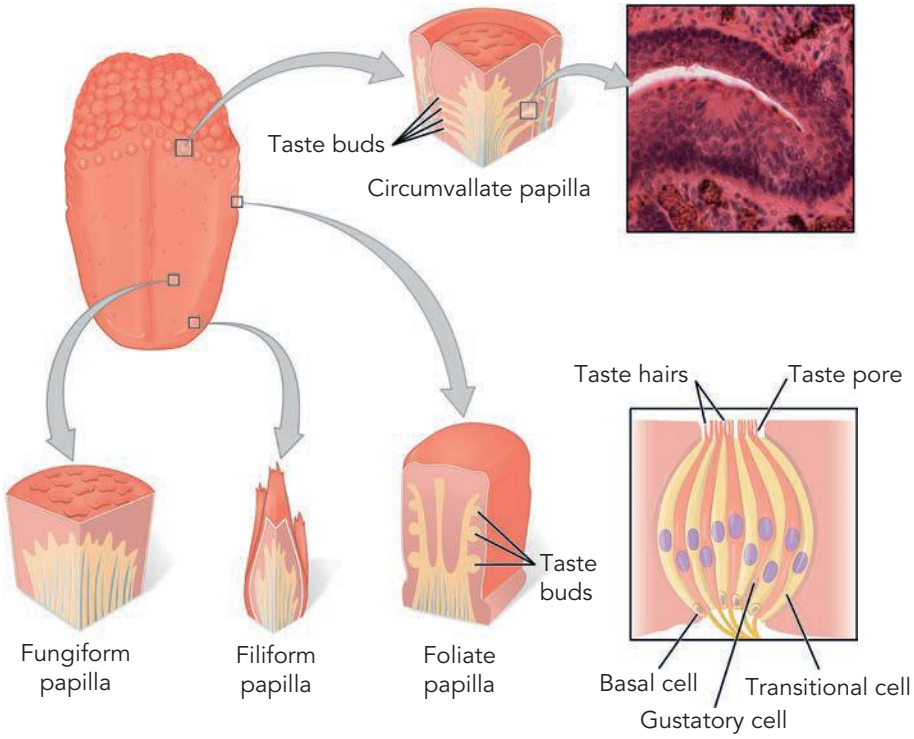


Figure 3.4 Animal tongues are covered with various types of papillae, and taste buds are hidden in the crevices between them.

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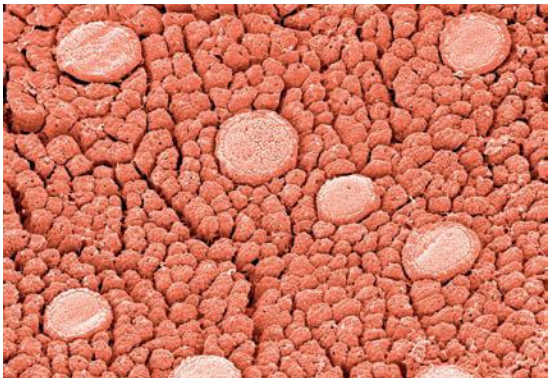


Figure 3.5 Papillae on a tongue



Figure 3.6 A cross-section of papillae. At 50× magnification, a taste bud is visible (circled) on the central papilla.

Look carefully at Figures 3.5 and 3.6 and answer the following questions.

1. Describe what you *see* in the images of papillae.
2. How do these images make you *feel*?
3. What do the images make you *think* about?
4. What questions do you have after looking at the images? What does it make you *wonder* about taste buds and other receptors?

The *See, feel, think, wonder* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Negative feedback loops

Negative feedback mechanisms are essential for maintaining homeostasis. These mechanisms use a stimulus–response pathway, with an extra step called a 'feedback loop'. In this loop, the response works to fix the original problem (stimulus), and this correction is sent back as feedback (see the red arrow in Figure 3.8).

VIDEO Negative feedback

This mechanism relies on receptors detecting when something in the body goes outside the normal range. This information is processed, and the body responds to bring things back to within normal levels, or 'set point'. Negative feedback loops are used to maintain physiological parameters within narrow limits, such as temperature, blood glucose levels, blood pH and blood pressure.

negative feedback a regulatory process that reduces the output of a system in response to a deviation from a set point

hypothalamus a part of the brain that plays a key role in maintaining homeostasis, acting as a link between the nervous and endocrine systems

Responses to changes in temperature

The circulatory, integumentary, respiratory and muscular systems coordinate to regulate and maintain the body's core temperature within a narrow range.

If the body's core temperature starts to rise, thermoreceptors detect the increase in temperature and send signals to the **hypothalamus** (a part of the brain). The hypothalamus triggers several responses that work to bring the temperature back down. Sweat glands activate, releasing sweat onto the skin. As the sweat evaporates, it helps to cool the body down. Blood vessels in the skin also dilate (become larger), which allows more blood to flow to the surface of the skin, where it can release heat. These responses work together to reduce the body's temperature back to within the normal range.

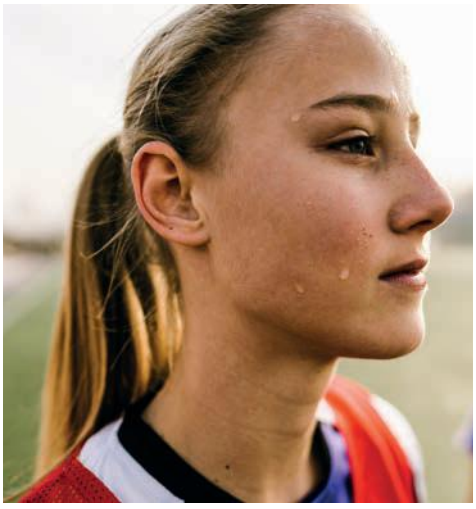


Figure 3.7 When the body's temperature increases, sweat glands are activated.

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The body responds to a decreased core temperature by constricting surface blood vessels, redirecting blood flow towards the central organs and shivering (as outlined in Figure 3.8). This response returns the core temperature to within normal limits and negatively feeds back to switch off the corrective mechanisms.

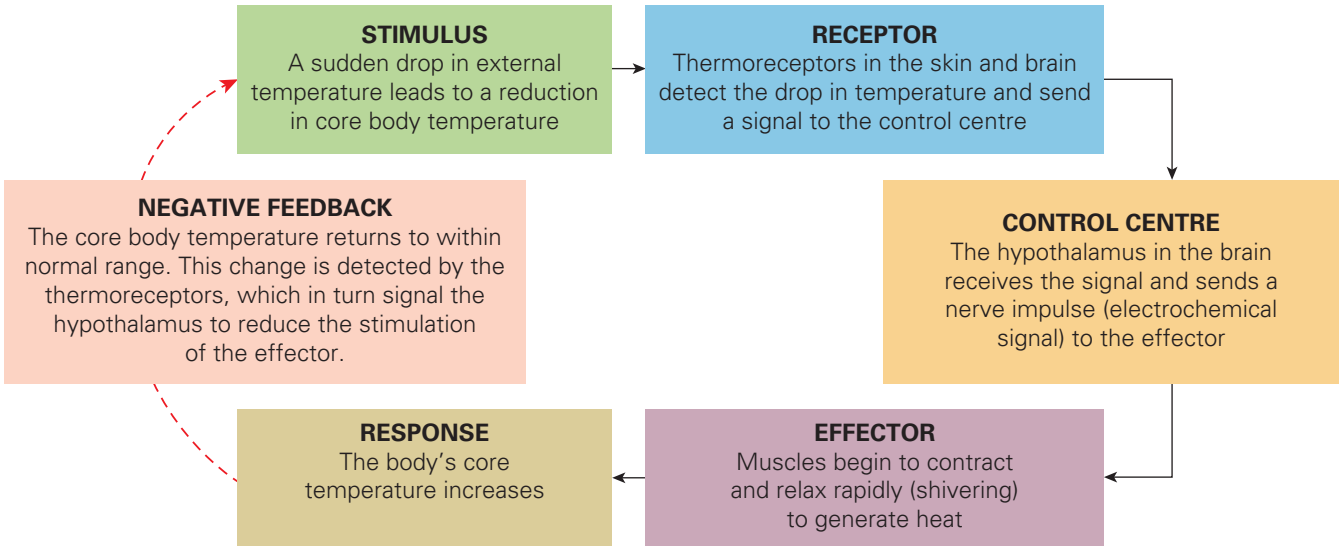


Figure 3.8 A summary of the stages of the stimulus–response model (and associated negative feedback loop) when core body temperature falls.

Responses to changes in extracellular pH

Extracellular pH refers to the pH level in the extracellular fluid (fluid located outside cells in the body). This fluid surrounds the cells and provides them with nutrients and removes waste products.

The normal extracellular pH range in humans is between 7.35 and 7.45, which is slightly alkaline. The respiratory and renal systems maintain the pH of the extracellular fluid within this narrow range. Any deviations from this range can lead to various health problems and can even be life-threatening.

Carbon dioxide is transported in the blood in the form of bicarbonate ions and dissolved carbon dioxide. When carbon dioxide combines with water in the blood, it forms carbonic acid, which makes the blood more acidic. To maintain the pH of the blood within the normal range, the respiratory and renal systems work together to eliminate excess carbon dioxide from the body. The respiratory system increases the rate and depth of breathing, which increases the elimination of carbon dioxide through exhalation, reducing the carbonic acid in the blood. This is why your respiration rate increases when you exercise: in addition to meeting rising oxygen demands, increased respiration helps to expel the extra carbon dioxide being produced by all the additional cellular activity (e.g. muscle contraction).

The excretory system also plays a role in regulating extracellular pH by excreting excess hydrogen ions or bicarbonate ions in urine.

Responses to changes in light

One of the most well-known responses to a change in light is the constriction or dilation of the pupil in the eye, which helps to control the amount of light that enters the eye. This response is also controlled by negative feedback mechanisms – the constriction or dilation of the pupil is triggered by signals from specialised cells in the retina that detect changes in

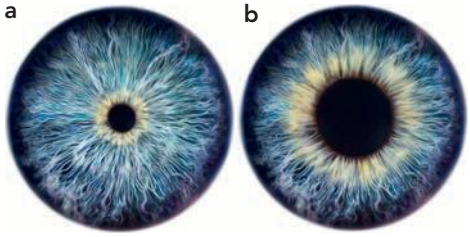


Figure 3.9 (a) A pupil constricts in bright light and **(b)** dilates in low light.

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light intensity and send signals to the brain, which in turn sends signals to the muscles that control the size of the pupil. When exposed to bright light, the pupil constricts to reduce the amount of light that enters the eye, whereas in low light, the pupil dilates to allow more light in (see Figure 3.9).

The body's sleep–wake cycle is also closely linked to changes in light. The hypothalamus in the brain contains a specialised group of cells called the suprachiasmatic nucleus (SCN), which acts as the body's master clock. The SCN receives information from the eyes about changes in light and uses this information to regulate the release of various hormones such as melatonin that help to control the sleep–wake cycle (see Figure 3.10).

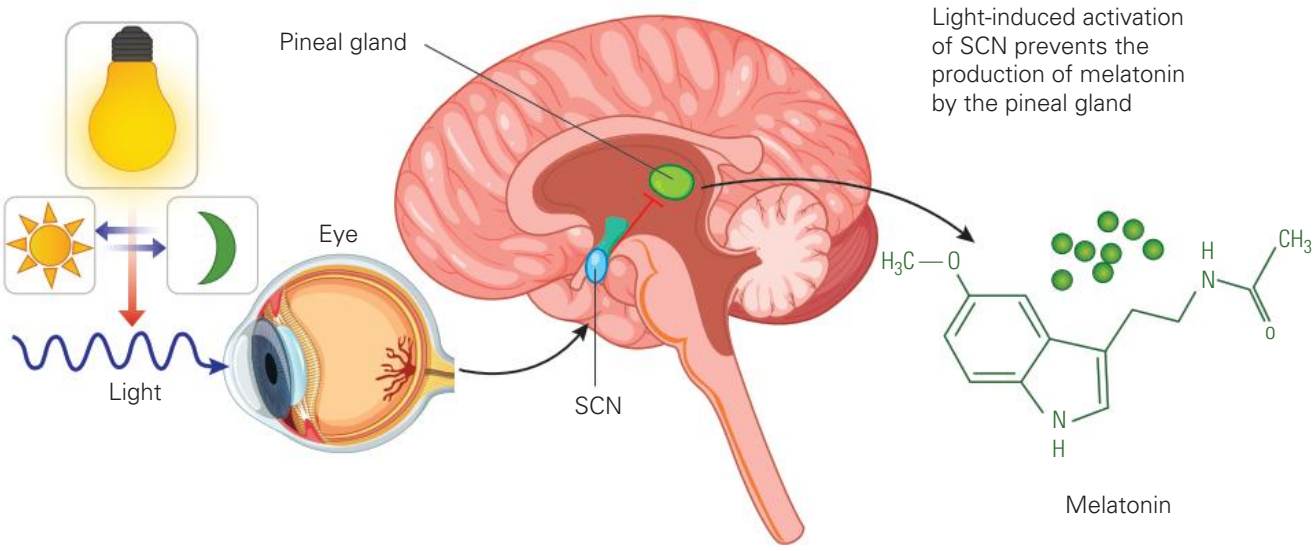


Figure 3.10 The suprachiasmatic nucleus (SCN) regulates the synthesis and release of the hormone melatonin by the pineal gland.

Changes in light can also affect mood and behaviour. Exposure to bright light can help to boost mood and increase energy levels, whereas exposure to low light can have the opposite effect, making people feel tired and lethargic.

Responses to danger

The fight-or-flight response is triggered by the release of stress hormones such as adrenaline and cortisol in response to perceived threats or stressors in the environment. These hormones increase heart rate and blood pressure, delivering more oxygen and nutrients to the body's tissues to prepare it for action. The rate and depth of breathing may also increase to ensure there is enough oxygen in the bloodstream to support the increased activity. This response is regulated by negative feedback mechanisms, as the release of hormones eventually decreases, causing heart rate and blood pressure to return to normal levels.



Figure 3.11 Many organisms have a fight-or-flight response.

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Responses to pathogens

pathogen any organism that can cause disease, such as bacteria, viruses or fungi

positive feedback a mechanism that maintains the direction of a stimulus and accelerates its effect

The body's observable responses to the presence of **pathogens** such as bacteria, fungi and viruses are evidence of the immune response. These responses can include inflammation, fever, pain, swelling and changes in behaviour, such as fatigue and lethargy.

Inflammation is a common response; it occurs when the body sends immune cells and fluid to the site of infection to help fight off the pathogen. Fever is another common response – the body raises its temperature to create an inhospitable environment for the pathogen. Once the pathogen is eliminated, negative feedback mechanisms cause the body's immune response to decrease, returning it to its baseline state. The immune system is discussed in greater detail in Chapter 4.



Figure 3.12 Fever is a physiological response to an infection caused by pathogens such as viruses, bacteria and fungi.

Quick check 3.2

1. **State** the part(s) of the body that are involved in maintaining homeostasis.
2. **Create** a stimulus–response model in your notes or on A4 paper and annotate it with information about each of the five parts, similar to Figure 3.2.
3. **Define** 'negative feedback'.
4. **Identify** the body systems responsible for maintaining the pH of extracellular fluid.
5. **Describe** how the eye responds to decreasing light levels.

Positive feedback

Unlike negative feedback, **positive feedback** mechanisms maintain the direction of a stimulus and accelerate its effect. In other words, positive feedback drives the system *further* from its initial state.

Childbirth and breastfeeding

Positive feedback is important in childbirth (see Figure 3.13). During childbirth, the hormone oxytocin is released. This stimulates contractions in the uterus, leading to the further release of oxytocin and stronger contractions. This positive feedback loop continues until the baby is born.

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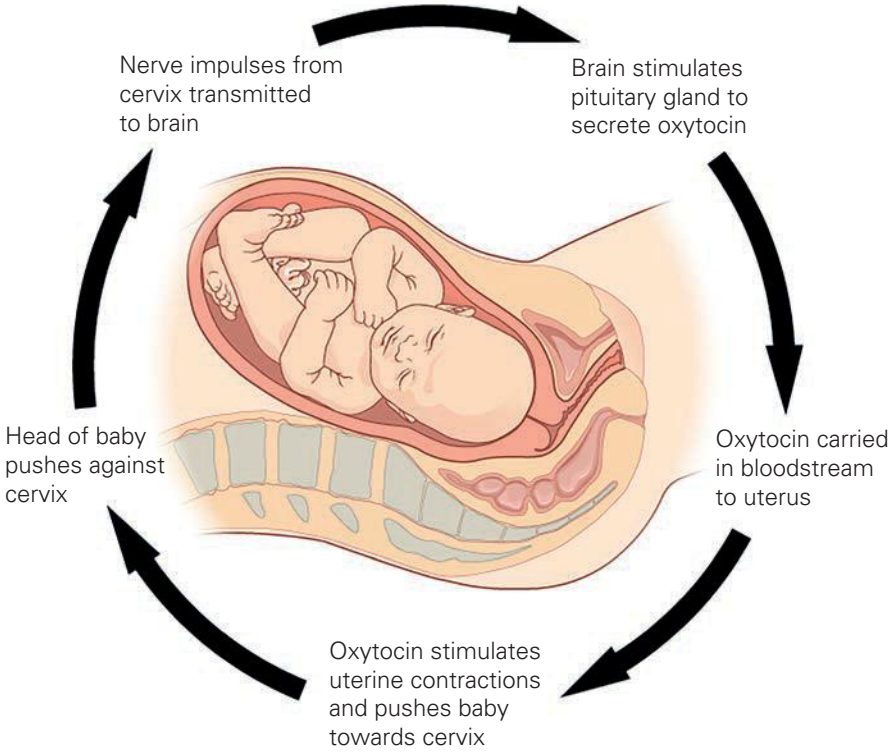


Figure 3.13 Positive feedback in childbirth involves the hormone oxytocin.

Oxytocin is also produced during breastfeeding. When a baby suckles on the breast, it triggers nerve endings in the nipple, which send a signal to the brain to release oxytocin. Oxytocin then stimulates the muscles surrounding the milk ducts in the breast, causing them to contract and push milk towards the nipple. This contraction further stimulates the nerve endings, which sends a signal to the brain to release even more oxytocin. This positive feedback loop ensures that more milk is produced and released in response to the baby's suckling.

Blood clotting

Another example of positive feedback in organisms is the blood clotting process. When a blood vessel is damaged, platelets in the bloodstream are activated and begin to clump together at the site of injury (see Figure 3.14). The platelets release chemicals that further activate more platelets, leading to the formation of a blood clot that seals the wound. This positive feedback loop ensures that the clotting process (see Figure 3.15) is rapid and therefore effective in stopping bleeding.

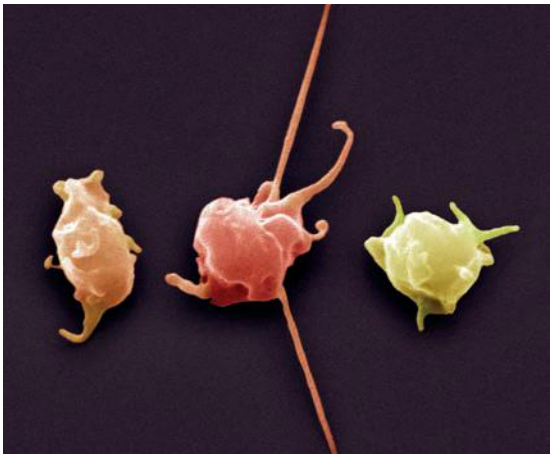


Figure 3.14 Activated platelets

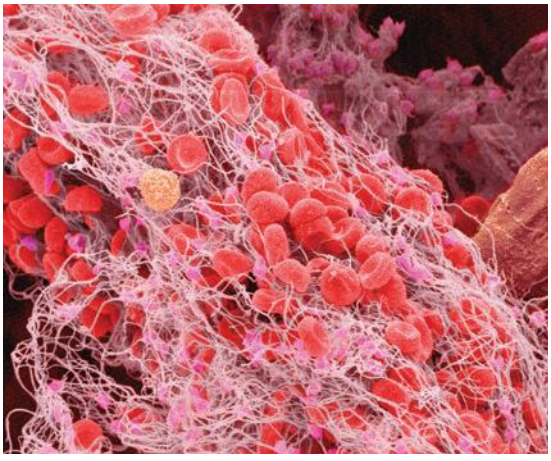


Figure 3.15 A blood clot is the result of a positive feedback mechanism.

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Section questions 

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Section 3.1 questions

Remembering

1. Homeostasis is the maintenance of a relatively stable internal environment. **Name** four things that are tightly regulated within the human body.
2. **Identify** the type of feedback that maintains the direction of a stimulus and accelerates its effect.
3. **Recall** which systems are involved in providing the body with oxygen and removing carbon dioxide.
4. **State** the normal pH range of extracellular fluid in humans.

Understanding

5. **Describe** the negative feedback mechanisms that occur when the body's temperature increases.
6. **Describe** how the respiratory system can control extracellular pH.

Applying

7. **Summarise** the interactions that occur between body systems in order to deliver oxygen to body cells.

Analysing

8. **Categorise** the following examples as positive or negative feedback.
   a) During childbirth, the hormone oxytocin stimulates contractions of the uterus. As the contractions intensify, more oxytocin is released, leading to stronger contractions until the baby is born.
   b) When body temperature rises, the body begins to sweat, which cools the skin surface. As the skin cools, sweat production decreases until the body temperature returns to normal.
   c) During blood clotting, platelets release chemicals that attract more platelets to the site of injury. As the number of platelets increases, the rate of chemical release also increases, leading to more platelets being recruited until the clot is formed.
   d) In response to high levels of glucose in the bloodstream, the body produces insulin. Insulin helps cells to absorb glucose, which in turn reduces the amount of glucose in the bloodstream.
9. **Contrast** positive and negative feedback.

Evaluating

10. **Discuss** why the lungs and kidneys are both considered organs involved in excretion.
11. **Construct** a Venn diagram showing the digestive, circulatory and respiratory systems. In their overlapping zones, summarise in dot points how the systems interact.
12. **Construct** a labelled diagram showing the stages of the stimulus–response model.

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3.2 The nervous system

Learning goal

At the end of this section, I will be able to:

1. Describe the role and function of electrical impulses in the body's responses to internal and external stimuli.

WORKSHEET
Neurons

VIDEO
The nervous system

The brain controls all bodily functions by communicating with different parts of the body every second of every day. It does this in two ways:

1. by sending electrical signals and neurotransmitters via the nervous system
2. by communicating using chemical messengers (hormones) via the endocrine system.

Nervous system

The fundamental units of the nervous system are **neurons** (also spelled 'neurones'). A neuron is a single nerve cell responsible for transmitting signals between the brain and the body. Networks of neurons enable the communication of signals throughout the body, collectively making up the nervous system, which consists of up to one trillion neurons.

neuron
a nerve cell

nervous system
the body system consisting of the brain, spinal cord and peripheral nerves and receptors that communicate messages quickly within the body

somatic nervous system
the part of the peripheral nervous system involved with the voluntary control of body movements

autonomic nervous system
the part of the peripheral nervous system involved in involuntary physiological processes such as heart rate and digestion

The human **nervous system** is composed of two main parts:

- central nervous system (CNS), which includes the brain and spinal cord
- peripheral nervous system (PNS), which is all the neurons and nerve networks throughout the body that lie outside the CNS.

The PNS is further divided into the **somatic nervous system**, which controls the voluntary movement of muscles, and the **autonomic nervous system**, which controls involuntary body functions, such as digestion, lacrimation (making tears) and salivation. The autonomic nervous system can be further divided into the sympathetic and parasympathetic systems, which have opposing excitatory and relaxing actions on the body. Figure 3.16 shows the key components of the human nervous system.

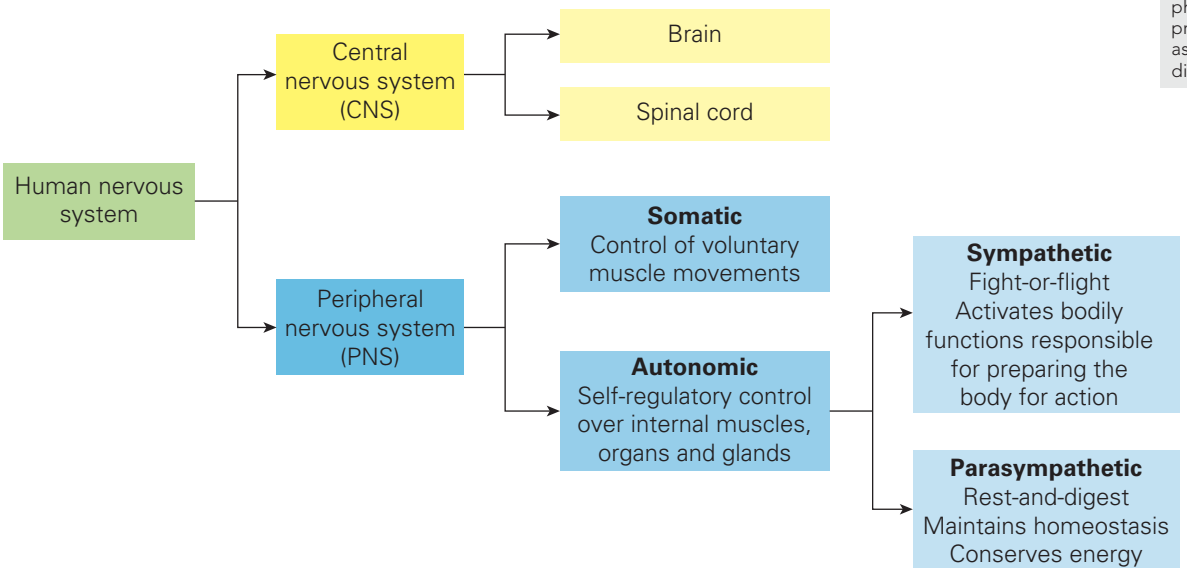


Figure 3.16 The components of the human nervous system

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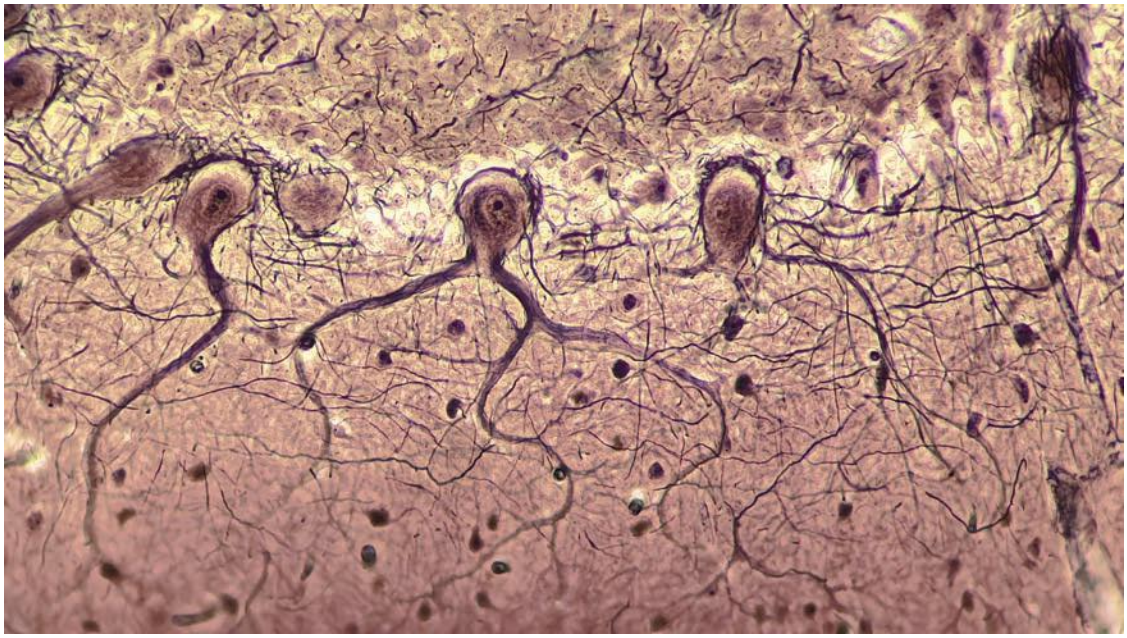


Figure 3.17 The neuron is the basic building block of the human nervous system.

Quick check 3.3

1. **State** another name for an individual nerve cell.
2. **Recall** the components that make up the CNS (central nervous system) and the PNS (peripheral nervous system).
3. **Describe** the role of the somatic nervous system, giving examples that illustrate the somatic nervous system in action.

Types of neurons

Neurons transmit neural information to, from and within the CNS. There are three types of neurons (see Figure 3.19).

sensory neuron
a nerve cell that transmits messages from the sensory receptors to the central nervous system

interneuron
a nerve cell that transmits information within the brain and spinal cord (central nervous system)

motor neuron
a nerve cell that transmits messages from the central nervous system to effectors

- **Sensory neurons** transmit neural information from sensory receptor sites in the PNS to the CNS. The sensory information being transmitted could be from any of your five senses.
- **Interneurons** (also called relay neurons) transmit neural information within the spinal cord and brain. Interneurons connect the sensory and motor neurons and can only be found in the CNS.
- **Motor neurons** transmit neural information from the CNS to the PNS. The purpose of this information is to initiate a response in an effector, which could be a muscle or gland.

To help remember the three types of neurons, think of a SIM (sensory, inter, motor) card in a mobile phone.

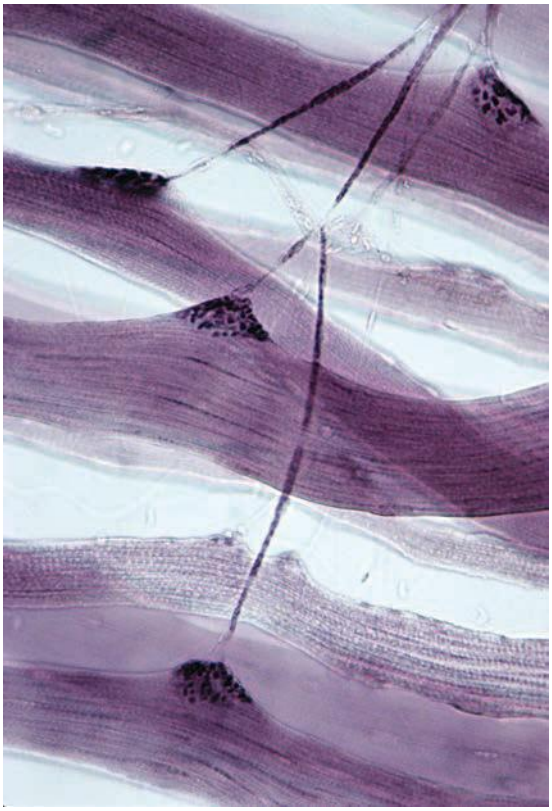


Figure 3.18 100× magnification of motor neurons attached to muscle tissue

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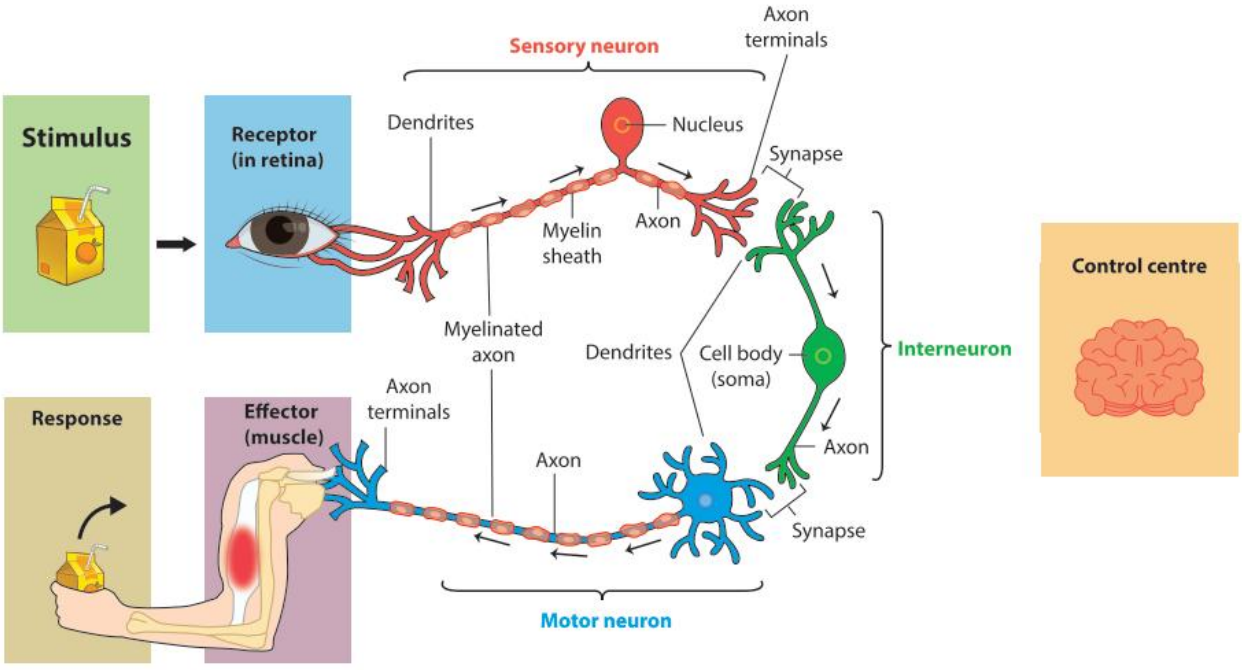


Figure 3.19 The three types of neuron (sensory, inter and motor) form an arc. The sensory neuron has receptors to detect a stimulus and the motor neuron stimulates the effector and causes the response.

Structures of a neuron

The key structures of the neuron include the dendrites, cell body (soma), axon, myelin sheath, axon terminals and **synapse**. The synapse is not a true structure – it is the junction between neurons. The synapse includes the axon terminal (of the sending neuron), the gap between the neurons (synaptic cleft) and the dendrite (of the receiving neuron). Chemicals called **neurotransmitters** are released from a neuron on one side of the synapse and travel across to bind to the neuron on the other side. Table 3.2 and Figure 3.20 show the key structures of a neuron.

synapse the junction between two neurons

neurotransmitter the chemical messenger that is released from one neuron and travels across the synapse to bind to the next neuron

Neuron structure	Function
Dendrite	Contains receptor sites that receive neurotransmitters from neighbouring neurons
Cell body (soma)	Contains most of the cell's organelles, including the nucleus
Nucleus	Control centre of the cell; contains the cell's genetic material
Axon	Transfers electrical impulses from the cell body to the synapse. Axons are called 'nerves' when they are grouped together in a bundle.
Myelin sheath	A fatty, insulating layer made of Schwann cells that covers the axon. It helps keep the electrical signals inside the cell, allowing faster transmission.
Schwann cells	Specialised cells that form the myelin sheath
Axon terminal	Found at the end of the axon and contains neurotransmitters that are held in vesicles. Neurotransmitters are released once an electrical impulse is received.
Synapse	Electrical messages are passed along the neuron, but neurons do not touch one another. There is a gap between the neurons called a synapse. When an electrical impulse is received, the signal diffuses (travels) across the synapse in the form of chemical signals called neurotransmitters. The neurotransmitters then bind to the receptors on the dendrites of the neighbouring neurons.

Table 3.2 Neuron structures and their associated function

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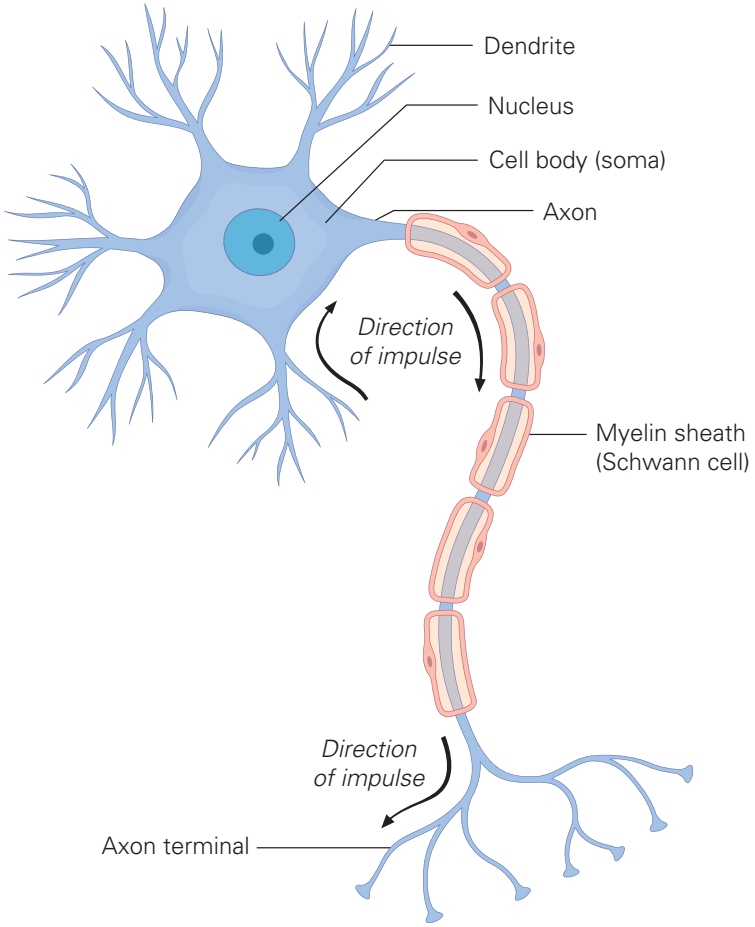
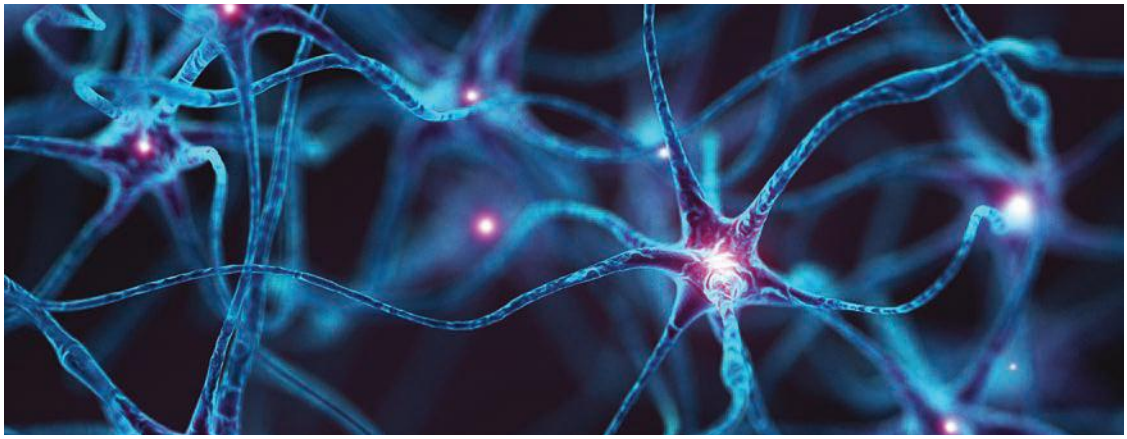


Figure 3.20 The key structures of a motor neuron. The neural impulse travels in one direction only along the neuron, from the dendrites to the axon terminals.

Quick check 3.4

1. **Name** the three different types of neurons.
2. **Recall** where interneurons are found in the body.
3. Interneurons are sometimes called relay neurons. **Explain** why you think that is an appropriate name.
4. **State** the function of the myelin sheath that covers the axon.
5. A fly lands on someone's face and they brush it off. **Name** the three types of neurons involved, in the order they would be activated when the stimulus is detected.



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Try this 3.1

Making model neurons

Create a poster with models of two neurons, showing their structure and function. Make sure your poster has the following features: a title, a model of two adjacent neurons, labels for every structure on one of the neurons (along with a dot point explaining their function) and a label for the synapse.

You will need a piece of A3 paper, and your teacher will provide you with a selection of materials to make the model neurons. Suggestions include pipe cleaners, aluminium foil, pom-poms, drinking straws and modelling clay/plasticine or similar.

Suggested method

1. Cut a pipe cleaner into three pieces. Wrap the pieces of pipe cleaner around a pom-pom. The pipe cleaner pieces will be the dendrites and the pom-pom will be the soma (the cell body of a neuron).
2. Wrap the end of another pipe cleaner around the soma, so you have a long piece coming down. This represents the axon.
3. Cut pieces of drinking straw about 2.5 centimetres (cm) long and thread them onto the axon. Leave gaps between the lengths of straw. You should have a bit of pipe cleaner left at the end. The straw represents the myelin sheath.
4. Take the end of the pipe cleaner near the bottom of the last myelin sheath, twist it into a loop and cut it so it splits – or add more small pipe cleaner pieces. You are beginning to make the axon terminals.
5. Repeat steps 1–4 for the next neuron.
6. Stick the neurons onto the sheet of paper and label the parts of one neuron with a dot point explaining the function of each structure (including the synapse).
7. Put up your posters in the classroom so that the axon terminals of one person's poster connect to the dendrites on the next poster. You should have a chain of neurons forming a nerve!

Communication along and between neurons

Communication along a neuron: Action potential

An **action potential** is another name for the electrical or neural impulse that moves along a neuron. Once the action potential reaches the axon terminal, neurotransmitters pass the action potential on to the next neuron.

action potential the electrical impulse (message) that is transmitted along a neuron

When a neuron is not sending a neural impulse along its axon, it is 'at rest'. Each neuron requires a minimum level of stimulation – called the neuron's threshold potential – to activate an action potential. When enough neurotransmitters arrive from other neurons, and the threshold is reached, an action potential will begin and move along the axon like a wave. If the threshold is not reached, no action potential can start. This is known as the 'all or none' principle. Once an action potential has been triggered, it is self-sustaining; that is, it will continue to the end of the axon without further stimulation.

The speed of an action potential moving along an axon varies for different neurons. The fastest travel more than 100 metres (m) per second; the slowest travel at about 1 m per second. The speed depends on two factors:

- the diameter (width) of the axon – the larger the diameter, the faster the impulse
- whether the axon is insulated with a myelin sheath – an action potential travels faster down an axon with a myelin sheath.

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Explore! 3.1

Multiple sclerosis

Multiple sclerosis (MS) is a chronic and often disabling autoimmune disorder that affects the CNS. It is caused by the immune system attacking the protective myelin sheath that covers nerve fibres, leading to inflammation and damage to the CNS (see Figure 3.21). This damage can cause a range of symptoms, including muscle weakness, fatigue, vision problems and difficulties with coordination and balance. MS can affect people of any age, but it is typically diagnosed between the ages of 20 and 40, and it is more common in women than men.

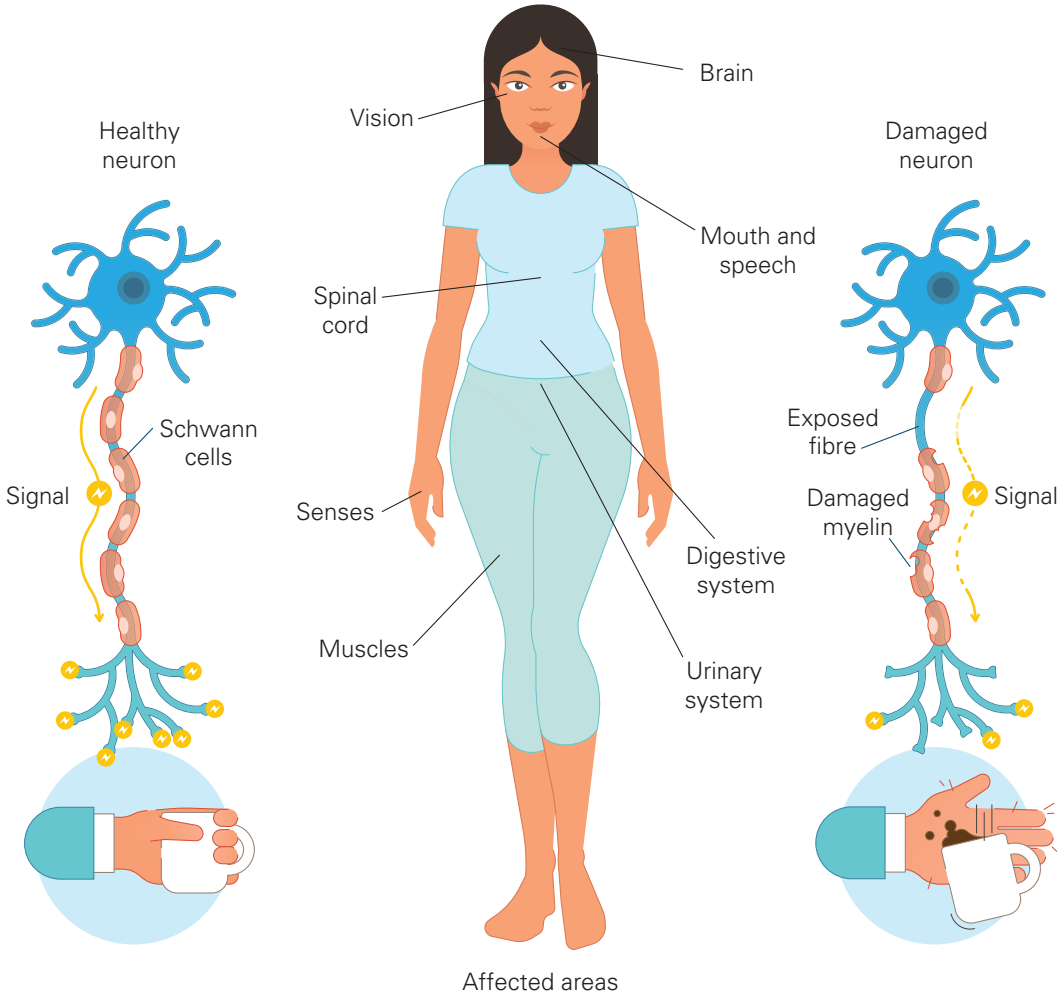


Figure 3.21 Multiple sclerosis affects many areas of the body.

Conduct some research to answer the following questions.

1. Recent research has suggested a link between glandular fever (caused by the Epstein-Barr virus) and MS. What evidence has been found to suggest this link?
2. Why is the drug cladribine effective in MS treatment?

Communication between neurons: The synapse

When neurons communicate with each other, the action potential travelling down the axon causes neurotransmitters to be released from synaptic vesicles within the axon terminal. This part of the synapse is known as the presynaptic neuron. These specialised chemical messengers then move across the gap between neurons (the synaptic cleft). Scientists have managed to identify more than 100 different neurotransmitters in the human brain alone, but evidence suggests there are significantly more than that. Some of the more common neurotransmitters are described in Table 3.3.

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Neurotransmitter	Role	What can go wrong?
Dopamine	Acts within the brain on pathways associated with motor functions (movement) and emotional arousal and motivation	A lack of dopamine-producing cells in the brain can cause Parkinson's disease, a neurological condition characterised by tremors, stiffness and uncoordinated movements.
Acetylcholine	Transmits the message from the axon terminals of a motor neuron to a skeletal muscle	Curare is a plant-based toxin that was used by South American Indigenous peoples to paint the arrows of blow-darts. When shot at a victim, this toxin prevented acetylcholine from binding to the postsynaptic neuron, causing paralysis.
Serotonin	Produced in the intestine and central nervous system; regulates appetite, mood, memory and behaviour	Some scientists theorise that low levels of serotonin are linked to depression.
Glutamate	A neurotransmitter in the CNS, involved with memory and learning	High glutamate levels are involved with depression, anxiety and symptoms typical of attention deficit hyperactivity disorder (ADHD), such as the inability to concentrate. Low levels of glutamate are linked to insomnia, lack of concentration and low energy levels.

Table 3.3 Some common neurotransmitters and their roles

Once the neurotransmitters cross the synaptic cleft, they bind to special receptor sites on the dendrite of the next neuron – called the postsynaptic neuron. The receptor sites convert the information back into electrical signals, which are then transmitted to the cell body of the postsynaptic neuron and along the axon. This process continues until the last neuron in the pathway connects to a muscle or gland, causing a response. This process is shown in Figures 3.22 and 3.23.

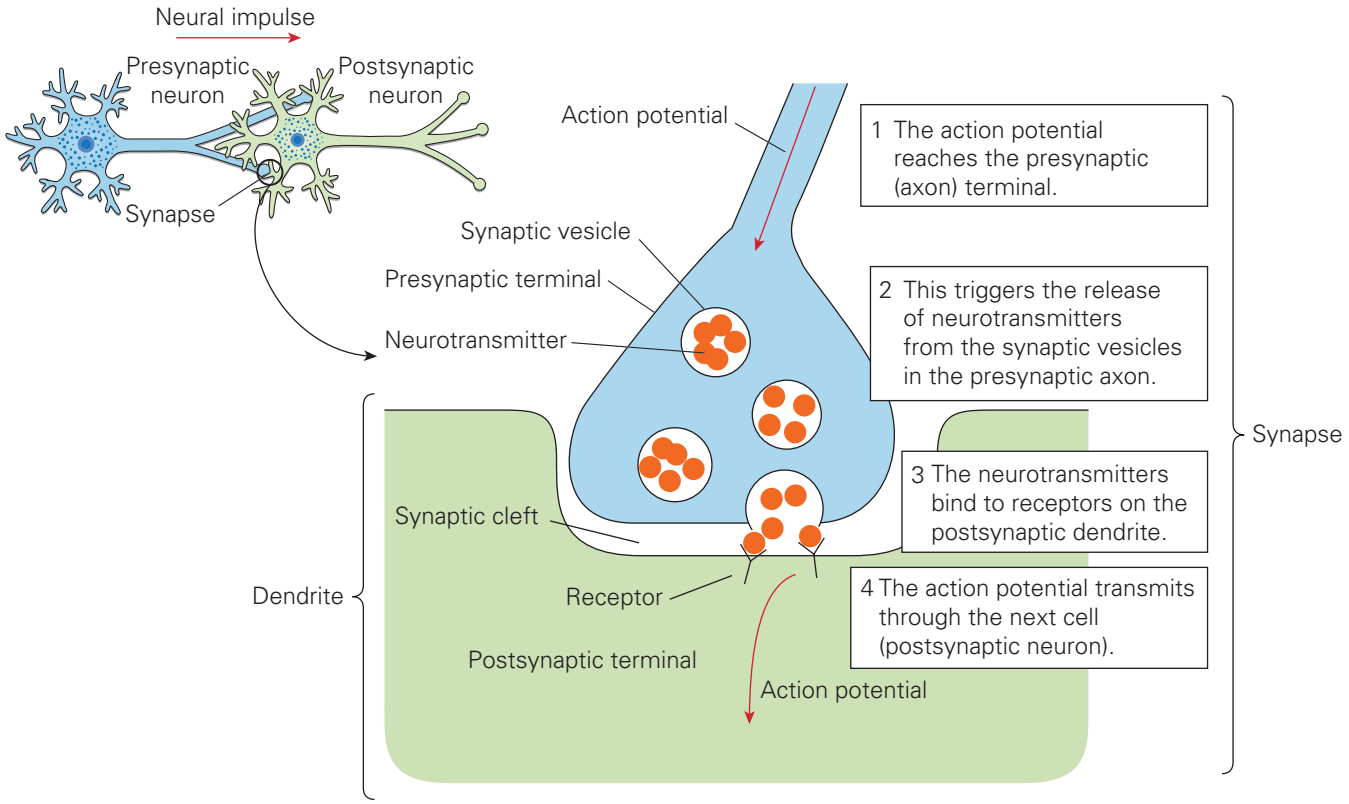


Figure 3.22 Communication between neurons. An action potential triggers the release of neurotransmitters from their synaptic vesicles in the presynaptic neuron. The neurotransmitters move across the gap and bind to receptors on the postsynaptic neuron.

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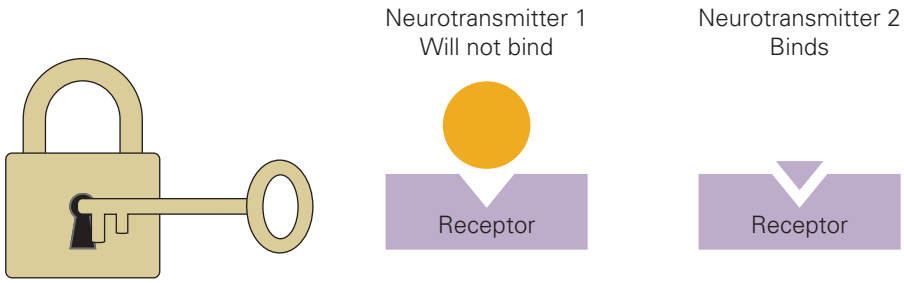


Figure 3.23 Similar to a key fitting into a lock, a specific neurotransmitter will bind only to its corresponding receptor, which ensures that it only causes the intended response.

Recall that the human body produces many different types of neurotransmitters, and each neurotransmitter has a specific role in the functioning of the brain. Neurotransmitters do this by only binding to specific receptor sites. A neurotransmitter binds to a receptor in much the same way that a key fits into a lock, as Figure 3.23 shows.

Neurotransmitter messages can be categorised as either excitatory or inhibitory. An excitatory neurotransmitter *increases* the likelihood of the action potential being sent along the next neuron, whereas an inhibitory neurotransmitter *decreases* the likelihood of the action potential being sent along the next neuron. They are both considered important because they can initiate a response or stop something from happening at the effector site.

For example, GABA is the primary inhibitory neurotransmitter in the central nervous system and has a calming effect. Low levels of GABA have been linked with excess electrical activity in the brain, characterised by seizures.

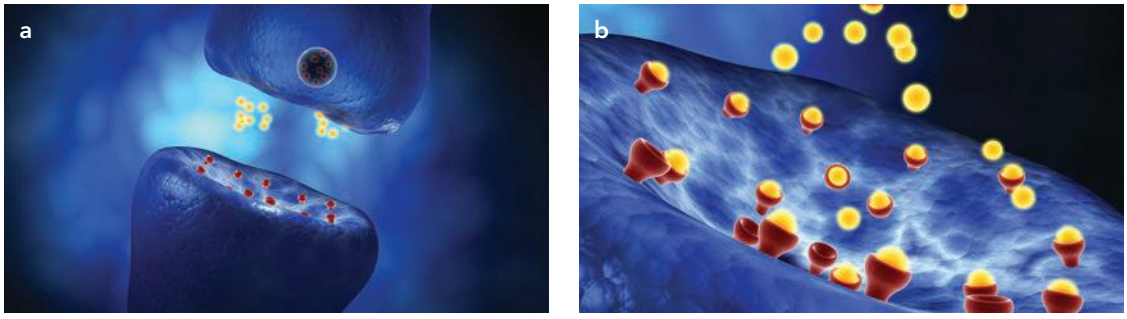


Figure 3.24 Illustrations of a synapse. **(a)** A synaptic vesicle in the axon terminal storing neurotransmitters, and the neurotransmitters (yellow) crossing the synapse to be received by the receptor sites (red) on the neighbouring neuron's dendrite. **(b)** Neurotransmitters (yellow) being released across the synaptic cleft and being received by the receptor sites (red) of the dendrite if they share the same distinct size and shape.

Did you know? 3.1

The longest neuron

The sciatic nerve contains the longest neuron in the human body. It extends from the spine to the tip of the toe and can be up to one metre in length. It is formed by the combination of five sets of paired nerve roots in a section of the spine and has a diameter of about 2 centimetres, which is about as thick as your thumb!

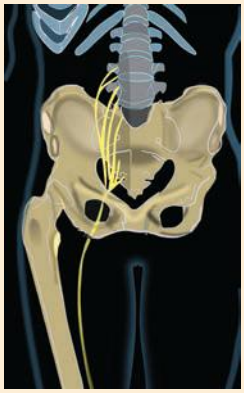


Figure 3.25 The sciatic nerve contains the longest neuron in the human body.

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Making thinking visible 3.2

Headlines: Mapping the human brain

The human brain consists of billions of neurons. These form a complex network of neural pathways, which are responsible for our thoughts and memories. Despite its importance, scientists still lack the technology to map even a small number of the connections within the human brain.



Figure 3.26 The first digital connectome of an organism – a fruit fly. A connectome is a map of neural connections in the brain.

However, in March 2023, an international team of scientists at the MRC Laboratory of Molecular Biology, University of Cambridge, UK, and Johns Hopkins University, USA, successfully mapped a fruit fly brain. This is the most complex brain to be mapped to date. While different in scale and complexity to the human brain, the fruit fly brain has many similarities: it has two hemispheres, a brainstem-like structure, and a spinal cord equivalent. So, the fruit fly brain may offer insights into the functioning of the human brain.

- Write a headline that captures the most important part of this research.
- How does your headline differ from what you might have said yesterday?

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

Quick check 3.5

1. **State** if an action potential is a signal between two neurons, along a neuron or along an axon.
2. **Recall** what the 'all or none' principle means.
3. **Define** 'neurotransmitter'.
4. **Describe** the role of the postsynaptic neuron.
5. **Recall** three common neurotransmitters, including their functions.
6. **Organise** the stages of the following flow chart in the correct order, showing how an action potential passes from one neuron to another.

Action potential stimulates synaptic vesicles to release neurotransmitters	Action potential is initiated once threshold is reached	Neurotransmitters are released into synaptic cleft	Action potential travels along axon of presynaptic neuron	Neurotransmitters bind to receptor sites on dendrites of postsynaptic neuron

Did you know? 3.2

Drugs

Drugs are substances that affect the brain by altering the way neurons send, receive and process information. Certain drugs, such as marijuana and heroin, imitate naturally occurring neurotransmitters to activate neurons. Other drugs, such as cocaine and amphetamines, stimulate neurons to produce more of the natural neurotransmitters, amplifying signals, blocking recycling of the chemicals, and disrupting communication channels.

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Explore! 3.2

Parkinson's disease

Neurodegenerative diseases refer to a variety of conditions that primarily affect neurons in the human brain. They include Parkinson's disease, Alzheimer's disease and multiple sclerosis. Parkinson's disease is a progressive and degenerative neurological condition that impairs a person's ability to control their body movements, resulting in both motor and non-motor symptoms. This is caused by the loss of cells in various areas of the brain, including the substantia nigra, where dopamine production occurs. As dopamine production decreases, the nervous system's motor functions become impaired, leading to symptoms such as tremors and rigidity.

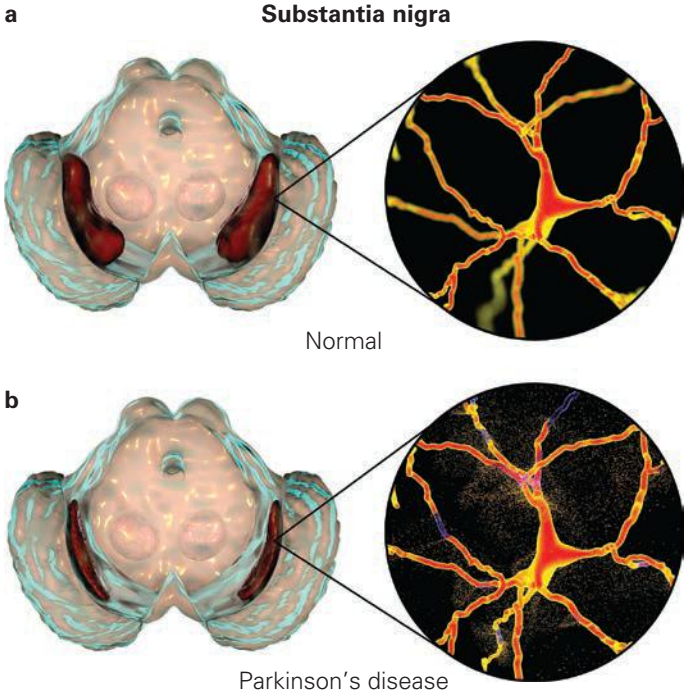


Figure 3.27 A computer-generated illustration of the human brain showing **(a)** a healthy substantia nigra and **(b)** a degenerated substantia nigra.

Although there is currently no cure for Parkinson's disease, medication can help manage its motor symptoms by increasing dopamine levels or mimicking the neurotransmitter's effects. The development of diagnostic and treatment technologies for neurodegenerative diseases relies on advances in brain imaging and diagnostic tools. For example, a NeuroMotor Pen developed by a British company can diagnose nerve disorders such as Parkinson's disease by assessing a patient's handwriting and drawing tasks. Abnormalities are identified and used as 'digital biomarkers' to monitor patient progress. Additionally, low-cost wearable sensors and mobile phone applications can continuously detect and quantify a patient's symptoms, generating daily reports that alert doctors of any unusual data.

Conduct some research on one of the following topics:

- an imaging technique that allows us to identify and learn about Parkinson's disease (e.g. PET scans or DaT/SPECT imaging)
- a technology developed to aid people with Parkinson's disease (e.g. wearable sensor networks, MagnaReady's line of men's and women's shirts with magnetic buttons, SteadyMouse, the NexStride mobility aid or GlideTrak).

Summarise your findings by explaining how technologies have improved knowledge and understanding of Parkinson's disease or have helped people with Parkinson's live better lives.

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Try this 3.2

Neurotransmission at the synapse

Use a stop-motion app to create a short animation that clearly represents how neurotransmission occurs between neurons. Alternatively, you could construct a comic-book-style outline or a poster.

Label the following components.

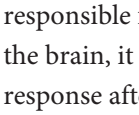
- Presynaptic neuron (axon terminal)
- Synaptic vesicles
- Neurotransmitters
- Postsynaptic neuron (dendrites)
- Receptor sites
- Synapse
- Action potential
- Synaptic cleft

Your animation should show the movement of vesicles binding with the cell membrane and releasing neurotransmitters to the next neuron.

Reflex actions

A **reflex action** is a fast, automatic response that protects the body from harm. At times, the body must react quickly without waiting for the brain to process the stimulus and issue instructions (relying on the stimulus–response model). During such instances, the spinal cord is mainly responsible for detecting the stimulus and initiating a response. While a message is passed to the brain, it is done so only after a brief delay, and the brain registers both the stimulus and the response after the reflex action has already taken place.

reflex action
a fast, involuntary motor action that protects the body from harm



WORKSHEET
Response time data analysis

A reflex action, also known as a reflex arc, involves a maximum of three neurons. The signal travels to the spinal cord and then returns to the muscle, prompting a rapid contraction that does not involve the brain. Figure 3.28 shows an example of a reflex arc.

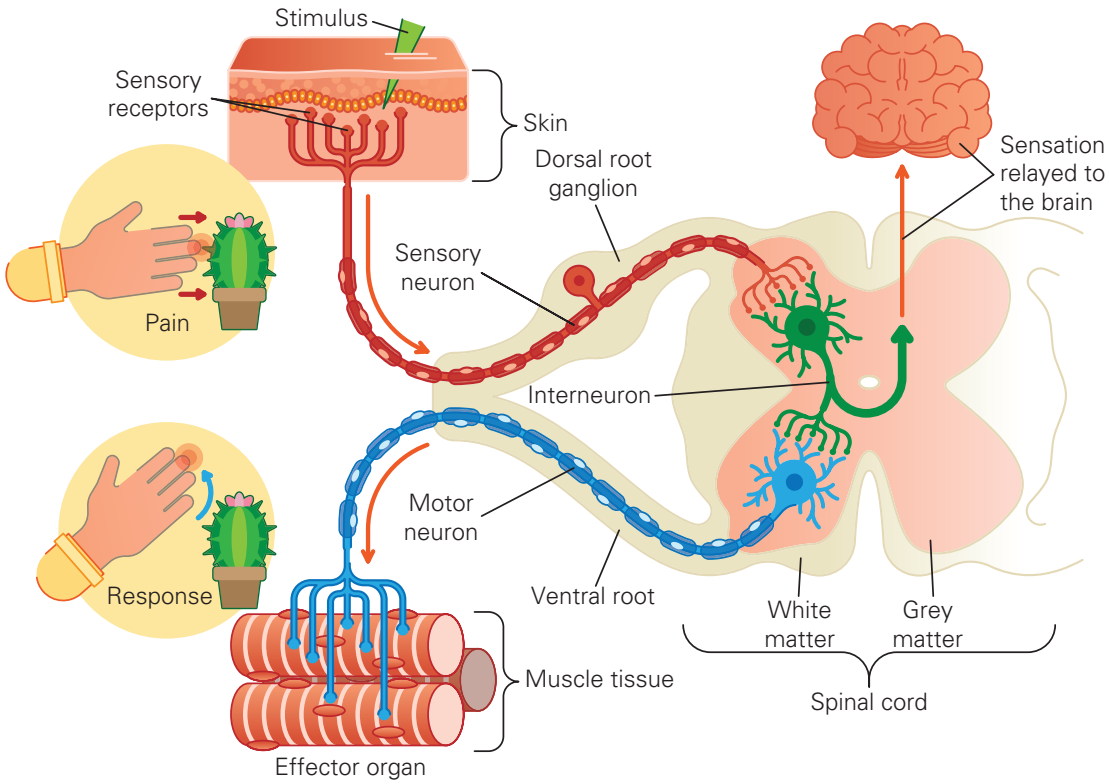


Figure 3.28 An example of a reflex arc. When you touch a prickly cactus with your finger, a receptor in a sensory neuron detects the pain and initiates an action potential. The impulse is carried to the spinal cord, where the sensory neuron connects to an interneuron. The interneuron then connects to a motor neuron that sends an action potential through to the muscle tissue. Your muscles contract and you move your hand away from the sharp cactus.

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Try this 3.3

Stimulus–response model

A person sees a can of soft drink sitting on the bench. They feel quite thirsty, so they reach out and pick up the can to have a drink.

Referring to the components defined in the following table, describe how the person's actions fit the stimulus–response model.

Part of the stimulus–response model	Definition of this part
Stimulus	Change in the environment
Receptors	Detect the stimulus and stimulate the sensory neuron
Sensory neurons	Transmit an action potential (nerve impulse) to the integration area (the CNS)
CNS	Brain coordinates an appropriate response by sending nerve impulse along interneurons that connect to motor neurons
Motor neurons	Transmits an action potential (nerve impulse) to the effector organ (muscle or gland)
Effectors	Act to cause the response
Response	Body's reaction to the stimulus

Knee-jerk reflex

The 'knee-jerk' reflex is a common type of reflex action. During a knee-jerk reflex test, a healthcare professional taps the quadriceps tendon beneath the kneecap with a reflex hammer (see Figure 3.29). The quadriceps tendon is connected to the quadriceps muscle located on top of the thigh. The tap of the hammer induces a slight stretch within the quadriceps muscle. Receptors in the muscle detect this stretch and send a message to the muscle. The knee-jerk reflex is unique because it is monosynaptic, meaning that no interneurons are involved. Instead, the sensory neuron transmits the message directly across a synapse to a motor neuron in the spinal cord. The motor neurons then conduct the impulse back to the quadriceps, causing a muscle contraction that triggers a kick. This kick confirms to the healthcare professional that a specific section of the spinal cord and the associated nerves are functioning correctly. Various reflex tests are required to obtain a more precise health assessment of the entire nervous system.

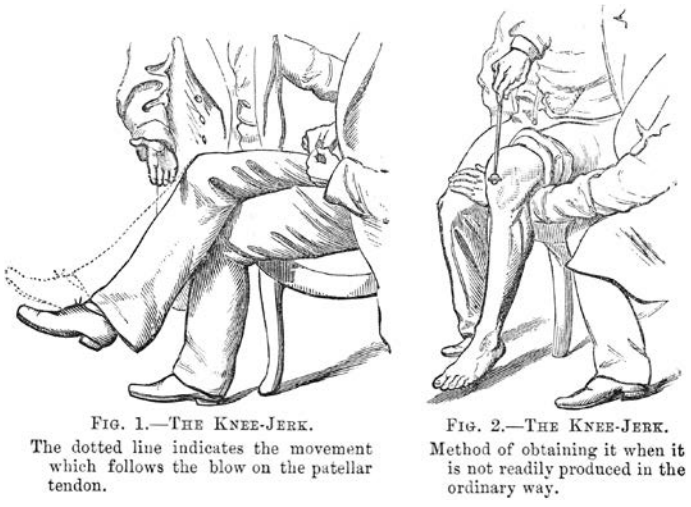


FIG. 1.—THE KNEE-JERK.
The dotted line indicates the movement which follows the blow on the patellar tendon.

FIG. 2.—THE KNEE-JERK.
Method of obtaining it when it is not readily produced in the ordinary way.

Figure 3.29 This illustration of the 'The Knee-Jerk' was drawn by William Richard Gowers (1845–1915), a pre-eminent clinical neurologist, for his *Manual of Diseases of the Nervous System*, published in 1886.

The knee-jerk reflex is in use whenever a person stands up. When standing upright, the muscles are continuously contracting and stretching to maintain balance. If a person leans back while standing, their quadriceps are stretched, and the reflex is activated. Since the person is standing, the muscle contraction that would usually cause a kick upwards instead brings them back to a stable central position. This reflex, in combination with the Achilles reflex, helps people maintain balance while walking.

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Try this 3.4

Part A: Testing your pupillary reflex

1. In a well-lit room, look closely at the eyes of your partner and estimate the diameter of their pupils in millimetres.
2. Ask your partner to close their eyes for 60 seconds and tilt their head down towards the floor. Time this using a stopwatch.
3. Ask your partner to tilt their head up towards the light and open their eyes. Observe the response in their pupils closely.

Part B: Testing your knee-jerk reflex

1. Position your partner sitting in a chair, with one leg crossed over the other. Refer to Figure 3.29.
2. Using the side of your hand or a ruler, gently strike the patellar tendon just below the kneecap and observe what happens. Note: You may need to repeat this several times to get a result.

Practical 3.1

Testing your reaction times

Reaction time is a measure of how quickly a person responds to a stimulus. Many factors can affect reaction time, including age, gender, practice, blood sugar, alcohol, caffeine and general fitness.

Aim

To investigate the effect of practice on reaction times

Materials

- stopwatch
- ruler
- well-lit room

Method

1. Write a rationale on reaction times and the factors that affect this.
2. Create a relevant and specific research question based on the experimental method outlined.
3. Write a risk assessment for this practical.
4. Do not practise the experiment before starting to collect the results. You should start measuring immediately to ensure that you can determine the effect of practice time.
   Have your partner lean their forearm on a bench with their weaker hand extending over the edge. If they are left-handed, they should use their right hand and vice versa. Ask them to make a pincer grip with their thumb and index finger with a gap of 2 cm between them.
5. Dangle the ruler above their hand so that the end marked 0 cm is hanging between their thumb and index finger.
6. Instruct them to catch the ruler with their thumb and index finger when they notice you have released it.
7. Release the ruler without warning.
8. Take note of the measurement on the ruler where they have caught it. This is the number of centimetres that the ruler fell before the person responded. Use the conversion table (Table 3.4) to determine the reaction time.
9. Each person should complete the drop test 10 times. Record the ruler reading and reaction time for each test.

continued ...

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Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)
1	0.05	21	0.21	41	0.29	61	0.35	81	0.41
2	0.06	22	0.22	42	0.29	62	0.36	82	0.41
3	0.08	23	0.22	43	0.30	63	0.36	83	0.41
4	0.09	24	0.22	44	0.30	64	0.36	84	0.41
5	0.10	25	0.23	45	0.30	65	0.36	85	0.42
6	0.11	26	0.23	46	0.31	66	0.37	86	0.42
7	0.12	27	0.23	47	0.31	67	0.37	87	0.42
8	0.13	28	0.24	48	0.31	68	0.37	88	0.42
9	0.14	29	0.24	49	0.32	69	0.38	89	0.43
10	0.14	30	0.25	50	0.32	70	0.38	90	0.43
11	0.15	31	0.25	51	0.32	71	0.38	91	0.43
12	0.16	32	0.26	52	0.33	72	0.38	92	0.43
13	0.16	33	0.26	53	0.33	73	0.39	93	0.44
14	0.17	34	0.26	54	0.33	74	0.39	94	0.44
15	0.18	35	0.27	55	0.34	75	0.39	95	0.44
16	0.18	36	0.27	56	0.34	76	0.39	96	0.44
17	0.19	37	0.28	57	0.34	77	0.40	97	0.45
18	0.19	38	0.28	58	0.34	78	0.40	98	0.45
19	0.20	39	0.28	59	0.35	79	0.40	99	0.45
20	0.21	40	0.29	60	0.35	80	0.40	100	0.45

Table 3.4 Conversion table for reaction times

Results

1. Create a results table for this experiment.
2. Construct a graph of drop test number versus reaction time.

Discussion: Analysis

1. Identify any patterns, trends or relationships in your results.
2. The ruler drop experiment is not really testing a reflex. Draw a stimulus–response flow chart, highlighting the part that proves this is not a simple reflex. Explain why this is the case.
3. Compare your results with those of other people in your class. Do students who play particular sports or musical instruments have faster reaction times?

Discussion: Evaluation

1. Identify any potential sources of error in this experiment.
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. Make a claim regarding practice and reaction times.
2. Support your claim by referring to your experimental data, and include potential sources of error.
3. Explain how the data supports your claim.

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Did you know? 3.3

WIDGET
Reaction times

Conscious and unconscious responses

A reflex action is an unconscious process because the brain is not initially involved in activating a response. This is different from a conscious process where the brain is involved in activating a response. The differences are shown in the following table.

Conscious response to stimuli	Unconscious response to stimuli
Reaction involves the brain and a level of awareness	Reaction does not involve a level of awareness by the brain
Attention must be paid to stimulus	Attention does not have to be paid to stimulus
Voluntary or intentional reaction	Involuntary or unintentional
Goal is often directed or purposeful	Reflexive or automatic, increasing chances of survival
Can be a more complex response	Most are simple responses
Tends to vary	Tends to occur in the same way each time
Can be learned	Does not require learning
Can be controlled	May not be controllable

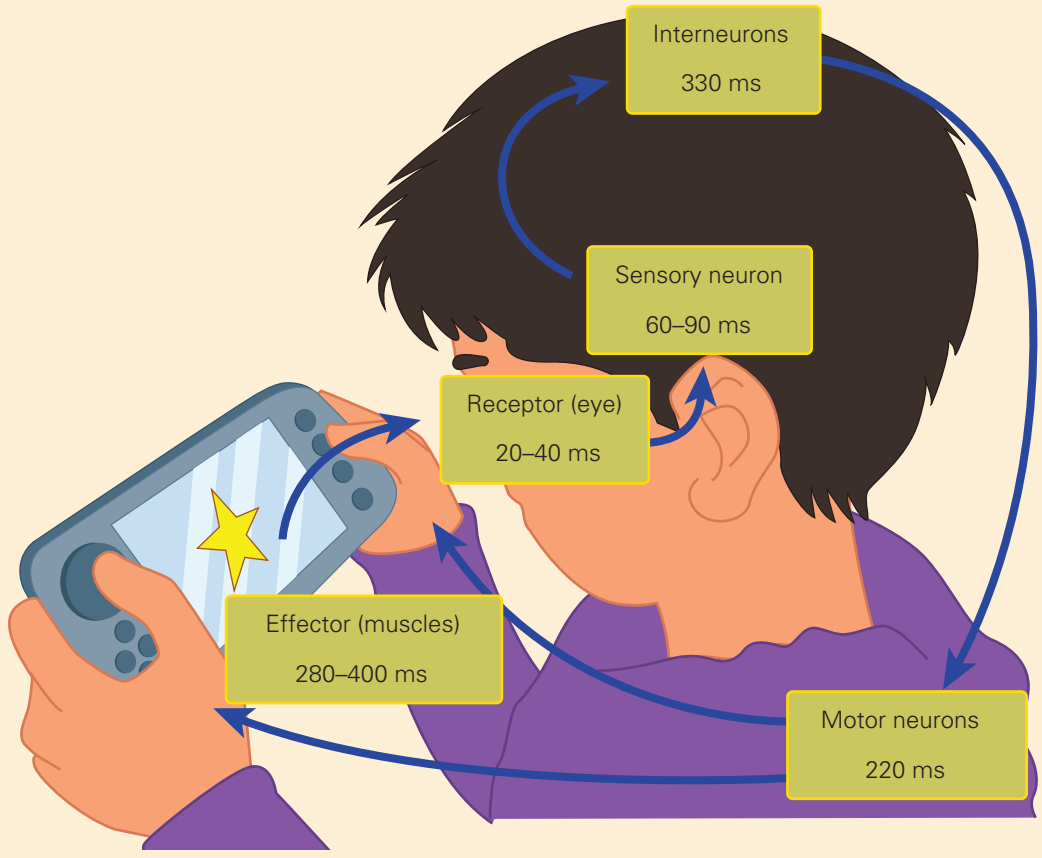


Figure 3.30 A child playing a game is an example of a conscious response. The approximate time in milliseconds (ms) is shown at each step of the process, from stimulus (light from the screen) to response (moving fingers to press buttons).

Quick check 3.6

1. 'The brain is not immediately involved in a reflex arc.' **Propose** whether this statement is true or false.
2. **Draw** a reflex arc for a person touching a flame.
3. **Compare** the reflex arc and stimulus–response models of the nervous system.

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Section 3.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 3.2 questions

Remembering

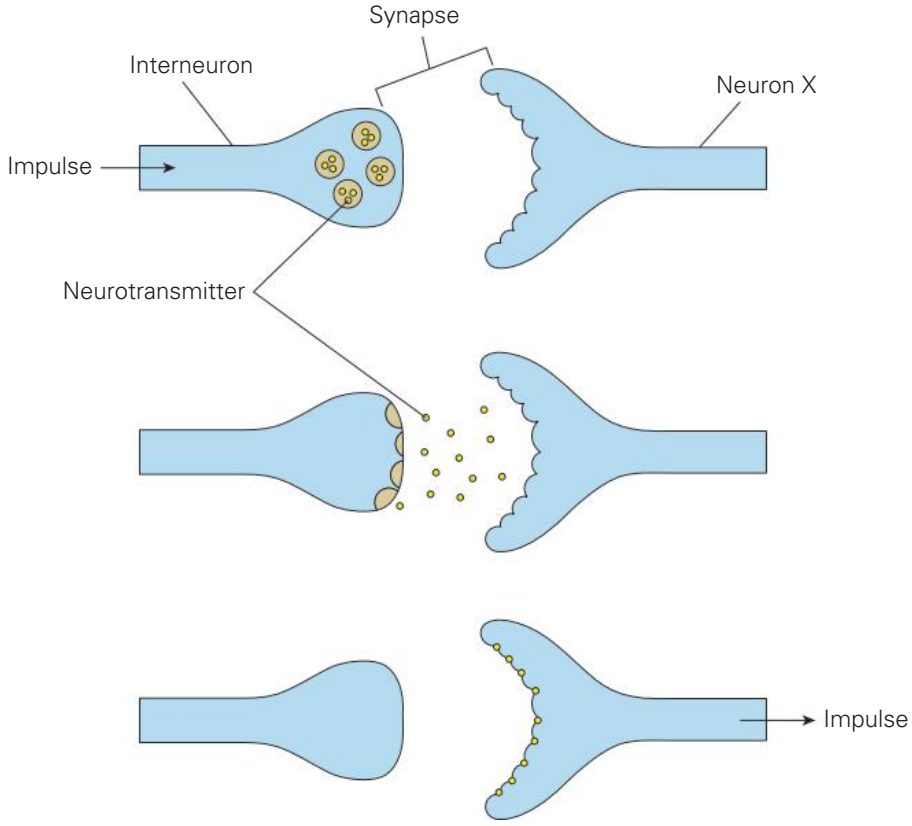
1. **Name** the three different types of neurons in the human nervous system.
2. a) **Define** 'reflex action'.
   b) **Describe** the role of a reflex action in defending the body against damage.
3. **State** an example of a reflex action.
4. **State** the function of dendrites.

Understanding

5. A person picks up a very hot cup of coffee and immediately drops it, breaking the cup. **Create** a flow chart of this action, beginning at the stimulus and ending in the response. Highlight the section of the flow chart that demonstrates whether this is a reflex or a response coordinated by the brain.
6. **Draw** a motor neuron, labelling all the key structures.
7. **Describe** how an action potential is triggered and transmitted from one neuron to the next.
8. **Describe** a synapse.

Applying

9. The diagram shows how an impulse moving along an interneuron causes an impulse to be sent along another type of neuron, neuron X.
   a) **Identify** the name given to neuron X.
   b) **Describe** how information passes from the interneuron to neuron X. Use the diagram to help you.



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10. **Explain** how neurotransmitters cross a synapse.
11. If a drug blocks the receptor sites, **explain** the effect it could have on neurotransmission across the synapse.

Analysing

12. **Distinguish** between the stimulus and the response in the knee-jerk reflex.
13. **Identify** two differences between a conscious and an unconscious response to stimuli.
14. **Contrast** the functions of the motor neuron and the sensory neuron.

Evaluating

15. Using the stimulus–response model, **construct** a flow chart showing the steps involved in the scenario that follows below. Be sure to include these terms on your flow chart: stimulus, motor neuron, muscle, interneuron, sensory neuron, receptor.

    Scenario: A person is standing in a crowd and hears someone call their name. They turn their head to see who called them.
16. Imagine this: You sneak up behind someone and make a sudden loud noise. They respond by blinking, twitching, moving their head suddenly, screaming or throwing their hands up. Using your knowledge of reflexes, **discuss** whether their response is voluntary, and give some reasons why this reflex might be a helpful mechanism to have.
17. Caffeine is known to increase alertness levels. You usually feel tired when the neurotransmitter adenosine is released. **Discuss** how caffeine may affect adenosine receptors.
18. Dopamine is a neurotransmitter that is involved in making us feel good. Caffeine works by slowing down the rate of dopamine leaving the brain to your body, while at the same time not affecting the rate at which it is released into your brain. This leads to an increased level of dopamine in the brain for a short time. **Deduce** how this might affect your feelings and behaviour.



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3.3 The endocrine system

WORKSHEET
Body communication systems

Learning goals

At the end of this section, I will be able to:

1. Describe the role and function of hormones in the body's responses to external stimuli.
2. Describe how negative feedback mechanisms serve to maintain balance in internal systems.
3. Describe the effects of a disorder in a feedback system.

VIDEO
Parts of the endocrine system

endocrine system the system of glands that controls hormones in the body

The nervous system works in tandem with the **endocrine system**. The endocrine system includes glands throughout the body that secrete hormones that regulate a variety of bodily processes, such as metabolism, digestion, blood pressure and growth. Although the endocrine system is not directly connected to the nervous system, the two interact in many ways. Some of the most important endocrine glands are in the brain. These include the pineal gland, the hypothalamus and the pituitary gland.

At the base of the forebrain is a tiny collection of neurons known as the hypothalamus (see Figure 3.31). The hypothalamus links the nervous and endocrine systems. It is responsible for regulating several behaviours, such as sleep, hunger, thirst, sexual behaviour, and emotional and stress responses. The hypothalamus also controls the pituitary gland and the release of several different hormones.

Other important glands in the body are the thyroid, thymus and adrenal glands, and the pancreas, ovaries and testes (see Figure 3.32). These glands are involved in regulating metabolism, fight-or-flight responses and reproductive processes.

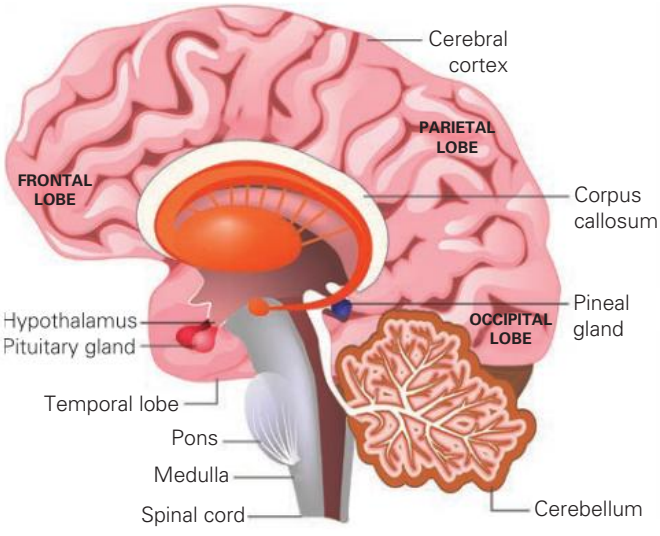


Figure 3.31 A cross-sectional view of the brain showing the location of the pineal gland, pituitary gland and hypothalamus

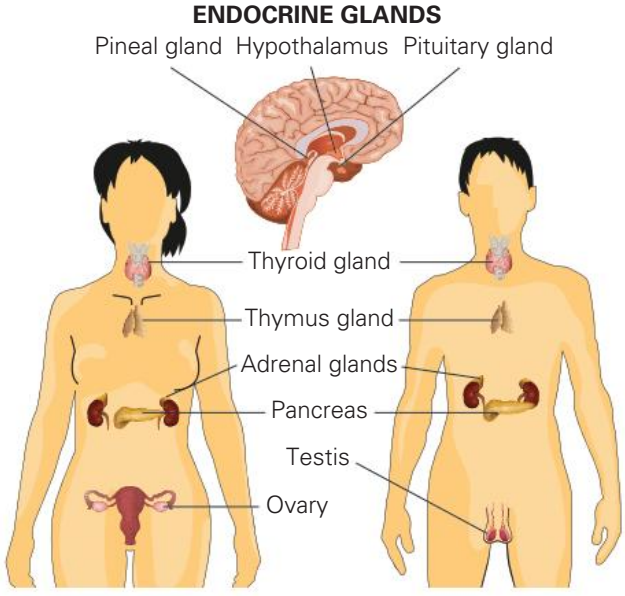


Figure 3.32 Endocrine glands in the female and male body

VIDEO
Hormones

Hormones

Hormones are chemical messengers sent by the endocrine system to communicate with other parts of the body. They are made by endocrine glands, which secrete the hormones directly into the circulatory or lymphatic systems. The blood or lymph carries the hormones around the body, so hormones are transported to, and have an effect in, a different part of the body from where they are made.

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The cells that hormones affect are called **target cells**. Target cells have receptors on their surface that are specific to that hormone, which explains why hormones can circulate through the body freely without affecting other tissues.

target cell
a cell affected by a specific hormone

Organisms are coordinated by many hormones, and small amounts of these chemicals can have major effects. Table 3.5 shows where some hormones are produced and what effect they have when they reach their target site.

Hormone	Endocrine gland where produced	Action of hormone
Insulin	Pancreas	Reduces blood glucose levels by increasing glucose uptake by cells and promoting the conversion of excess glucose to glycogen in liver and muscle cells.
Glucagon	Pancreas	Increases blood glucose levels by stimulating the conversion of stored glycogen into glucose and releasing it into the bloodstream.
Adrenaline	Adrenal gland	Secreted during times of fear, stress or excitement. Increases heart rate, constricts blood vessels near the skin, dilates blood vessels to some muscles, raises blood pressure, and elevates blood sugar, preparing the body for physical action during the fight-or-flight response.
Erythropoietin	Kidneys	Promotes the production of red blood cells by the bone marrow.
Growth hormone (GH), antidiuretic hormone (ADH) and others	Pituitary gland	GH promotes cell division, growth and repair in the body; ADH regulates the levels of water in the blood, by acting on the kidney tubules.
Melatonin	Pineal gland	Regulates sleep patterns by inducing sleep. It is released in darkness and ceases to be produced in light.
Testosterone	Testes	Promotes bone growth, muscle development, facial hair growth and deepening of the voice in males during puberty.
Oestrogen	Ovaries	Promotes breast and hair development and changes the shape of the hip bones in females during puberty.
Various thyroid hormones, including thyroxine	Thyroid	Controls the body's rate of energy production and metabolism and regulates the body's sensitivity to other hormones.
Parathyroid hormone	Parathyroid gland	Controls the amount of calcium in the blood and bones.
Thymosin	Thymus	Stimulates the development of T-cells, which are important in maintaining a healthy immune system.

Table 3.5 Endocrine glands and their hormones and actions

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Explore! 3.3

Endocrine-disrupting chemicals in plastics

What might be causing the increasing rates of cancer and metabolic conditions such as diabetes? What is the potential explanation for declining fertility rates? One hypothesis is that exposure to endocrine-disrupting chemicals is affecting our bodily functions. Although the scientific research supporting this hypothesis is mostly based on studies conducted on rats and mice, some researchers believe that it is applicable to humans as well. These chemicals are present in many household products including plastics. As a result, understanding safe levels of exposure is a topic of ongoing research.

1. Where might you find endocrine-disrupting chemicals in your house?
2. What everyday products might you find that contain BPA (bisphenol A)?
3. Discuss the stages of your life during which exposure to endocrine-disrupting hormones might be more harmful.
4. List some ways you could limit your exposure to endocrine-disrupting hormones.

Did you know? 3.4

Melatonin and sleep

Adolescents typically need 9.25 hours of sleep a night, but their body clock is shifted 1–3 hours later than other age groups. This means that melatonin, a hormone that regulates sleep, is released later in adolescents, causing them to feel drowsy later than others. Factors such as digital technologies, social media, and academic or athletic commitments can further disrupt sleep patterns. As a result, many adolescents experience sleep deprivation and struggle to wake up in the morning.

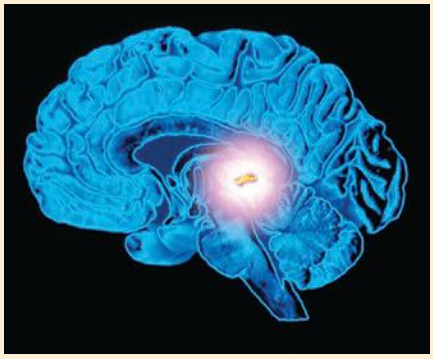


Figure 3.33 The pineal gland (highlighted) secretes the hormone melatonin, which controls the body's biological clock.

Try this 3.5

Calculating your sleep debt

1. Every morning for 7 days, record the amount of sleep you had the previous night. Calculate your total sleep over the 7 days in hours.
2. The recommended number of hours of sleep for an adolescent in 7 days is:
   9.25 × 7 days = 64.75 hours
   Express the amount of sleep you got as a percentage by following this formula:
   $$\text{percentage of required sleep} = \frac{\text{your hours}}{64.75} \times 100$$
   If the percentage is greater than 100, you are getting sufficient sleep. If it is below, you are suffering from sleep debt. The lower the percentage, the greater the sleep debt.
   For example, if you get 8 hours of sleep each night for 7 days, then 8 × 7 = 56, so $\frac{56}{64.75} \times 100 = 86.49\%$. This means you are only getting 86% of the required sleep for a week and are suffering a 14% sleep debt.
3. Collect the results of the whole class and find the average sleep debt of your class.

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Did you know? 3.5

Hypothermia

Hypothermia is a medical condition that occurs when the body's core temperature drops below normal levels, typically below 35°C. It can occur if the body's feedback systems fail to work properly.

For example, if the hypothalamus is damaged or not functioning correctly, it may not be able to detect changes in body temperature and adjust the body's response accordingly. This can result in the body losing heat faster than it can produce it, leading to hypothermia.



Figure 3.34 Hypothermia is a medical emergency.

Another way that disorders in feedback systems can lead to hypothermia is by disrupting the body's ability to produce heat. For example, if the thyroid gland is not functioning correctly and not producing enough thyroid hormone, it can slow down the body's metabolism, leading to a decrease in heat production. This can also result in hypothermia.

Hypothermia can also lead to some unusual behaviours. Conduct some research on paradoxical undressing and terminal burrowing.

Quick check 3.7

1. **Recall** the name of the part of the brain at the base of the forebrain that controls many bodily functions such as sleep, hunger and thirst.
2. **Describe** how hormones are transported around the body.
3. **Name** the hormone that is responsible for regulating sleep patterns and inducing sleep.
4. **Define** 'target cells'.
5. **Discuss** the effects of oestrogen and testosterone.

Regulating water levels

Regulation of water levels in the blood is a very important example of homeostasis. It is often referred to as **osmoregulation**. The amount of water in the blood is measured continuously by a group of osmoreceptors in the hypothalamus of the brain. They can detect if there are low levels of water in the blood (the blood is very concentrated) or high levels of water in the blood (the blood is very dilute). Figure 3.35 shows the osmoregulation stimulus–response model and associated negative feedback loop.

osmoregulation the regulation of water levels in the blood/body

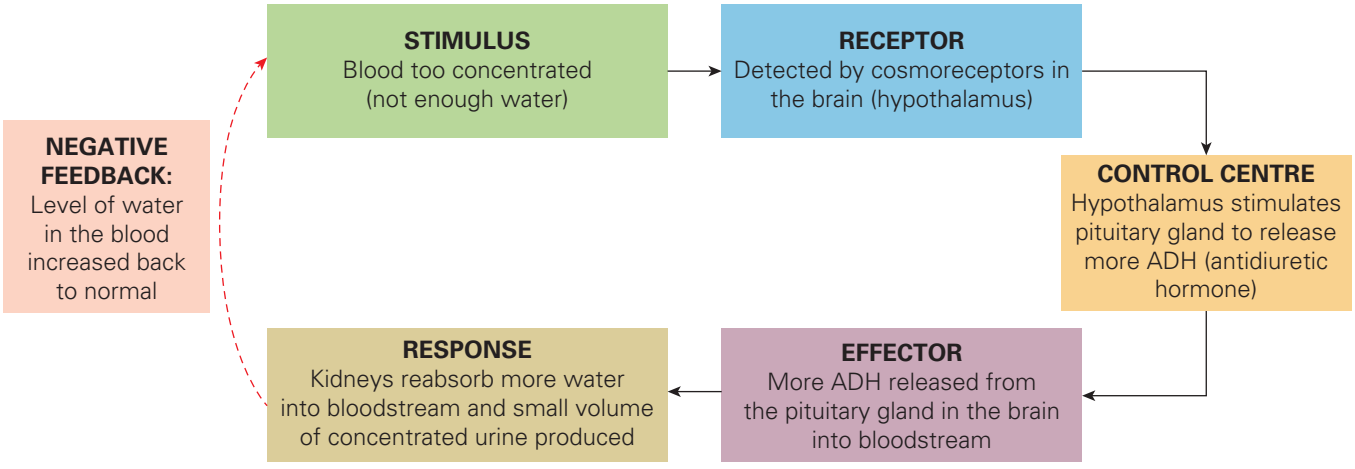


Figure 3.35 The stimulus–response flow chart (shown in black) and negative feedback mechanism that occurs when water levels are too low.

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Try this 3.6

Regulating blood water levels

Using the information provided in this chapter, construct a flow chart showing the stimulus–response model in action for negative feedback regulation of high water levels in the blood (blood becomes too dilute). Ensure your flow chart features all the stages: stimulus, receptor, control centre, effector, response and negative feedback.

Osmoregulation in response to dehydration is controlled by antidiuretic hormone (ADH), which is formed in the hypothalamus but stored in the pituitary gland. Many body systems are involved in the process:

1. Osmoreceptors in the hypothalamus (CNS) detect low blood water levels (the stimulus).
2. The hypothalamus triggers the pituitary gland (the effector; CNS) to release ADH.
3. ADH is carried by the blood (circulatory system) to the kidneys.
4. ADH increases the ability of the kidney tubules (excretory system) to reabsorb water and return it to the blood.
5. This response causes water levels in the blood to increase, and return to their normal level, completing the negative feedback loop.

Figure 3.36 shows a dehydration colour chart. By matching the colour of urine to the chart, you can tell whether you are dehydrated.

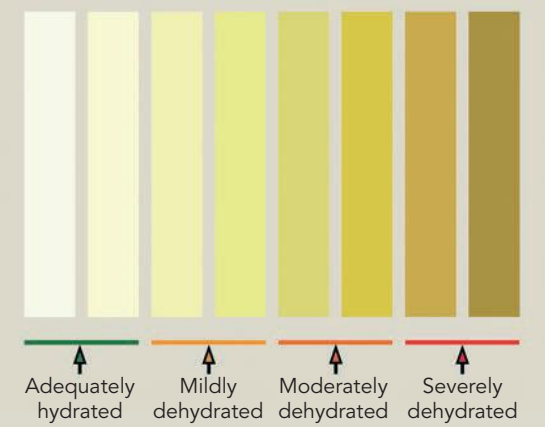


Figure 3.36 The dehydration colour chart. The colour of urine indicates how concentrated it is, and therefore how dehydrated a person is.

Quick check 3.8

1. **Recall** the organs that are involved in excretion of wastes.
2. **State** two functions of the excretory system.
3. **Recall** what ADH stands for and its role in osmoregulation.
4. **State** the part of the brain that monitors blood water concentration.

Regulating blood glucose levels

insulin a hormone secreted by the pancreas that triggers cells to take up glucose from the bloodstream and the liver, which is then stored as glycogen, lowering blood glucose levels

glucagon a hormone secreted by the pancreas that triggers the liver and muscle cells to convert glycogen into glucose, raising blood glucose levels

Body cells function best when conditions are stable within narrow physical and chemical ranges, and one of the substances that needs to be highly regulated is the concentration of glucose in blood. Your brain requires a constant glucose supply and is highly sensitive to changes in blood glucose levels, as both high and low blood glucose levels can have serious consequences on the body. The pancreas is the endocrine gland that acts as both the receptor and the control centre in regulating blood glucose levels.

Negative feedback mechanisms play a crucial role in maintaining blood glucose levels. These are controlled by the opposite actions of two pancreatic hormones. **Insulin** is released by the pancreas when blood glucose levels are high. Insulin signals the liver, muscle and adipose (fat) tissue to take up glucose and store it as glycogen or fat, decreasing the concentration of glucose in the blood. **Glucagon** is secreted by the pancreas when blood glucose levels are low. Glucagon signals the liver to break down glycogen and release glucose back into the bloodstream, increasing the concentration of glucose in the blood (see Figures 3.37 and 3.38). Once blood sugar levels return

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to normal, negative feedback mechanisms signal the pancreas to reduce glucagon secretion, preventing blood sugar levels from rising too high. This balance of insulin and glucagon secretion is critical for maintaining stable blood glucose levels and preventing the harmful effects of hyperglycaemia (high blood sugar) and hypoglycaemia (low blood sugar).

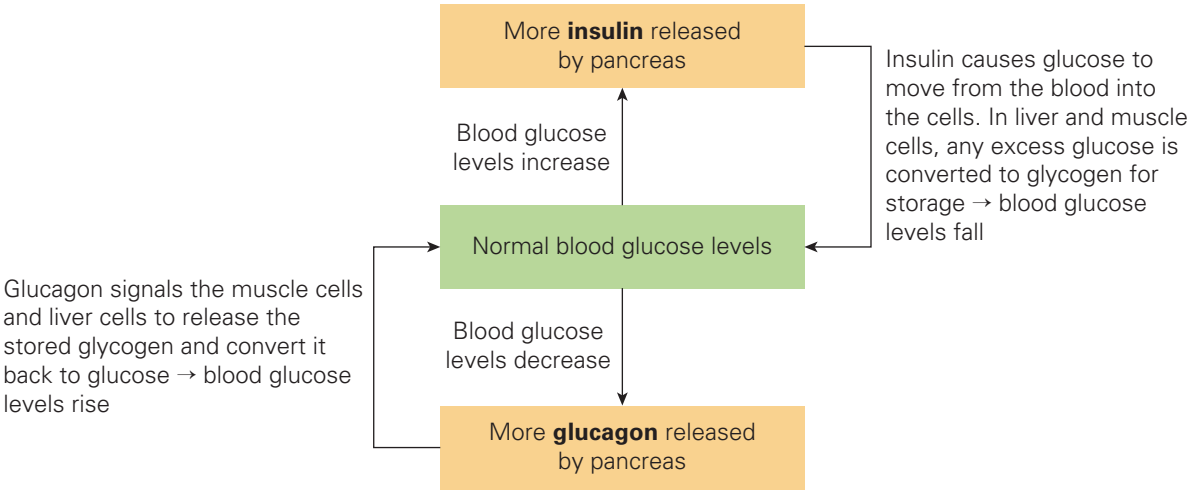


Figure 3.37 A flow chart showing how insulin and glucagon maintain stable blood glucose levels

In cases of hyperglycaemia, there is an excess of glucose in the bloodstream. Over time, this can cause damage to blood vessels, nerves and organs, leading to complications such as cardiovascular disease, kidney disease and vision problems. Hypoglycaemia occurs when glucose levels drop too low, which can result in symptoms such as confusion, dizziness and fainting. If left untreated, severe hypoglycaemia can lead to seizures, coma and even death.

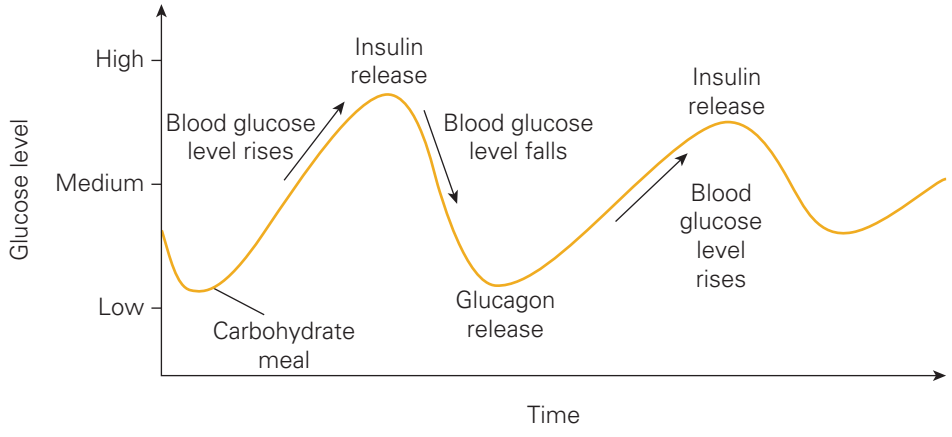


Figure 3.38 After a carbohydrate-rich meal, insulin levels in the bloodstream increase because the body needs to decrease the blood glucose levels.

Try this 3.7

Regulating blood glucose levels

Using the information provided in this chapter, construct a flow chart showing the stimulus–response model in action for negative feedback regulation of blood glucose levels. You may choose either scenario: blood sugar levels are too high or blood sugar levels are too low. Ensure your flow chart features all the stages: stimulus, receptor, control centre, effector, response and negative feedback.

Extension: Try to draw a double loop that shows both scenarios.

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Explore! 3.4

Diabetes

Diabetes is a medical condition where the body does not produce enough insulin or the body cells become resistant to insulin over time. It has become increasingly common in the Australian population, due in part to some lifestyle factors. Conduct some research to answer the following questions.



Figure 3.39 Adhesive patches can be used to continuously monitor blood sugar levels.

1. Contrast type 1 and type 2 diabetes.
2. Who is normally affected by each type of diabetes and at what age is it typically diagnosed?
3. How is each type of diabetes treated?
4. What are some of the factors that predispose people to developing diabetes?
5. Conduct some research on some of the new technologies that are being developed to support people with diabetes. You may want to consider new insulin pumps, infusion devices, continuous glucose monitors and smartphone apps.

Quick check 3.9

1. After a meal rich in simple carbohydrates, your blood glucose levels rise sharply. **Recall** the hormone that is released by the pancreas to decrease the levels.
2. **Define** 'hypoglycaemia'.
3. **Outline** the role that glucagon plays in the body.

Explore! 3.5

Diabetes-induced blindness

Disorders in feedback systems can lead to diabetes-induced blindness through a process called diabetic retinopathy. In diabetes, the high levels of glucose in the blood can damage the blood vessels throughout the body, including those in the retina of the eye.

The retina is a layer of tissue in the back of the eye that is responsible for transmitting visual signals to the brain. The blood vessels in the retina can become damaged due to high blood sugar levels. The small blood vessels in the retina become weakened and leak fluid, leading to swelling and eventually scarring. As the condition progresses, new blood vessels may grow to compensate for the damage, but these vessels are often weak and prone to bleeding, which can further damage the retina and lead to vision loss.

Disorders in feedback systems, such as those that regulate blood sugar levels, can exacerbate the development of diabetic retinopathy. Poorly controlled blood sugar levels can accelerate the progression of the condition, making it more likely that a person with diabetes will develop blindness.

Complete some research to find out why people with diabetes also have to be careful about their foot care.

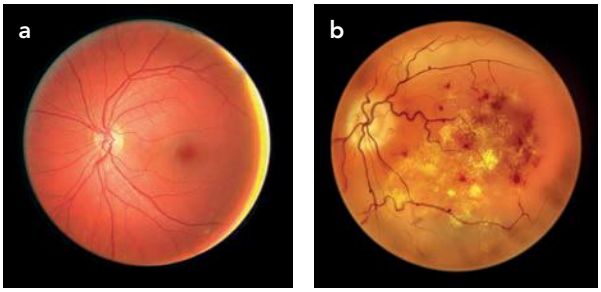


Figure 3.40 (a) A normal retina and **(b)** a retina damaged from diabetes

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Regulating hunger

The two key hormones involved in regulating hunger are ghrelin and leptin. Ghrelin is produced by the stomach and stimulates hunger by increasing appetite and food intake. When the stomach is empty, ghrelin levels rise, signalling to the brain that the body needs food. Ghrelin then activates certain brain regions involved in appetite regulation, including the hypothalamus, which triggers the release of chemicals that increase appetite and food intake.

Ghrelin levels fluctuate throughout the day, with the highest levels typically occurring before meals and the lowest levels occurring after meals. Leptin is produced by fat cells (in adipose tissue) and signals to the brain that the body has enough energy stores, suppressing appetite and promoting energy expenditure (see Figure 3.41).

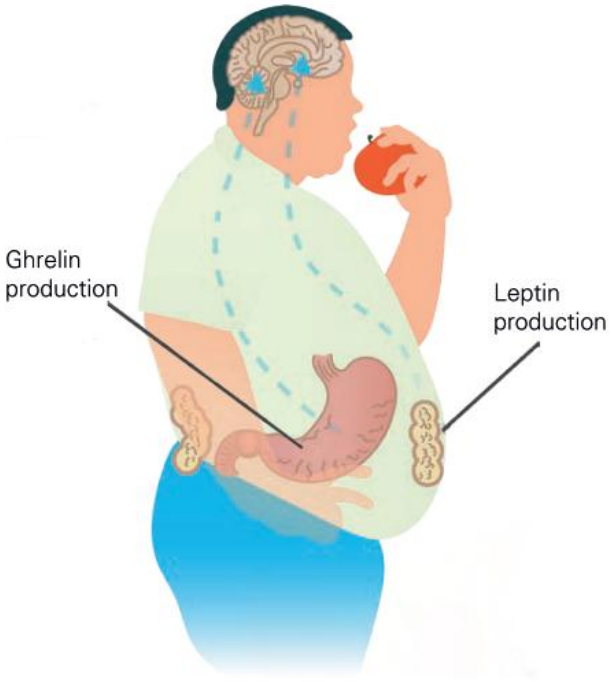


Figure 3.41 Ghrelin is produced by the stomach, and leptin is produced by fat cells.

Did you know? 3.6

Improving body performance

The understanding of feedback mechanisms has enabled pharmaceuticals and other products to be developed that address various health issues and enhance performance. For example, scientists have developed synthetic insulin that mimics the natural hormone's actions to help people with type 1 diabetes maintain healthy blood glucose levels.

Similarly, sports drinks often contain electrolytes such as sodium, potassium and magnesium, which are essential for maintaining proper hydration and electrolyte balance during exercise. The feedback mechanism involving the kidneys and hormones such as aldosterone helps regulate electrolyte levels in the body. Understanding these mechanisms has enabled the development of sports drinks that help enhance athletic performance by promoting proper hydration and electrolyte balance.



Figure 3.42 Insulin is injected into the body by a person with type 1 diabetes.

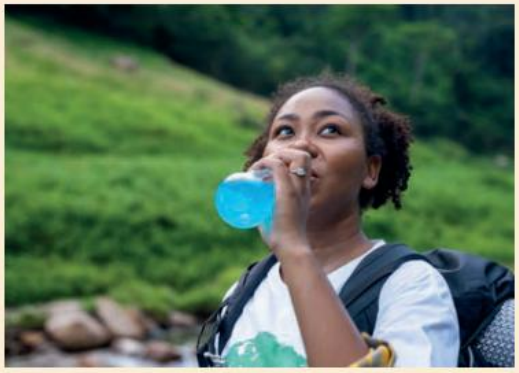


Figure 3.43 An electrolyte drink may help keep you hydrated when out hiking.

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Regulating blood pressure

The homeostatic control of blood pressure is essential for survival. Both high and low blood pressure can be dangerous, resulting in damage to internal organs or even loss of consciousness. To maintain blood pressure within a safe range, the heart and blood vessels contain specialised pressure receptors called baroreceptors, which detect changes in blood pressure.

When blood pressure is too low, the brain stem receives signals from the baroreceptors and sends signals to the heart to increase its rate and to the blood vessels to constrict, raising blood pressure. Conversely, when blood pressure is too high, the brain stem sends signals to the heart to slow down and to the blood vessels to dilate, thereby lowering blood pressure.

The kidneys and antidiuretic hormone (ADH) are also involved in maintaining the homeostasis of blood pressure. The kidneys play a crucial role in regulating blood pressure by controlling the water balance in the body. When blood pressure is too high, the kidneys respond by decreasing the reabsorption of water, leading to increased urine production. This helps to eliminate excess water from the body, subsequently reducing blood volume and lowering blood pressure.

When blood pressure is low, ADH increases the kidneys' permeability to water, allowing them to reabsorb more water into the bloodstream. This reduces urine production and helps to conserve water in the body, increasing blood volume and raising blood pressure.

Did you know? 3.7

Measuring blood pressure

Blood pressure monitors work by measuring the force of blood against the walls of the arteries as it circulates through the body. There are two main types of blood pressure monitors: manual and electronic.

Manual blood pressure monitors, also known as sphygmomanometers, have a cuff that is wrapped around the upper arm and inflated until it stops blood flow. The healthcare professional listens to two sounds in the artery as the cuff deflates. The first sound shows the pressure when the heart contracts and the second sound shows the pressure when the heart is at rest.

Electronic blood pressure monitors, also known as digital or automatic blood pressure monitors, use an electronic sensor to detect the vibrations of blood flow through the brachial artery. The cuff is wrapped around the upper arm and inflated automatically by the device. As the cuff deflates, the device measures the vibrations caused by blood flow and converts them into digital readings that display on a screen.



Figure 3.44 A patient measuring their own blood pressure with an electronic blood pressure monitor

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Explore! 3.6

Controlling iron levels

Iron is a vital nutrient that is necessary for many biological processes, including oxygen transport and DNA synthesis. However, excess iron can be toxic to the body, so it is essential to maintain iron levels within a narrow range.

The body's negative feedback mechanisms regulate iron levels through the hormone hepcidin, which is produced in the liver. Hepcidin binds to ferroportin, a protein on the surface of cells that moves iron from the cell into the bloodstream. The binding of hepcidin causes ferroportin to degrade, which reduces the amount of iron that is released into the bloodstream.

When iron levels in the blood are low, the body produces less hepcidin, which allows ferroportin to move more iron into the bloodstream, increasing iron levels. Conversely, when iron levels are high, the body produces more hepcidin, lowering iron levels.

This negative feedback loop helps to maintain balance in internal iron levels by regulating the amount of iron that is absorbed from food and the amount that is released from iron stores in the body, such as the liver and the spleen.

In addition to hepcidin regulation, the body has other mechanisms to control iron levels, such as iron-binding proteins, which bind to excess iron and prevent it from causing damage to tissues and organs.

Complete some research to determine why adolescent girls are at a higher risk of having an iron deficiency.



Figure 3.45 Extreme fatigue and weakness are common symptoms of iron deficiency.

Try this 3.8

Regulating blood pressure

Using the information provided in this chapter, construct a flow chart showing the stimulus–response model in action for negative feedback regulation of blood pressure. You may choose either scenario: blood pressure is too high or blood pressure is too low. Ensure your flow chart features all the stages: stimulus, receptor, control centre, effector, response and negative feedback.

Then, convert your flowchart into an interactive presentation using slideshow/animation software. Users should be able to navigate through each step to explore how the body regulates blood pressure via negative feedback.

Extension: Try to draw a double loop that shows both scenarios.

Quick check 3.10

1. **Recall** the location of the baroreceptor sites that detect changes in blood pressure.
2. Other than the heart, **name** an organ that is involved in maintaining blood pressure.
3. **Recall** what parts of the body produce leptin and ghrelin.

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Practical 3.2

Exercise, heart rate and breathing rate

Your body's energy needs vary according to how active you are. When you are resting, you require less energy, so you consume less oxygen. During exercise, your respiratory and circulatory systems must work together to meet your increased energy needs.

As you exercise, your large muscle groups contract harder and more frequently, which requires energy. The cells require more oxygen because it is a required reactant of **cellular respiration** (breaking down glucose to release energy). This increased oxygen demand is achieved by:

- increasing your respiratory rate (breaths per minute) – breathing harder and faster means more oxygen can enter the bloodstream and you can also exhale more carbon dioxide
- increasing your heart rate and blood pressure – this pumps the oxygen faster to the cells.

cellular respiration the chemical process through which cells release energy by converting glucose and oxygen into carbon dioxide and water

Aim

To investigate the effect of low- and high-intensity exercise on heart rate and breathing rate

Materials

- stopwatch
- calculator
- (optional) sporting watch/device that can record pulse in bpm, or a pulse oximeter

Method

1. Construct a specific and relevant research question based on the experimental method.
2. Copy the following results table.
3. Measure your partner's resting heart rate by placing your index and middle fingers on the inside of their wrist (see Figure 3.46). Using the stopwatch, count the number of beats in a 15-second period. (Optional: Wear a heart-rate monitor.)
4. Get your partner to count how many times they take a breath in this 15-second period.
5. Multiply both numbers by 4 to get heart rate (beats per minute) and breathing rate (breaths per minute). Record these in the table.
6. Instruct your partner to walk at their usual pace outside for a 2-minute period (low intensity). Then, immediately measure your partner's heart rate and get them to count how many times they take a breath in a 15-second period.
7. Multiply both values by 4 and record this in the table.
8. Measure the heart rate and breathing rate twice more: once 1 minute after they stopped walking and once 2 minutes after.
9. Instruct your partner to run around outside for a 2-minute period (high intensity). Then, immediately measure their heart rate and get them to count how many times they take a breath in a 15-second period.
10. Multiply both values by 4 and record this in the table.
11. Measure the heart rate and breathing rate twice more: once 1 minute after they stopped running and once 2 minutes after.



Figure 3.46 How to measure heart rate

continued …

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Results

Copy and complete the following table.

Table showing change in heart rate and breathing rate in response to exercise

Time after exercise (min)	Heart beats in 15 s	Heart rate (bpm)	Breaths in 15 s	Breathing rate (breaths per minute)
At rest (resting)				
Low-intensity exercise (2-minute walk)				
0				
1				
2				
High-intensity exercise (2-minute run)				
0				
1				
2				

Using Excel or graph paper, construct a graph showing the change in breathing rate and heart rate per minute when performing low-intensity and high-intensity exercise.

Discussion: Analysis

1. Describe any trends, patterns or relationships in your results.
2. Explain your results (both heart rate and breathing rate) with reference to the homeostatic mechanisms occurring in the body.
3. Compare how long it took for the heart rate and breathing rate to return to rest after low-intensity and high-intensity exercise.

Discussion: Evaluation

1. Discuss any potential sources of error in this experiment.
2. Propose at least two improvements to this experiment.

Conclusion

1. Make a claim regarding exercise intensity and the effects on heart rate and breathing rate.
2. Support your claim by referring to your experimental data, and include potential sources of error.
3. Explain how the data supports your claim.

Extension

1. Create your own experiment that measures the effect of low- and high-intensity exercise on heart rate and breathing rate.



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Two systems working together

Homeostasis is maintained by the endocrine and nervous systems working together. The nervous system plays the primary role in controlling and coordinating most actions of the human body. It works in partnership with the endocrine system, which produces particular hormones that are released into the bloodstream in response to external or internal changes.

The two systems work as a team by using chemical messengers and electrical impulses to communicate with cells and glands. The speed of message transmission and the length of the effects differ between the two systems: the nervous system provides fast-acting, short-lasting effects and the endocrine system triggers slow-acting, long-lasting effects.

The endocrine and nervous systems work in a coordinated way with all the other body systems to maintain a relatively stable internal environment and protect the body from harm.

The key differences between the features of the endocrine and nervous systems are summarised in Table 3.6.

Feature	Nervous system	Endocrine system
Signals	Electrical impulses along an axon, and chemical messages via neurotransmitters across synapses	Chemical messengers (hormones)
Pathway	Transmission by neurons in the nervous system	Transported in the bloodstream (circulatory system) and lymph (lymphatic system)
Speed of information transfer	Fast	Slow
Duration of effect	Short-lived	Typically longer-lasting
Type of action and response	Voluntary or involuntary	Involuntary
Target cells	Localised cells	Systemic (many cells may be affected)
Example of action	A friend throws a ball towards you. Your sensory receptors capture the visual stimulus, and relay the message to your brain via a network of sensory neurons. Messages are conveyed by interneurons through the CNS. Motor neurons branching from the spinal cord to the muscles stimulate the muscle to contract, and you reach out and catch the ball.	When a male reaches puberty, the pituitary gland secretes a hormone called luteinising hormone. This acts on the testes and stimulates them to release testosterone. As the amount of testosterone builds up, it triggers sperm production, muscle development, hair growth and changes to the voice.

Table 3.6 A comparison of the nervous and endocrine systems

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Section 3.3 review

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Section 3.3 questions

Remembering

1. **Name** two endocrine glands in the brain.
2. **Recall** how hormones reach their target cells.
3. **Recall** the hormones secreted by the pancreas and what effect they have.

Understanding

4. **Explain** the difference in the speed of transmission within the nervous system as compared to the endocrine system.

Applying

5. **Construct** a Venn diagram that shows the similarities and differences between the nervous and endocrine systems.

Analysing

6. The graph in Figure 3.47 shows the results of a glucose tolerance test for two patients, A and B. Use data from the graph to **identify** which patient has diabetes.
7. A person who has undergone a serious and lengthy surgical operation stands up for the first time after the surgery. They lost a significant amount of blood during the procedure and their blood pressure is low, making them feel dizzy. **Construct** a stimulus–response model showing the steps the body would take to address this deviation from normal blood pressure.

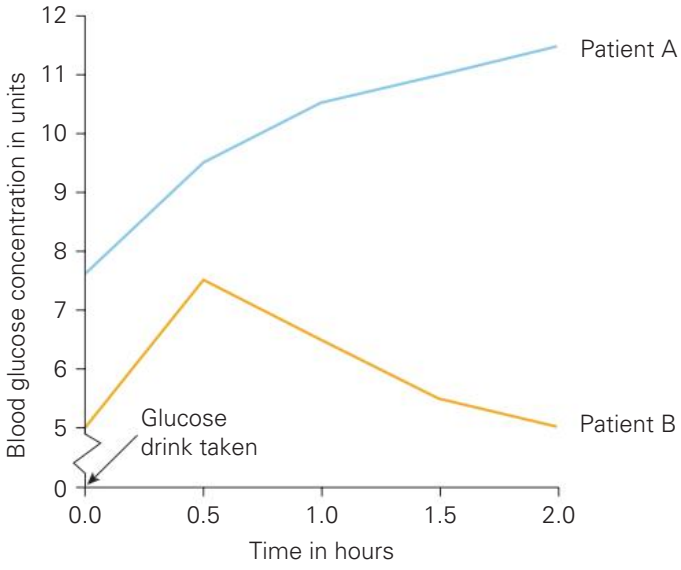


Figure 3.47 Blood glucose concentration over time for Patients A and B

Evaluating

8. The contraceptive pill contains a chemical that acts like the hormone oestrogen. The pill must be taken daily by women to be effective at preventing pregnancy. It attempts to stop sperm reaching an egg in several ways, including:
   - suppressing ovulation so an egg is not released from the ovaries
   - making the cervical mucus thicker so that it becomes more difficult for sperm to reach an egg
   - decreasing the thickness of the lining of the womb so it is not thick enough for an egg to attach to it.

   Deduce some reasons why the pill is *not* guaranteed to work 100% of the time.

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Chapter review

Chapter checklist

Success criteria		Linked questions
3.1	I can describe how the body responds to external and internal stimuli.	1, 2, 13b
3.1	I can describe the relationships between body systems that are necessary to coordinate a response to stimuli.	10
3.1	I can explain how the process of regulation is monitored and adjusted by connections between the receptor, command centre and effector.	7, 11
3.1	I can describe how positive feedback mechanisms maintain the direction of a stimulus and accelerate its effect.	17
3.2	I can describe the role and function of electrical impulses in the body's responses to internal and external stimuli.	3, 4, 5, 8, 9, 12, 13a, 15
3.3	I can describe the role and function of hormones in the body's responses to external stimuli.	12
3.3	I can describe how negative feedback mechanisms serve to maintain balance in internal systems.	14, 16a
3.3	I can describe the effects of a disorder in a feedback system.	6, 16b

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

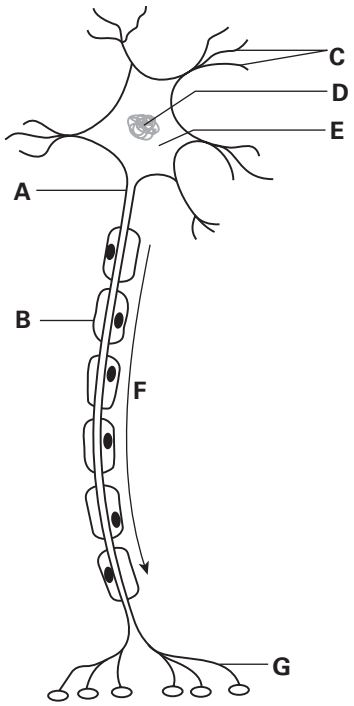
Remembering

1. **Define** 'homeostasis'.
2. A professional hockey player loses several litres of water during the game. **Recall** two homeostatic responses their body would use to retain water and maintain blood pressure.



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3. **Name** the key structures A–G of the following neuron.



Understanding

4. **Describe** a synapse.
5. **Describe** the steps involved in neurotransmission across a synapse.

Applying

6. **Describe** how a disorder in a feedback system can lead to hypothermia.
7. **Explain** how the process of regulation is monitored and adjusted by connections between the receptor, command centre and effector.

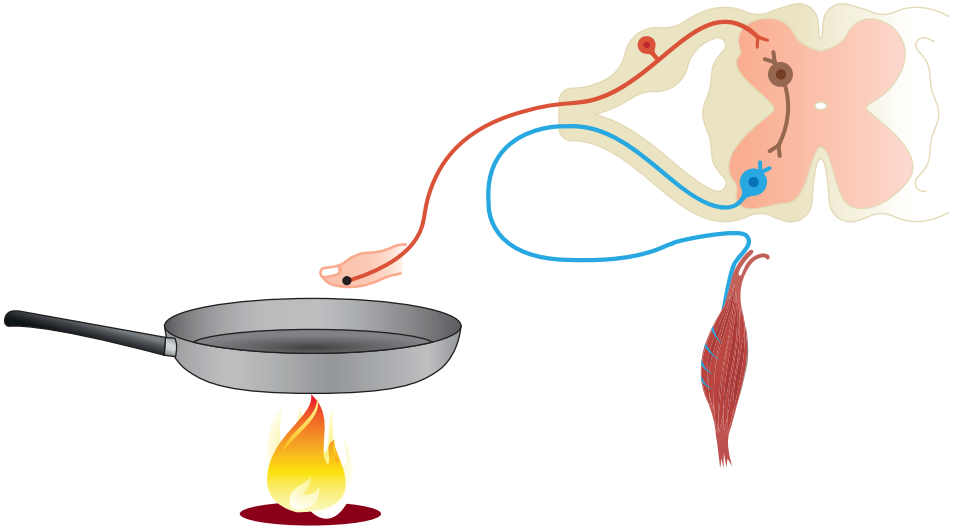
Analysing

8. **Compare** the somatic and autonomic divisions of the nervous system.
9. **Classify** the following events as being under somatic or autonomic control.
   a) Sweating
   b) Walking
   c) Lacrimation
   d) Contractions of the intestine to move food along
10. **Summarise** how the digestive, circulatory and respiratory systems interact with each other.
11. **Categorise** the following organs as receptors or effectors.
   a) Hypothalamus
   b) Mechanoreceptors
   c) Liver
   d) Kidney tubules
   e) Pancreas
   f) Skeletal muscles
12. **Compare** the role and function of electrical impulses and hormones in the body's responses to external stimuli.

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13. Sophia accidentally touches a hot pan and automatically snatches her hand away from it. The diagram shows the structures involved in this action.

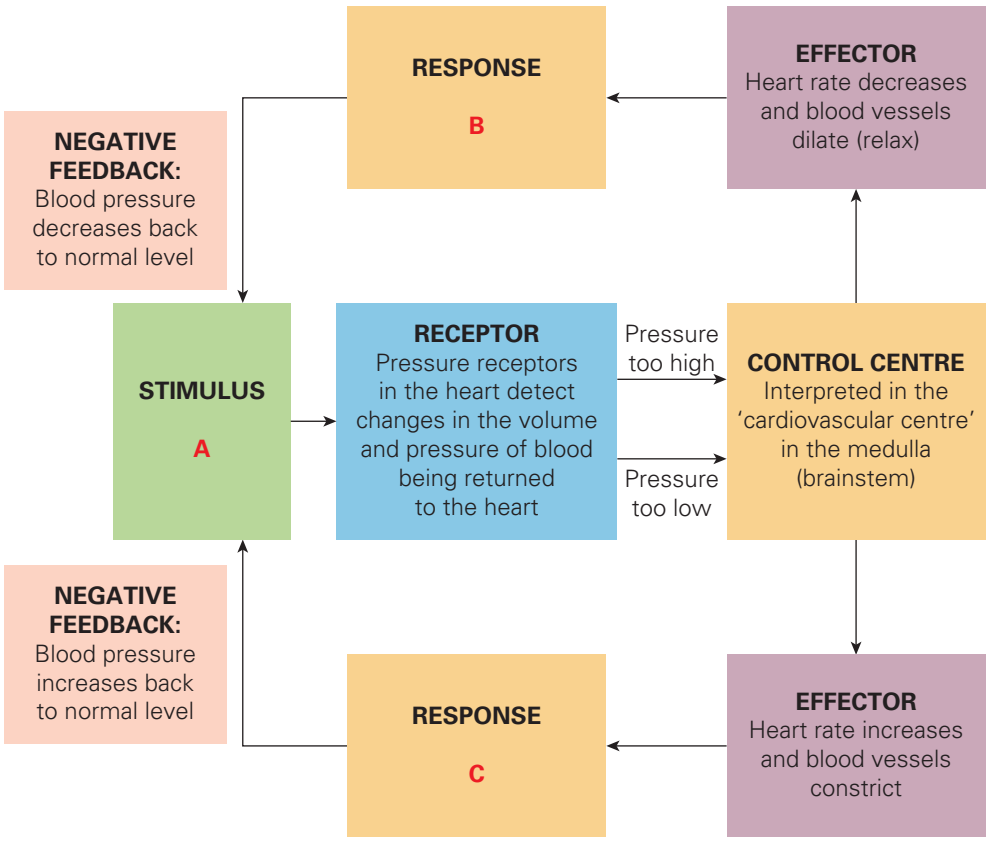
a) **Identify** the structures and label the diagram below.



b) **Contrast** Sophia's response with when she uses an oven mitt to pick up the pan.

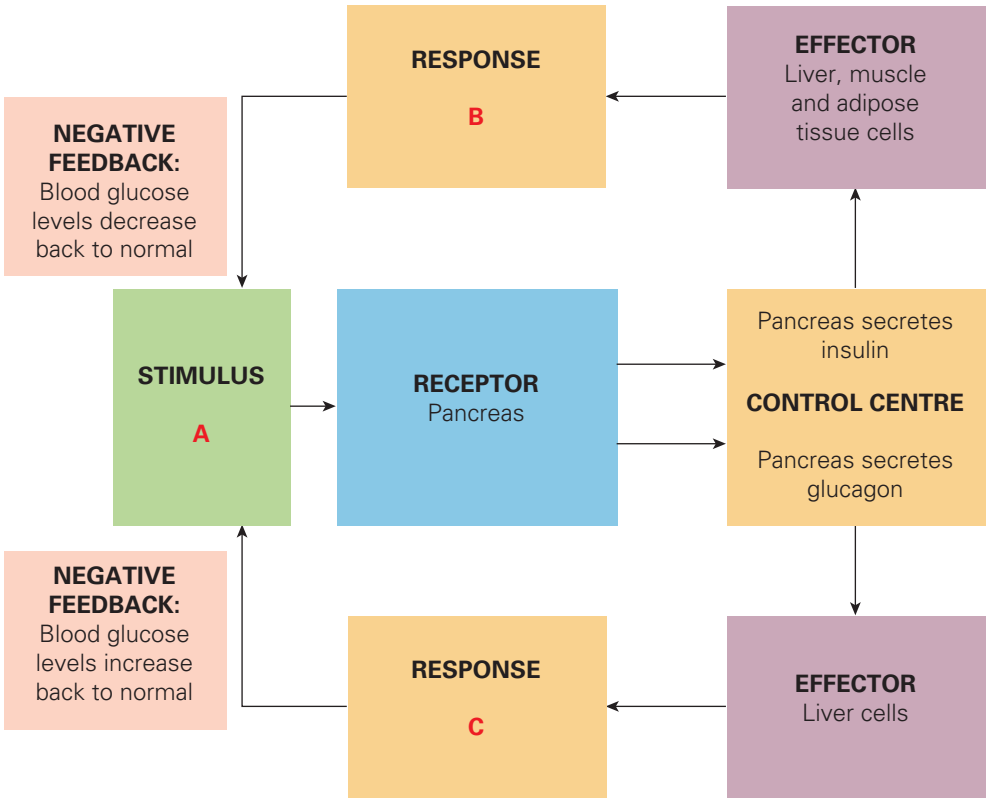
14. Copy and complete the flow charts to **compare** how the body responds to each of the following scenarios. You can do this by **identifying** what the letters represent.

a) High blood pressure versus low blood pressure

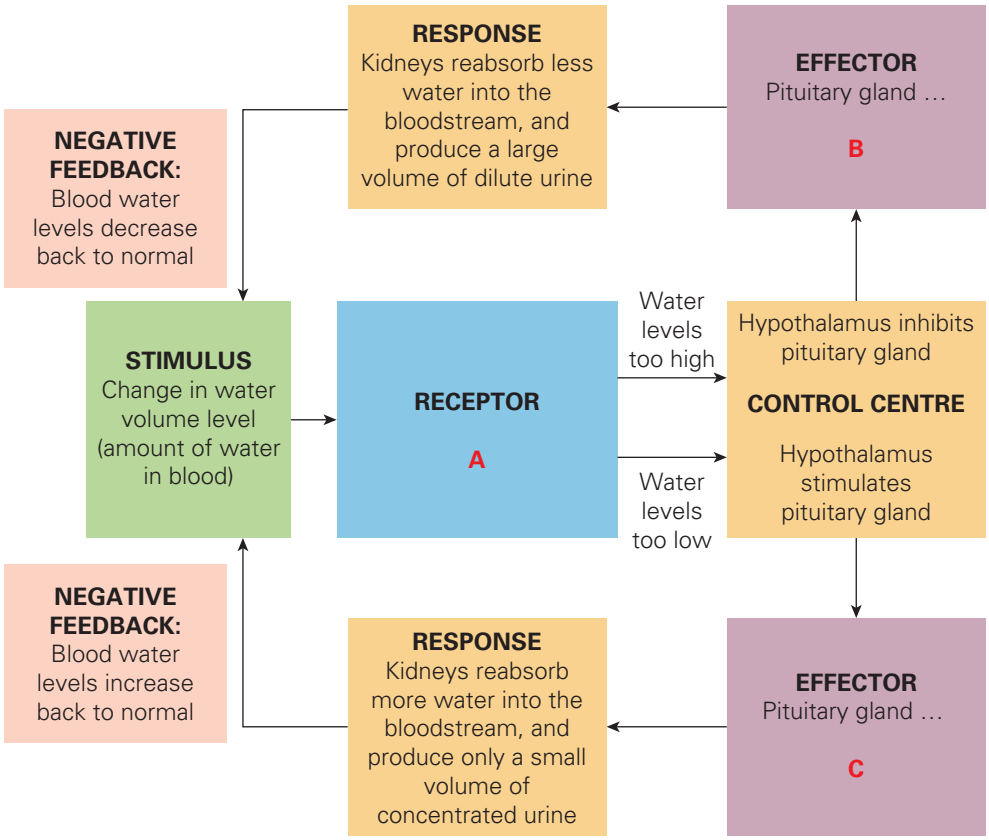


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b) High blood glucose levels versus low blood glucose levels



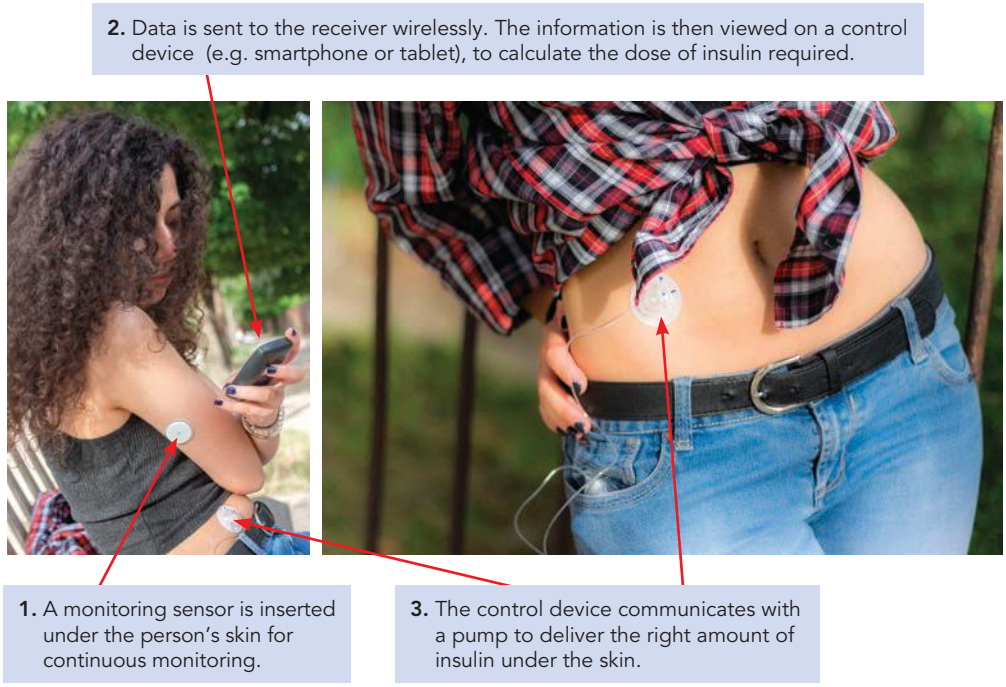
c) High levels of water in the blood versus low levels of water (dehydration)



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Evaluating

15. If a particular drug blocked the receptor sites on the dendrites of the postsynaptic neuron, **propose** how this may affect the neurotransmitters.
16. People with type 1 diabetes inject insulin to control their blood glucose level. A pancreas transplant is another treatment for type 1 diabetes. One risk of a pancreas transplant is organ rejection, because the body recognises the transplanted organ as 'non-self'. Scientists have developed an artificial pancreas to treat type 1 diabetes; however, it is still at early stages of commercial use. The figure below shows how an artificial pancreas works.



A woman with type 1 diabetes has an artificial pancreas. The woman eats a meal that causes her blood glucose level to rise sharply.

a) **Discuss** the steps that would occur to return the blood glucose levels to normal.
b) Assess some problems that could arise if using the artificial pancreas system above and **decide** whether it is a viable solution for individuals with type 1 diabetes.

17. **Decide** why positive feedback is important in childbirth.



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Data questions

A Year 9 student with diabetes measures their blood sugar level hourly and the data is plotted in blue in Figure 3.48. Another student, who does not have diabetes, also measures their blood sugar as a comparison, and this is plotted in orange. The students are careful to eat the same three meals on this day – breakfast, lunch and dinner at the same time – and the student with diabetes injects insulin after each meal.

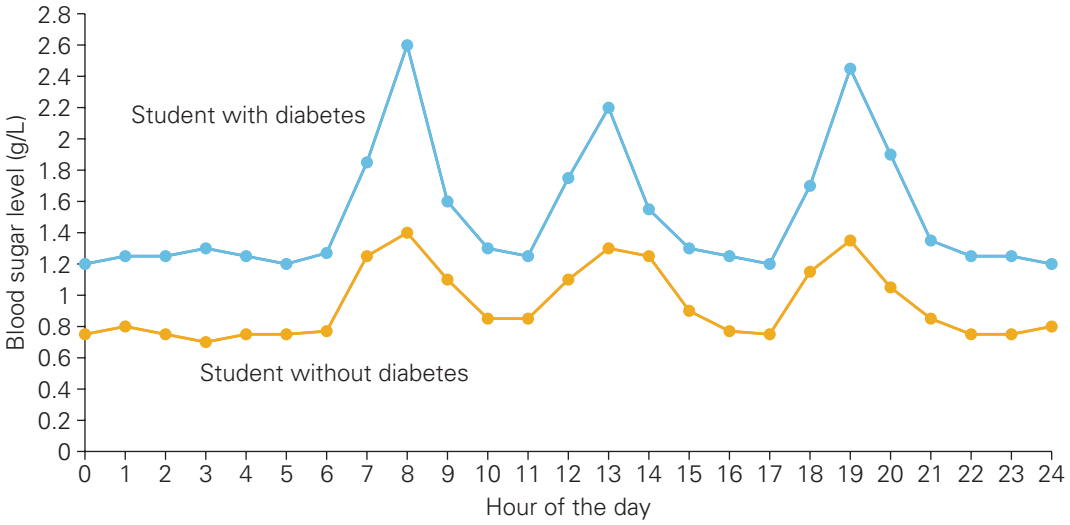


Figure 3.48 Relative blood sugar level over a 24-hour period

Applying

1. **Identify** the homeostatic (steady state) blood sugar level for each student.
2. **Determine** the times that the students ate breakfast, lunch and dinner.
3. **Recognise** the peak blood sugar level for both students on this day.

Analysing

4. **Identify** any patterns or trends that appear in the data.
5. **Contrast** the change in blood sugar level after each meal and provide a reason for the difference.

Evaluating

6. **Infer** a reason for the lower peak in blood sugar for the student with diabetes after eating lunch than after the other meals.
7. **Justify** whether the comparison of data would be valid if the students ate different meals on this day.
8. After the student with diabetes ate dinner, **deduce** the time that insulin was injected into the bloodstream.
9. **Predict** what would happen to the plotted data if the student with diabetes did not use insulin directly after the breakfast meal.

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STEM activity: Texting and reaction times – what do the numbers say?

Background information

Reacting to a stimulus may appear to be an automatic process, but it actually involves the coordination of the various receptors in our body with the brain. To illustrate this, consider a scenario where you are in a car with your friend, when suddenly a dog runs in front of the car. Your friend quickly reacts by pressing the brake pedal, and the dog escapes unharmed.

During this process, the light receptors in your eyes detect the sudden change in lighting conditions on the road and send this information for processing to the brain. The brain then determines if any action is necessary based on this information. Your friend's brain compares the data from the light sensors with a vast collection of images in their memory and determines that the object in front of the car is likely to be a dog. The brain then sends signals through the nervous system to specific muscles, causing your friend to press the brake pedal.

This entire process takes around 0.25 seconds on average, but the speed may vary depending on levels of alertness. For instance, if your friend was distracted by texting while driving, the outcome could have been different.

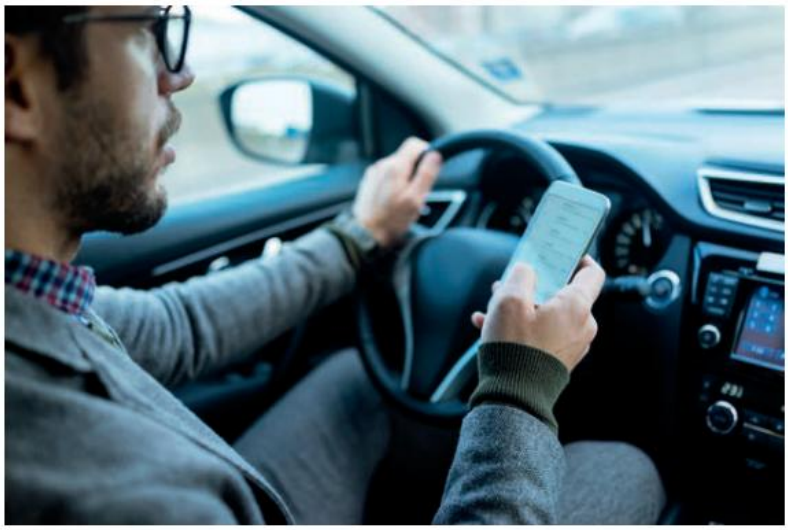


Figure 3.49 In Victoria, it is illegal to use a mobile phone while driving. The penalty is a fine of $593 and four demerit points added to your traffic history. This applies even if you are stopped at traffic lights or in traffic.

DESIGN BRIEF

Investigate whether texting is a distraction to people performing tasks.

Activity instructions

In this activity, you will use materials and your imagination to create an experiment that produces:

- at least three sets of data
- at least three bar graphs
- a conclusion that clearly responds to the following scenario.

The Department of Transport and Main Roads in Queensland has concerns about young people's attitudes towards texting while driving. They have hired your start-up company to carry out a series of experiments in the community to investigate whether texting can impair a person's reaction time.

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Suggested materials

- 30 cm ruler
- scissors
- cardboard
- paper
- pen
- mobile phone to record slow-motion videos
- Microsoft PowerPoint, Google slides or Apple Keynote for presentations
- video-editing software for making short documentaries

Research and feasibility

1. Conduct some research and make a list of the factors that influence a person's reaction time.
2. Create a table like the one below, and make predictions of how these factors will decrease or increase a person's reaction time. An example has been provided for you.

Factor	Reaction time effect	Reason
Being tired	Decrease reaction time moderately	When a person is tired, they have a decreased ability to absorb information, which decreases reaction time.

3. Discuss in your group, then list the important information you will need to record about your participants whose reaction times will be tested. Hint: Make sure you have thought about all the factors that might affect a person's reaction time, such as sleep, exercise and video game playing.

Design and sustainability

4. Using the materials on the material list, design a way to test the effect of texting on a teenager's reaction time.
5. Design a table that includes information about each participant's recorded information.

Create

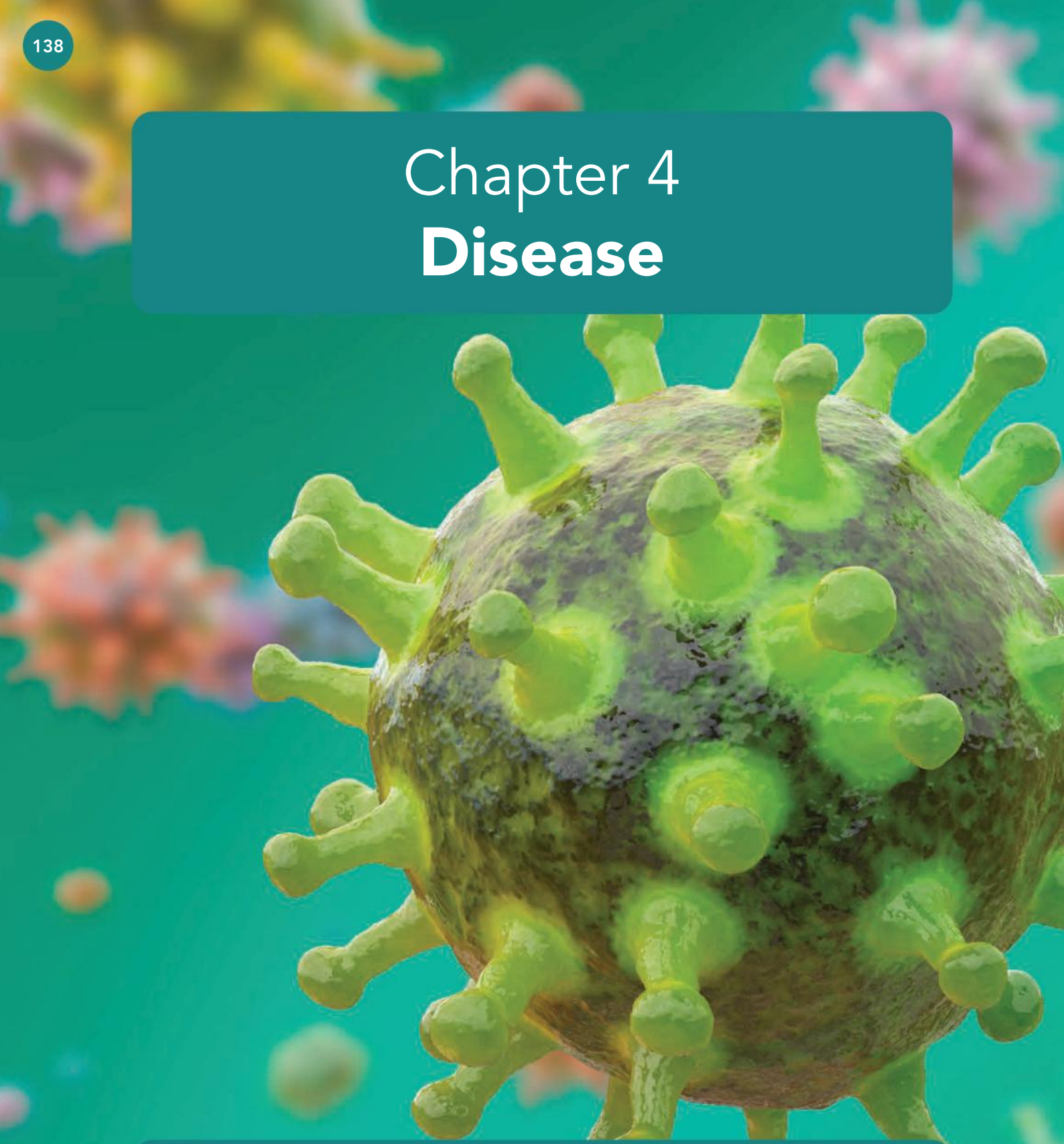
6. Perform your experiment, making sure you collect multiple sets of data for each participant and their important information.

Evaluate and modify

7. Discuss with your group the challenges you have encountered throughout this project. List the strategies or actions that allowed you to overcome each challenge.
8. Reflection is an integral and vital aspect of any project in the real world. How could you use digital tools (e.g. apps, video or slow-motion camera) to enhance this experiment?
9. If using a ruler for testing reaction times, the results may change depending on the type of ruler used, such as metal, plastic or timber. In this case, predict how the size or length of the ruler, and whether the dominant or non-dominant hand was used, might have affected the results.
10. Consider adding other distracting sounds and sights during the activity, such as turning on a TV set or flicking a torch on and off. Does response time slow when there are multiple sensory signals?
11. Create a graphical representation of your results and present them to the class like you would if you were presenting to the Queensland Department of Transport and Main Roads.

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Chapter 4
Disease



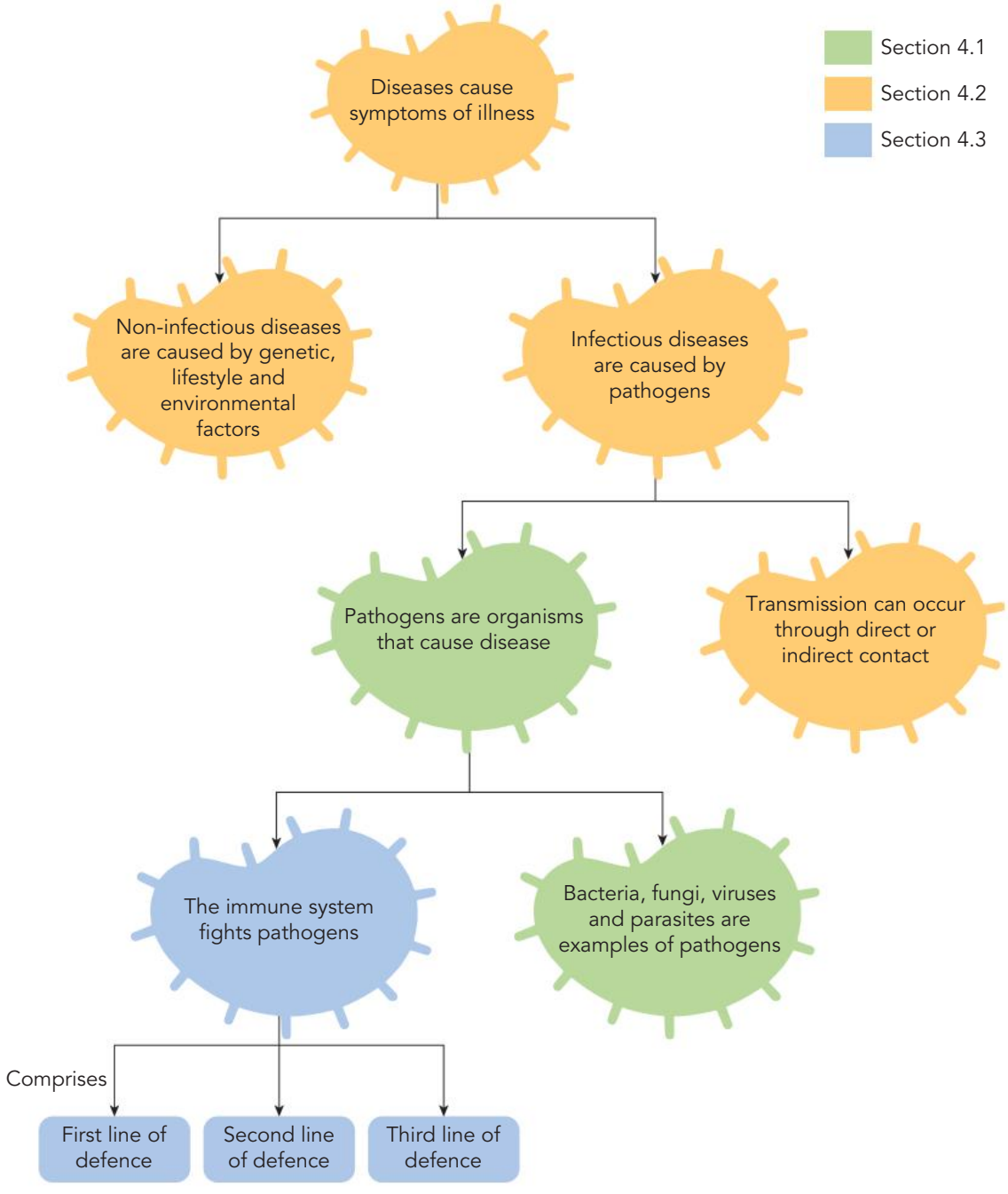
Chapter introduction

Through all stages of life, people encounter illness. Disease comes in many forms: from the common cold to cancer, everyone is at risk. In this chapter, you will learn to distinguish between infectious and non-infectious diseases. Throughout the chapter, you will explore different examples of infectious and non-infectious diseases and their causes. You will also consider the different ways in which infectious diseases can spread in a population and how to combat disease transmission to prevent epidemics or pandemics.

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Concept map



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Curriculum content

infectious and non-infectious diseases are caused by different organisms and agents; measures to control the transmission of infectious diseases include personal hygiene, quarantine protocols, medical treatment and public education programs (VC2S10U03)	
• differentiating between infectious diseases that are caused by different pathogens, such as tuberculosis (caused by bacteria), influenza (caused by viruses), candidiasis (caused by a fungus) and tapeworm infection (caused by a parasite)	4.1
• conducting an investigation to compare the effectiveness of handwashing by counting the number of bacterial colonies growing on agar plates	4.2
• visualising biological processes associated with diseases, such as viewing an animation about how a vaccine works or constructing a model to simulate blood flow in an artery blocked by cholesterol	4.2, 4.3
• exploring the data and rationale for different strategies to stop the spread of infectious diseases, such as handwashing, mask-wearing, isolation and surface disinfection	4.2
• researching how factors such as genetics, age, malnutrition, environment and lifestyle may cause non-infectious diseases such as cancer, asbestosis, Alzheimer's disease, diabetes and epilepsy	4.2
• researching the impact of diseases introduced with the arrival of Europeans to Australia, for example the severity of the impact of smallpox was partly because this virus was new to Aboriginal communities and so they lacked an immune response to it	4.3
• storyboarding for a social media clip that explains how healthy lifestyles may contribute to lower risk of non-infectious diseases	4.2

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Glossary terms

Antibiotic	Epidemic	Outbreak
Antibody	Fermentation	Pandemic
Antifungal	Fungi	Parasite
Antigen	Immune system	Pathogen
Antiseptic	Infection	Phagocytosis
Antiviral	Infectious disease	Prokaryote
Bacteria	Lymphocyte	Septic
Binary fission	Lysis	Transmission
Budding	Memory cell	Vaccine
Cilia	Microbe	Virus
Contagious	Non-infectious disease	
Disease	Normal flora	

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4.1 Pathogens

Learning goals

At the end of this section, I will be able to:

1. Define 'pathogen'.
2. Describe the different types of pathogens.
3. List examples of common pathogens.

VIDEO
Types of pathogens

Everyone has been sick at some point in their lives. Think about the last time you caught a cold or fell ill with food poisoning. This happened because a **microbe** with the ability to cause disease entered your body and started to multiply. Microbes are organisms that are too small to see with the naked eye, such as bacteria or fungi. Not all microbes are harmful; our gut is full of beneficial bacteria that help us to digest food.

microbe
an organism that is too small to see with the naked eye

disease
an illness that causes specific symptoms

pathogen
any organism that can cause disease, such as bacteria, viruses or fungi

Did you know? 4.1

Human cell composition

The adult body has around 30 trillion human cells and 39 trillion microbes. Although these numbers vary between individuals, on average this means we are made up of 43% human cells, with the rest being microscopic colonists.

Disease occurs when an organism displays symptoms of an illness. Microbes that have the ability to cause disease in humans are called **pathogens**. Pathogens make us sick by interfering with the normal functioning of our cells and tissues. They can do this by invading and destroying our cells or by releasing toxins that damage our tissues. For example, food poisoning is caused by eating food contaminated with large numbers of a bacterium called *Salmonella*. *Salmonella* releases toxins that damage the cells of the small and large intestine, causing abdominal cramps and diarrhoea.

WORKSHEET
Pathogens



Figure 4.1 A person with a cold experiences symptoms such as runny nose, sneezing and coughing.

Pathogens are categorised as either cellular or non-cellular. Cellular pathogens are living organisms made of cells, such as bacteria, fungi and parasites. Non-cellular pathogens include viruses, which are considered non-living because they are not made of cells. Individual pathogens within an infected individual reproduce very quickly under their optimum conditions and need to be destroyed as quickly as possible to avoid illness.

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Table 4.1 lists common diseases caused by bacteria, fungi, viruses and parasites.

Bacterial diseases	Fungal diseases	Viral diseases	Parasitic diseases
Tuberculosis	Candidiasis	Influenza	Tapeworm infection
Tetanus	Tinea	Common cold	Toxoplasmosis
Strep throat		HIV	Malaria
Syphilis		Chickenpox	
Pneumonia		Hepatitis	

Table 4.1 Examples of diseases caused by different types of pathogens

Try this 4.1

Symptoms of disease

Pick one example of each pathogen from Table 4.1 and research the symptoms associated with each.

Bacteria

bacteria (singular: bacterium) microscopic, unicellular (single-celled) organisms

prokaryote a cell that lacks membrane-bound organelles (such as a nucleus)

Bacteria (singular: bacterium) are simple unicellular organisms called **prokaryotes**. All bacteria lack membrane-bound organelles (see Figure 4.3), although some bacteria contain a cell wall. Individual bacteria cannot be seen with the naked eye, but a bacterial colony (group of millions of bacteria) will be visible if it contains enough bacteria. Scientists therefore need a microscope to study individual bacteria. The best light microscopes at school can magnify about 1000 times. Scientists generally use electron microscopes, which can magnify cells up to 500 000 times.



Figure 4.2 Coloured scanning electron micrograph (SEM) of *Escherichia coli* bacteria (pink) on a gecko's tongue. The magnification is 8000×.

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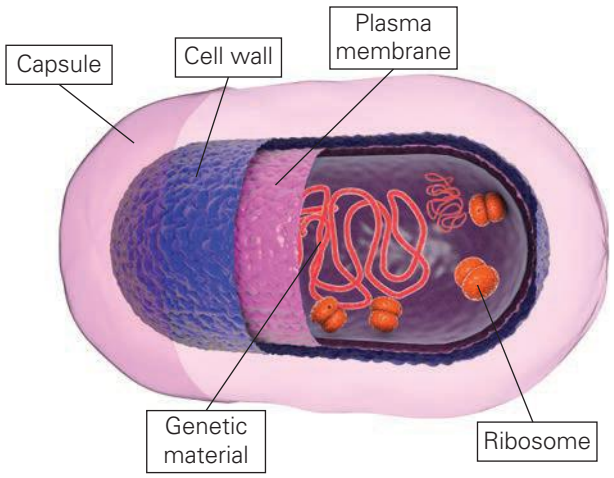


Figure 4.3 General structure of a bacterial cell

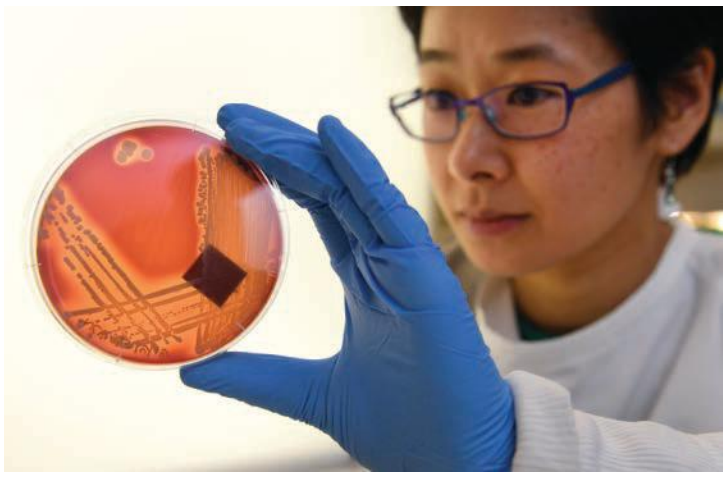


Figure 4.4 Bacterial colonies growing on a nutrient agar plate

Most bacteria reproduce by a process called **binary fission** whereby the genetic information of the bacterium replicates and the cell divides into two. Each cell produced during binary fission is a genetic clone of the parent cell.

binary fission a type of asexual reproduction in which the cell divides, creating two identical cells; the most common form of reproduction in prokaryotes, such as bacteria

Some bacteria like *Escherichia coli* can divide every 20 minutes, under optimum conditions. So, if you start with only one bacterium, after 20 minutes you will have two bacteria, then, following another 20 minutes, four bacteria, and so on, until after just 3 hours you have had nine cell divisions, equating to a growth from one through to 512 bacteria. After 20 divisions, under suitable conditions, there would be over one million bacteria. That is why you can quickly become ill when harmful bacteria invade your body.

Some bacteria can remain dormant inside the body without causing any symptoms of disease. *Mycobacterium tuberculosis* is the pathogen responsible for causing tuberculosis. Often affecting the lungs, *M. tuberculosis* is spread through respiratory droplets when infected people cough or sneeze. About one quarter of the world's population are infected with *M. tuberculosis*, but only 5–10% of people infected will develop tuberculosis.

Not all bacteria are harmful; of the estimated millions of species of bacteria that inhabit Earth, less than 5% of these species are thought to be pathogens. In fact, it is believed that around 50% of all the cells in and on our bodies are actually our own, with the rest being harmless and often useful bacteria that form what is referred to as our 'natural flora'.



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Types of bacteria

One way of classifying bacteria is by the shape of their individual cells. The main shapes are rods, spheres and spirals.

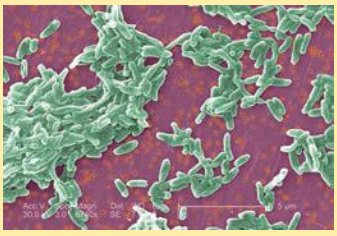
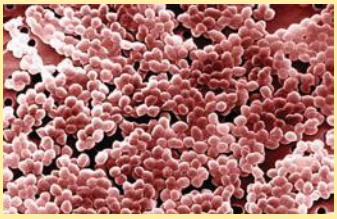
Shape	Biological name	Diseases	Magnified image
Rod	Bacillus (plural: bacilli)	Tuberculosis Pneumonia	
Spiral	Spirillum (plural: spirilla)	Syphilis	
Spherical	Coccus (plural: cocci)	Strep throat	

Table 4.2 Common pathogenic bacteria and their shapes

Practical 4.1: Teacher demonstration

Observing bacteria under a microscope

At least three different microscopes have been set up to show some different types of bacteria that have been stained for you to see under a magnification of 1000.

Aim

To observe different types of bacteria under the microscope

Materials

- microscopes
- slides of different types of bacteria (e.g. Coccus, Bacillus, Spirillum)

Method

1. Using the microscopes, observe the bacteria under a magnification of 1000.
2. Using a pencil, sketch each type of bacteria. Provide a title for each sketch.

Results

Sketch what you can see under the magnification of 1000×.

Discussion: Evaluation

1. Were you able to differentiate between the three different types of bacteria? Write a few sentences to describe how you did this.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising your experimental observations.

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Practical 4.2

Using nutrient agar plates to grow bacteria

Aim

To grow bacteria on nutrient agar plates

Materials

- Petri dish containing sterile nutrient agar × 2
- sterile cotton buds × 2
- marker pen
- masking tape
- disposable gloves

Be careful

Ensure gloves are worn when handling nutrient agar plates.

Do not sneeze or otherwise expose the agar to any pathogenic organisms.

Hands are to be washed with soap immediately after handling nutrient agar plates.

Sealed agar plates are not to be opened. Once plates have been observed, they will be collected and destroyed.

All working surfaces are to be wiped down with disinfectant after all nutrient agar plates are collected.

Method

1. Label the bottom of one agar plate 'Control' and the other plate with the location you will swab. Include your initials so you can identify your plates next lesson.
2. Using a cotton bud, wipe over an object of choice, such as a phone screen, computer keyboard, mouse or door handle. Place the swab back inside the sterile packet.
3. Open the Petri dish labelled with the location of your swab and lightly rub the cotton bud over the nutrient agar as shown in Figure 4.5. Rotate the Petri dish 90 degrees and repeat.

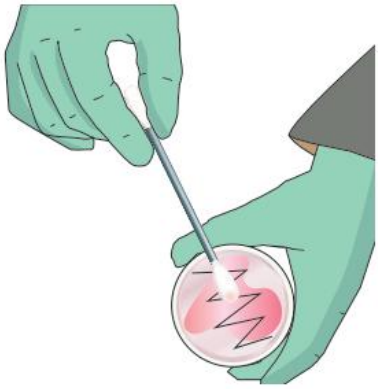


Figure 4.5 How to swab a Petri dish

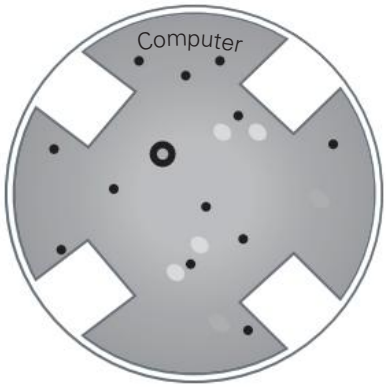


Figure 4.6 Remember to clearly label your agar plates!

4. Place the lid on top and secure with sticky tape.
5. Wipe down all work surfaces with disinfectant after all the nutrient agar plates have been collected.
6. The plates will be stored upside down (with the agar at the top) in an incubator at 37°C for 1–2 days.
7. Remove the plates from the incubator, place in a clear zip-lock bag and observe the colonies of bacteria that have grown.

   Warning: Microbes can produce harmful toxins, so it is very important to seal them in airtight containers. Taking careful precautions and minimising exposure to the microbes can protect us from dangerous infections. It is essential that the plates produced are sealed, collected and destroyed (incinerated or autoclaved).

continued …

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Results

1. Sketch the colonies that you can see on your agar plate. Try to distinguish between the bacterial colonies that have a smoother surface, compared to the colonies of mould that tend to have a furry appearance.
2. Count the number of colonies and record the type of colonies you have observed.
3. Record every group's results in a class tally of number of bacterial colonies and number of mould colonies. Using the class results, construct a column graph highlighting the proportion of each type of colony.

Discussion: Analysis

1. Choose another student's agar plate and comment on the similarities and differences as compared to your agar plate. Explain why this may be the case.
2. Rank the objects or places from the class results in order from least to most bacterial growth on the agar dishes. Explain why these differences exist by looking at the original location of the sample.

Discussion: Evaluation

1. Suggest two potential sources of error for this experiment.
2. Propose two ways in which this experiment could be improved.

Conclusion

1. Make a claim from this experiment regarding the growth of bacterial and mould colonies on agar.
2. Support your claim by referring to your experimental observations, and include potential sources of error.
3. Explain how the data supports your claim.

Quick check 4.1

1. **Define** 'pathogen'.
2. **Explain** why bacteria are classified as prokaryotes by describing their structure.
3. **Describe** how a strain of pathogenic bacteria can cause disease.
4. **List** the different names and shapes of bacteria.

Explore! 4.1

Poo transplants

Faecal microbiota transplantation (FMT) is a treatment for recurrent infections by the bacterium *Clostridium difficile* (*C. diff*). Faeces from a healthy donor is introduced into a patient's gastrointestinal tract in order to add healthy bacteria to control the *C. diff* infection.

Use the internet to explore how FMT is performed and why it is used against *C. diff* infections.

Fungi

fungi (singular: fungus) single-celled or multicellular organisms that contain a nucleus and a cell wall made of chitin

Fungi are eukaryotic organisms that contain membrane-bound organelles such as a nucleus and mitochondria. They have a cell wall made of chitin and can be either unicellular or multicellular. Familiar fungi include yeasts, moulds and mushrooms. Unlike plants, fungi cannot photosynthesise to make their own food. Instead, they use their long, fibrous cells to penetrate plants and animals, breaking them down and extracting nutrients. You may have seen a furry growth on decaying food – this is a type of fungus. For example, the furry growth on a rotten orange is the mass of fruiting bodies produced by the fungus that has infected the orange. Mushrooms and toadstools are the fruiting bodies of fungi that feed on things in the soil. Several species of fungi, mostly yeasts, live harmlessly on the human body, but others can cause skin diseases like tinea and ringworm.

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Candida is an opportunistic pathogen. This means that it commonly inhabits the human body without causing disease and only becomes pathogenic when conditions for growth are favourable. Around 30–50% of people carry *Candida albicans* in their oral cavity, gastrointestinal and reproductive tracts, but helpful bacteria in the body stop *C. albicans* from overgrowing. When the amount of *Candida* is off-balance, the yeast overgrows and causes an infection called candidiasis.



Figure 4.7 An overgrowth of *Candida* on the tongue



Figure 4.8 The pink area between this person's toes is a localised tinea infection (commonly known as 'athlete's foot').



Figure 4.9 Furry mould can be seen growing on an orange.

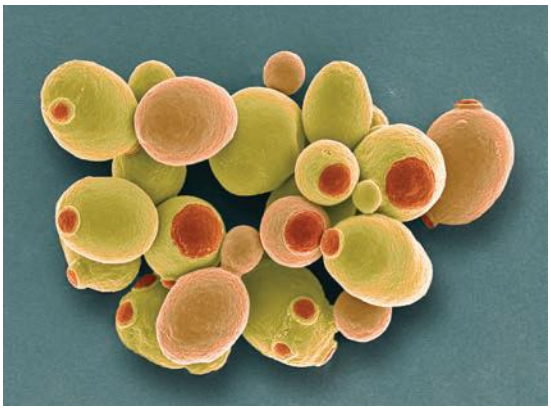


Figure 4.10 A coloured SEM of baker's yeast, a single-celled fungus, at 4000× magnification

Practical 4.3

Fermentation

Yeast is a type of fungus and is very useful in the production of many foods. You might have some baker's yeast in the cupboard at home – it is used when baking bread. Yeast exists as single cells and reproduces by a process called **budding**, where a yeast cell develops a small 'bud', which grows and eventually separates to form a new yeast cell.

Yeast feeds on sugar. This specialised process, known as **fermentation**, involves yeast, in the absence of oxygen, breaking down sugar to produce alcohol and carbon dioxide.

sugar → alcohol + carbon dioxide

If the carbon dioxide is not allowed to escape, the resulting product (e.g. ginger beer) will be fizzy. A similar reaction causes the bubbles in baked goods that make breads and cakes rise.

budding
a type of asexual reproduction, used by organisms such as yeast and hydra; it involves the daughter offspring growing off the side of the parent and then dropping off

fermentation
a chemical process by which energy is produced in the absence of oxygen

Aim

To investigate the process of fermentation using yeast

continued …

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Materials

- test tubes x 5
- test-tube rack
- sugar
- yeast
- 10 mL measuring cup
- balloon
- limewater
- delivery tube with stopper
- teaspoon
- marker pen

Method

1. Collect five test tubes. Place the first four in a rack and label them A, B, C and D (as shown in Figure 4.11).

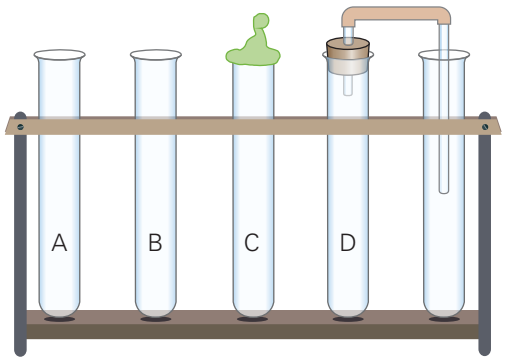


Figure 4.11 Experimental set-up

2. Fill each test tube according to the following table.

Table showing the contents of the experimental test tubes

A	B	C	D
• 2 teaspoons sugar • 10 mL warm water	• 1 small heaped teaspoon yeast • 10 mL warm water	• 2 teaspoons sugar • 1 small heaped teaspoon yeast • 10 mL warm water	• 2 teaspoons sugar • 1 small heaped teaspoon yeast • 10 mL warm water

3. Place a balloon over the end of test tube C.
4. Attach a delivery tube to test tube D and place the outlet into some limewater in a fifth test tube, as shown in the diagram.
5. Leave all test tubes for approximately 30 minutes. Observe the results after this time.

Results

Create a table of results for your observations, including about smell.

Discussion: Analysis

1. Why was it important to use warm water but not water that was too hot?
2. Suggest some reasons for the different results obtained in test tubes A, B and C, making reference to the contents of the test tubes.

Discussion: Evaluation

1. Describe two potential sources of error in this experiment.
2. Suggest two improvements you could make to the experimental design.

Conclusion

1. Make a claim from this experiment regarding the fermentation process.
2. Support your claim by referring to your experimental observations, and include potential sources of error.
3. Explain how the data supports your claim.

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Viruses

Viruses are tiny, non-cellular pathogens that are too small to see with a light microscope; an electron microscope is required to view them. They are made up of a core of genetic material surrounded by a protein coat. Viruses are unable to reproduce unless they enter a cell. When they infect a suitable host cell, they spring into action, taking over the cell and turning it into a virus-making factory. Once the host cell is full of viruses, it bursts (called **lysis**), releasing many more viruses that can infect other cells. The host cell dies in this process, leading to tissue damage. Different types of viruses target specific cell types. Influenza, for example, targets cells in the respiratory and intestinal tract, leading to symptoms such as a sore throat, cough and sometimes vomiting or diarrhoea.

virus
an extremely small non-cellular pathogen comprised of infectious particles that are inactive outside a living host cell

lysis
the breakdown of a cell due to the disruption of its membrane

VIDEO
Viruses

As you have learned, one of the key requirements for something to be considered living is the ability to reproduce. Since viruses depend on invading other cells and using the host cell to replicate and survive, viruses are not considered living. Nevertheless, viruses are an important part of all ecosystems, including the human body. In your body, viruses can infect both your own cells and the cells of the other bacteria that live inside you.

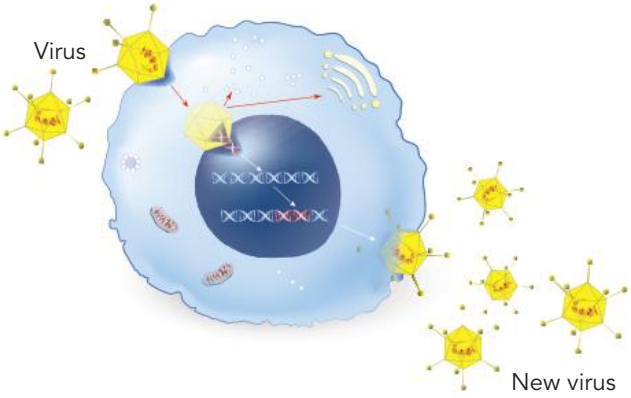


Figure 4.12 The replication of a virus inside a host cell

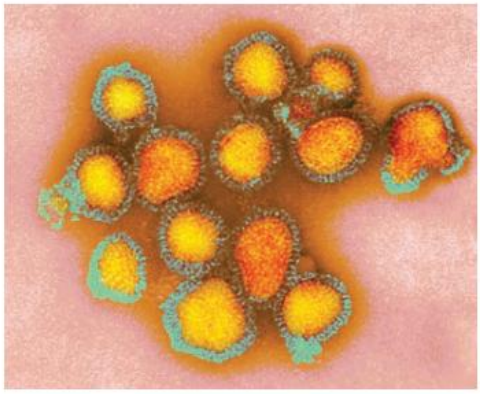


Figure 4.13 A coloured transmission electron micrograph (TEM) of the influenza virus

Quick check 4.2

1. **List** three common types of fungi.
2. **Outline** how fungi are able to obtain the nutrients they need to survive.
3. **Describe** the structure of viruses and how they reproduce.
4. Scientists argue that viruses are in fact non-living. **Discuss** why this may be the case.

Did you know? 4.2

Bacteriophages

Discovered independently by Frederick W. Twort in 1915 and Félix d'Hérelle in 1917, a bacteriophage (meaning 'bacteria eater') is a virus that only infects bacterial cells. Found everywhere on Earth, bacteriophages are being studied as an alternative to antibiotics.

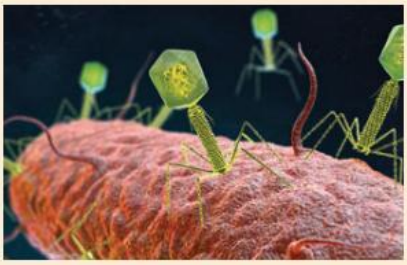


Figure 4.14 A 3D illustration of bacteriophages attacking a bacterium

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Parasites

parasite
an organism that lives on or in a host that causes harm by extracting nutrients from the host

Not all pathogens are microbes. **Parasites** are organisms that live on or inside a host. Some are large enough to see with the naked eye, which means they are not microbes. Parasitic pathogens rely on their host for food, often at the expense of the host organism. Fleas, lice, mites and ticks are examples of parasites that live on the outside of a host organism. They commonly infest the skin of humans and animals, causing skin lesions and discomfort, and can also transmit other pathogens when transferred between host organisms.



Figure 4.15 A human head louse



Figure 4.16 A tick



Figure 4.17 A flea in a dog's fur

A tapeworm is a parasite that infects humans and animals and that lives inside the host. Like other parasites, tapeworms can only survive inside the host animal. It attaches to the walls of the intestines and absorbs nutrients from the food the host eats. Often, tapeworms do not cause noticeable symptoms. However, in severe cases, infection can cause nutritional deficiencies, unexplained weight loss, abdominal pain and nausea. If you have a pet cat or dog, you might be familiar with administering worm medication on a regular basis to prevent infection. Cats and dogs can become infected with tapeworm by ingesting fleas that are infected with tapeworm larvae.

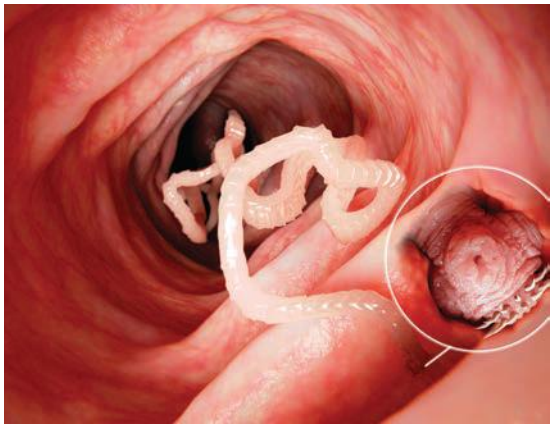


Figure 4.18 Tapeworms live in the intestinal tract and can grow up to several metres long.



Figure 4.19 Tick medication can be administered to pets to prevent infection.

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Making thinking visible 4.1

I used to think … now I think …: Microbes and diseases

When we began the chapter, you had some initial ideas about microbes and diseases. Take a minute to remember what ideas you previously had and write a few sentences using the sentence starter, 'I used to think …'.

Now, think about how your ideas about microbes have changed because of what you have learned so far in this chapter. Write down what you now think about microbes, pathogens and diseases in a few sentences. Start your sentences with, 'Now, I think …'.

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.

Section 4.1 review

Online quiz

Section questions

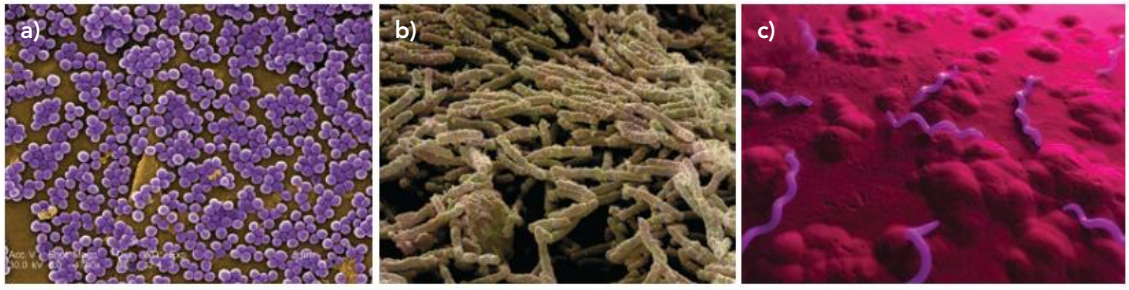
Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 4.1 questions

Remembering

1. **Define** 'parasite'.
2. **Recall** the structure of a virus.
3. **Recall** whether bacteria are classified as prokaryotes or eukaryotes.
4. **State** the biological name of each of the three pictured bacteria.



Understanding

5. **Explain** why a virus is considered non-living.
6. **Explain** how a virus causes disease.
7. **Describe** how bacteria reproduce.

Applying

8. **Categorise** the following types of pathogens as cellular or non-cellular.
   a) Bacteria b) Fungi c) Viruses d) Parasites
9. **Explain** why you get a sore throat when infected with an influenza virus.
10. **Describe** one use of fungi in everyday life.

Analysing

11. **Compare** and **contrast** bacteria and viruses.
12. If a wound becomes infected with an initial amount of 100 bacteria that can reproduce every 20 minutes, **calculate** how many bacteria would be present after 4 hours.

Evaluating

13. **Evaluate** the claim that we are more bacteria than we are human.

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4.2 Infectious and non-infectious disease

Learning goals

At the end of this section, I will be able to:

1. Distinguish between infectious and non-infectious diseases.
2. Describe how infectious diseases can spread between people.
3. Describe methods for limiting the spread of infectious diseases.

infection
the growth of a pathogen inside the body

infectious disease
a disease caused by a pathogen

non-infectious disease
a disease that is not caused by a pathogen

When a pathogen enters our body and is able to reproduce, we have an **infection**. A disease caused by a pathogen is known as an **infectious disease**. The previous section explored a number of different pathogens that are able to cause disease in humans, such as *Mycobacterium tuberculosis* and influenza. This section will focus on how infectious diseases can spread from person to person and what we can do about it.

Non-infectious disease

VIDEO
Non-infectious disease

Not all diseases are infectious. Diseases that are not caused by pathogens are called **non-infectious**. The causes of non-infectious diseases are complex; genetics, lifestyle and environmental factors, as well as their interactions, contribute to a person's chances of being affected. For example, a person's likelihood of developing cancer will be influenced by their genetics, exposure to certain chemicals or agents such as UV radiation, and their diet. Other common examples of non-infectious diseases include heart disease, Alzheimer's, cystic fibrosis and diabetes. These diseases are not contagious and cannot be spread within a population.



Figure 4.20 A person with diabetes needs to monitor their blood glucose levels throughout the day.

Quick check 4.3

1. **Define** 'infection'.
2. **Recall** one cause of non-infectious disease.
3. **List** two examples of non-infectious disease.

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Making thinking visible 4.2

See, think, wonder: Causes of death

Consider the data shown below about the causes of death in Australia in 2022 and answer the following questions:

1. What do you *see* in the data?
2. What do you *think* about that?
3. What does it make you *wonder*?

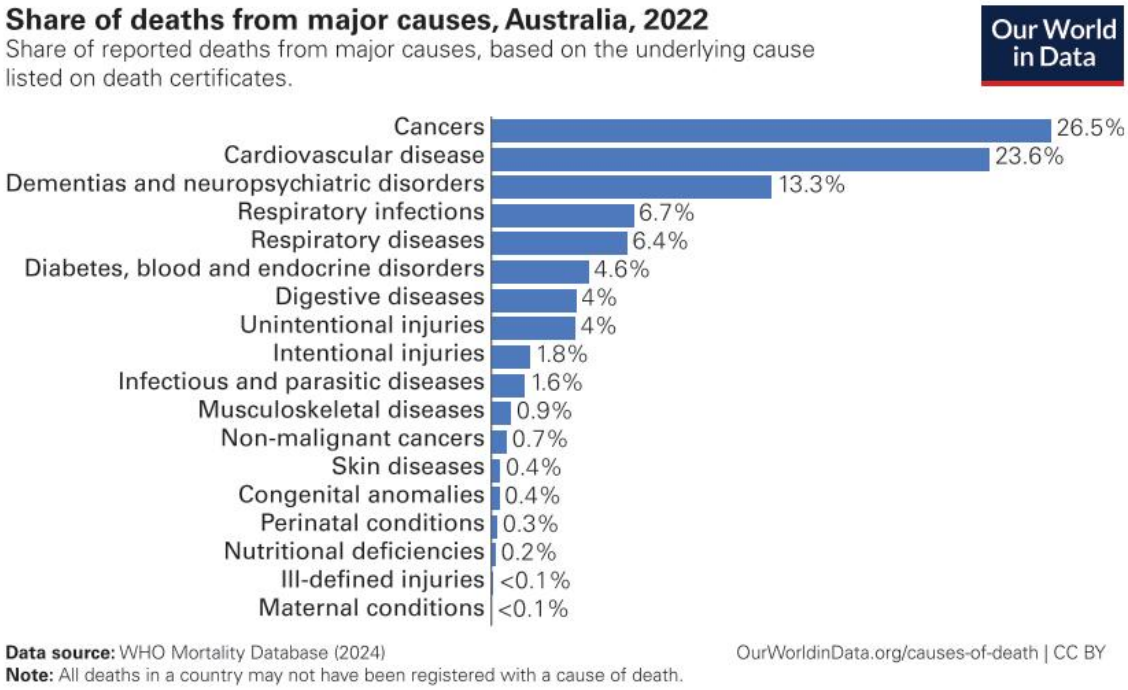


Figure 4.21 Causes of death in Australia in 2022

The *See, think, wonder* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Explore! 4.2

Causes of non-infectious disease

Choose one of the following non-infectious diseases and research the factors that contribute to causing the disease. Share a summary of your findings with the class.

- Cancer
- Asbestosis
- Alzheimer's disease
- Diabetes
- Epilepsy

Try this 4.2

Storyboarding healthy lifestyles

Create a storyboard for a social media clip that explains how a healthy lifestyle may contribute to a lower risk of developing non-infectious diseases. Ensure that the information you include is from reliable sources.

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Practical 4.4

Modelling blocked arteries

Between 2020 and 2021, 160 000 Australians were hospitalised due to coronary heart disease. In 2021, it accounted for 10% of all deaths in Australia. Coronary heart disease is caused by a build-up of cholesterol in blood vessels, narrowing the arteries and reducing blood flow to organs. A heart attack may result if blood flow to the heart is reduced due to a blockage in the coronary arteries. A combination of genetic and environmental factors causes coronary heart disease.

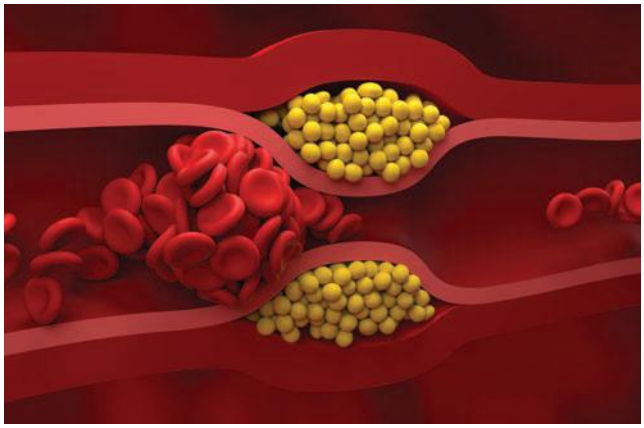


Figure 4.22 Narrowing of an artery due to the build-up of fat inside the artery walls causes reduced blood flow.

Aim

To construct a model to simulate blood flow in an artery blocked by cholesterol

Materials

- disposable plastic cups × 2
- straws of different diameters, cut to 5 cm in length × 2
- marker pen
- scissors
- a shallow tray
- 1 L of water coloured with red food colouring
- 500 mL measuring cylinder
- Blu-Tack

Method

1. Use the scissors to make a small hole approximately 2 cm from the bottom of each cup.
2. Insert the straws into the holes, widening the holes with the scissors if needed. Do not make the holes bigger than the straws.
3. Insert the straws into the holes, ensuring that they point slightly downwards.
4. Place Blu-Tack around the straw on both the inside and the outside of the cup to seal the hole.
5. Place one of the cups in the tray and seal the end of the straw with Blu-Tack.
6. Measure 400 mL of red water and pour it into the cup. Ensure that no water is leaking out of the straw.
7. Remove the Blu-Tack from the end of the straw and time how long it takes for the water to stop flowing. Record this time in a results table.
8. Repeat steps 5–7 with the other cup.

Results

1. Record how long it took each cup to empty.
2. Calculate the flow rate by dividing 400 mL by the time it took for each cup to empty.

Discussion: Analysis

1. Explain what both straws in the model represent.
2. State which straw allowed the red water (the blood) to flow faster, and explain why.
3. Explain how this experiment models a blocked artery.

Discussion: Evaluation

1. Suggest two limitations of this model.
2. Propose two ways this experiment could be improved.

Conclusion

1. Make a claim from this experiment regarding the modelling of an artery blocked by cholesterol.
2. Support your claim by referring to your experimental observations, and include potential sources of error.
3. Explain how your observations support your claim.

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Did you know? 4.3

Cystic fibrosis

Our cells contain genetic information in the form of DNA, which provides instructions on how we look and function. Mutations in DNA can result in faulty instructions, which can lead to disease. Cystic fibrosis is caused by a mutation in the CFTR gene, which maintains the flow of salt and fluids in and out of the cells in different parts of the body. People affected with cystic fibrosis have a build-up of thick mucus in their lungs and digestive tract, which leads to persistent lung infections and complications with digestion. A person can be a carrier for cystic fibrosis but not be affected by the disease. This means that a couple could pass on the disease to their children even if they are not affected by the disease themselves. Around 1 in 25 people are carriers for cystic fibrosis.

Infectious disease

Contagious disease

An infectious disease that can be spread from person to person is said to be **contagious**. Non-infectious diseases are not contagious, but many infectious diseases are. For a pathogen to survive and reproduce in the population, it must move between hosts in a process known as **transmission**. There are two main types of transmission:

- Direct transmission involves contracting a pathogen from an infected person either through physical contact or being near them.
- Indirect transmission occurs through contact with an infected surface or by breathing infected air.

contagious of an infectious disease that can be passed from one human to another

transmission the passing of a pathogen from one organism to another



VIDEO Transmission

Mode of transmission	Description	Example	Pathogens (and the disease they cause)
Direct			
Direct contact	Coming into direct, physical contact with the infected person	Hand shaking, hugging, sexual intercourse	Varicella-zoster virus (chickenpox), *Tinea pedis* (Athlete's foot)
Droplet spread	Inhalation of infected respiratory droplets	Being near an infected individual who is talking, sneezing or coughing	SARS-CoV-2 (COVID-19), *Bordetella pertussis* (whooping cough), influenza
Indirect			
Indirect contact	Touching an object that has come into contact with the pathogen	Touching objects such as tissues, clothes or water bottles used by an infected individual	Rhinovirus (common cold), *Clostridium tetani* (tetanus)
Airborne	Pathogens can remain suspended in tiny particles in the air for long periods of time	Inhaling contaminated air particles in a doctor's office long after the patient has left	SARS-CoV-2 (COVID-19), Rhinovirus (common cold), influenza
Faecal-oral	Pathogens excreted in faeces can contaminate food and water	Eating food prepared by an infected person or swimming in contaminated water	*Vibrio cholerae* (cholera), Rotavirus (gastro)
Vector	An organism that transmits a pathogen from one host to another	Getting bitten by a mosquito carrying a pathogen	*Plasmodium* (malaria)

Table 4.3 Different ways that pathogens can be transmitted

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Figure 4.23 A sneeze can have up to 30 000 droplets, while a cough contains 3000 droplets.



Figure 4.24 Shaking hands with an infected individual can transmit pathogens directly between people.

outbreak
a sudden increase in the incidence of an infectious disease within a certain area

epidemic
an outbreak of an infectious disease that has spread to the wider community

pandemic
an outbreak of an infectious disease that has spread across multiple continents

When there is a sudden increase in the occurrence of an infectious disease in a population, it is called an **outbreak**. Nursing homes commonly experience influenza and gastro outbreaks because of the proximity and frequent contact between staff, patients and visitors. A more widespread increase in disease in a short period of time is described as an **epidemic**. Epidemics are less localised than outbreaks; they can sometimes affect entire nations. When the disease spreads across continents, it becomes a **pandemic**.



Figure 4.25 Touching a contaminated object can transmit pathogens between people without them ever meeting.

Explore! 4.3

Pandemics throughout history

COVID-19 is a highly contagious respiratory disease caused by a new RNA virus, a coronavirus similar to the cold virus, called SARS-CoV-2. The first case of COVID-19 was identified in Wuhan, China in December 2019. The World Health Organization declared a global pandemic in March 2020. As of late 2024, over seven million deaths globally have been attributed to COVID-19, making it one of the deadliest pandemics in history. It has also had an enormous economic and social impact.

Choose one of the pandemics listed below and research the disease involved, including the symptoms, countries affected, when it occurred and the death toll.

- Black Death
- Spanish flu
- Swine flu
- HIV/AIDS

DOC
WORKSHEET
Controlling transmission

Controlling transmission

Knowing how a particular pathogen is spread among the population is helpful when considering how to control transmission if an outbreak occurs. Local and national government agencies monitor disease levels in Australia and have emergency response plans for impending outbreaks or epidemics. Governments around the world coordinate with the World Health Organization (WHO) and the United Nations (UN) to prevent or manage pandemics.

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Preventing the transmission of pathogens between individuals is the most effective way to avoid or control a disease outbreak. This can include:

- good hygiene practices such as regular handwashing
- sterilising objects and surfaces
- wearing a mask
- ensuring access to clean water
- social distancing (avoid being near other individuals)
- quarantining (isolate infected individuals until they are no longer contagious)
- lockdown of areas or restricting travel (restrict the movement of people)
- getting a vaccine if one is available
- public education programs.

Quick check 4.4

1. **Define** 'contagious'.
2. **List** two examples of a contagious disease.
3. **Describe** two ways to limit the spread of infectious disease.



Figure 4.26 Wearing a face mask prevents the spread of pathogens through respiratory droplets.



Figure 4.27 Proper handwashing techniques are important in preventing the spread of pathogens via direct contact.



Figure 4.28 Disinfecting surfaces and objects that are touched by multiple people limits spread through indirect contact.



Figure 4.29 Public education about handwashing was common during the COVID-19 pandemic.

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Investigation 4.1

Investigating the effectiveness of handwashing using different hand soaps

Aim

To measure the effectiveness of handwashing using different hand soaps

Materials

- Petri dishes containing sterile nutrient agar × 2
- sterile cotton buds × 2
- marker pen
- masking tape
- a variety of different hand soaps, including antibacterial handwashes

Method

1. Label the bottom of one agar plate 'Control' and the other plate with the handwashing agent you wish to investigate. Include your initials so you can identify your plates in the next lesson.
2. Wet your hands with water and use the sterile cotton bud to swab one finger for 15 seconds. Ensure you get around the nail and down the sides of the finger.
3. Open the Petri dish labelled 'Control' and lightly rub the cotton bud over the surface of the agar (as shown in Figure 4.5 in Practical 4.2). Rotate the Petri dish by 90 degrees and repeat.
4. Place the lid on top and secure with sticky tape.
5. Apply your chosen soap under clean, running water and lather up your hands, including the back, front, between the fingers and under the nails. Wash your hands for 30 seconds and then rinse well with water. Do not dry your hands.
6. Repeat steps 2–4, ensuring that you use the same finger you swabbed in the Control test.
7. The plates will be stored upside down (with the agar at the top) in an incubator at 37°C for 1–2 days.
8. Remove the plates from the incubator, place in a clear zip-lock bag and observe the colonies of bacteria that have grown.
   Warning: Microbes can produce harmful toxins, so it is very important to seal them in airtight containers. Taking careful precautions and minimising exposure to the microbes can protect us from dangerous infections. It is essential that the plates produced are sealed, collected and destroyed (incinerated or autoclaved).

Results

1. Sketch the colonies that you can see on your agar plate. Try to distinguish between the bacterial colonies that have a smoother surface, compared to the colonies of mould, which tend to have a furry appearance.
2. Count the number of colonies and record the type of colonies you have observed.
3. Record every group's results in a class tally of number of bacterial colonies and number of mould colonies. Using the class results, construct a column graph highlighting the proportion of each type of colony.

Discussion: Analysis

1. Explain whether there was a difference in the number or type of colonies observed between your control plate and your handwashing plate.
2. Choose another student's agar plate who used a different hand soap and comment on the similarities and differences compared to your agar plate. Explain why this may be the case.
3. Rank the hand soaps from the class results in order from least to most bacterial growth on the agar dishes. Explain whether there is a difference in the effectiveness of different hand soaps.
4. Explain the purpose of the control.

continued …

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Discussion: Evaluation

1. Suggest two potential sources of error for this experiment.
2. Propose two ways in which this experiment could be improved.

Conclusion

1. Make a claim from this experiment regarding the effectiveness of handwashing using different hand soaps.
2. Support your claim by referring to your experimental data, and include potential sources of error.
3. Explain how the data supports your claim.

Explore! 4.4

Exploring the data on handwashing

Maintaining good personal hygiene is critical to limiting the spread of pathogens. The data shows a clear connection between access to handwashing facilities and deaths from infectious diseases. Visit the Our World in Data website and search for the article 'Hygiene and handwashing'. Using the article, write five facts about the link between death rates and handwashing.

Science as a human endeavour 4.1

Australia's biosecurity

With only 5 kilometres separating the northernmost Torres Strait Island from Papua New Guinea (PNG), there is a high risk of pest, weed and disease transmission to the north of Australia. Transmission can occur via wind or tidal movements, animal carriers, or ships and aircraft. Pests such as fruit flies are known to be blown from PNG to the Torres Strait Islands in the wet season and can island-hop the short distance to mainland Australia. Mosquitoes that thrive in tropical environments, as well as migratory birds, can also bring harmful pathogens, some of which we may have no immunity against.

Before European colonisation, Australia was untouched by many pests, weeds and diseases that were prevalent in other countries. This made Australia's ecosystem especially susceptible to the devastating effects of these foreign invaders. Aboriginal and Torres Strait Islander communities work closely with the Australian Government to maintain an early warning system for exotic pest, weed and disease detection. The Northern Australia Quarantine Strategy (NAQS) has been working with Aboriginal and Torres Strait Islander communities for over 30 years to monitor the health of ecosystems. Indigenous ranger groups across the Torres Strait, Western Australia, the Northern Territory and Queensland monitor plant, animal and aquatic health. They work with the NAQS to provide ongoing insect surveillance, map plant species, collect and destroy potential threat material, and establish public awareness campaigns. With their deep knowledge of and connection to Country, Aboriginal and Torres Strait Islander communities play a key role in keeping Australia safe from biosecurity threats that could devastate our crops, livestock, precious ecosystems and the human population.



Figure 4.30 A biosecurity officer recording data from a Queensland fruit fly pheromone trap in a tree in Auckland, New Zealand

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Treatment

antibiotic
a type of medication used to treat bacterial infections

antiviral
a type of medication used to treat viral infections

antifungal
a type of medication used to treat fungal infections

antiseptic
a substance that stops or slows down the growth of microorganisms; used externally on skin

septic
of tissue infected with bacteria

Many infectious diseases have effective treatments, which means that getting sick is rarely a life-threatening situation. Have you ever gone to the doctor with a fever and been prescribed **antibiotics**? Antibiotics are a type of medication that kill bacteria. Doctors will prescribe a course of antibiotics to cure or prevent a bacterial infection. Antibiotics can be effective against certain types of bacteria but have little effect against others. Current research is focused on discovering new antibiotics and testing to determine against which bacteria they are most effective. Antibiotics are only effective against bacteria; **antivirals** and **antifungals** are used to treat viral and fungal infections respectively. Our own cells are not affected by antibiotics because they are structurally very different to prokaryotes.

Antibiotic resistance

Antibiotics have been used in medicine since the 1930s as the traditional method of fighting bacterial infections in the human body. However, scientists are becoming increasingly concerned about drug-resistant bacteria, because infections often last longer, cause more severe illnesses, require more doctor visits or longer hospital stays, and may even cause death. Antibiotic resistance happens when not all of the bacteria are killed by a round of antibiotics. The bacteria that remain, which are left to grow and multiply, form a colony of bacteria that may now be resistant to that antibiotic, and those resistant bacteria can be passed on to other people!

Antibiotics versus antiseptics

While antibiotics can kill and stop the growth of bacteria, **antiseptics** can prevent the growth and development of other pathogens, without necessarily killing them. They tend to work on a large variety of microbes and are most often used externally; for example, antiseptic hand washes or to clean a wound. When harmful bacteria grow in living animal tissue, the tissue is said to be **septic**. Many of the antiseptics used in the past killed the bacteria in wounds, but also damaged or killed the tissue around the wound. Modern antiseptics seldom injure the tissues.

Did you know? 4.4

Overuse of antibiotics

At least 30% of antibiotic courses prescribed are unnecessary, meaning that no antibiotic is needed at all. For example, people often seek antibiotics when they are suffering from the common cold, but it is actually a viral infection, which antibiotics are useless against. The overuse of antibiotics has caused widespread antibiotic resistance and the creation of 'superbugs' that cannot be killed by several types of antibiotics.

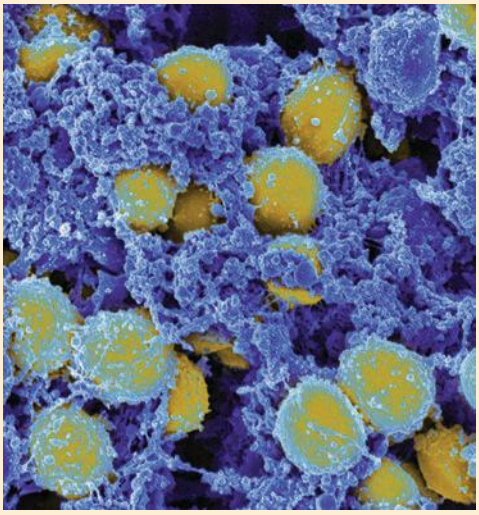


Figure 4.31 A SEM of methicillin-resistant *Staphylococcus aureus* (MRSA). This type of bacteria is becoming resistant to many common antibiotics.

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Practical 4.5

Effectiveness of antiseptics against soil bacteria

Be careful



Ensure gloves are worn when handling nutrient agar plates.

Do not sneeze or expose the agar to any pathogenic organisms.

Hands are to be washed with soap immediately after handling nutrient agar plates.

All working surfaces are to be wiped down with disinfectant after all nutrient agar plates are collected.

Aim

To determine the effectiveness of different antiseptics against soil bacteria

Materials

- soil sample with bacteria (e.g. potting mix)
- test tubes × 5
- 200 mL beaker
- test-tube rack
- different antiseptics × 4: methylated spirits, iodine, QAC, Dettol
  (Note: QAC stands for quaternary ammonium compounds, a class of chemicals or disinfectants used alone or added to cleaning products.)
- distilled water
- nutrient agar plate
- marker pens
- disposable gloves
- disinfectant
- handwash (soap)

Method

1. Construct a hypothesis for this experiment. In which test tubes do you think you will observe a growth of microbes?
2. Add a heaped teaspoon of soil to a beaker filled with 100 mL of water.
3. Put 5 drops of this soil/water mixture into each of the 5 test tubes. Label the test tubes A–E.
4. Add to each of the test tubes 5 drops of a different antiseptic.
   Test tube A: Methylated spirits
   B: Iodine (handle with care)
   C: QAC
   D: Dettol
   E: Distilled water (as a control)
5. Label five areas A–E on the bottom of an agar plate as in Figure 4.32. (Hint: If you write the letters backwards, they will appear the correct way when later viewed from above.)
6. Using a cotton bud, smear a tiny amount of the contents of test tube A onto the agar in the area you have labelled 'A'. Keep the agar plate covered as much as possible while you do this to prevent microbes in the air settling on the agar.
7. Using a fresh cotton bud each time, repeat with the contents of the other test tubes, matching the contents with its label on the agar plate.
8. Seal the lid with sticky tape.
9. Wipe down all work surfaces with disinfectant after all nutrient agar plates have been collected.
10. The plates will be stored upside down (with the agar at the top) in an incubator for 1–2 days.
11. After incubation, examine the agar plates. Take photos and discuss the types of microbes that are growing on your plates.

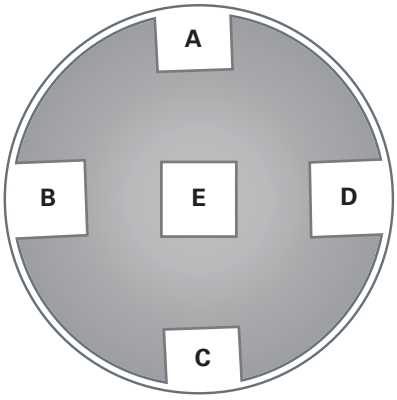


Figure 4.32 Clearly labelling your agar plate is essential for interpreting the results.

continued …

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Results

Copy and complete the table.

Table showing the observations for the different antiseptics

Antiseptic	Photo	Description of microbes
Methylated spirits		
Iodine		
QAC		
Dettol		
Distilled water (control)		

Discussion: Analysis

1. How does the pattern of microbial growth reveal the effectiveness of the antiseptic? What effect has the antiseptic had?
2. Do all the antiseptics tested have some effectiveness? How do you know?

Discussion: Evaluation

1. Identify two potential sources of error in this experiment.
2. Suggest two ways the experimental design could be improved.

Conclusion

1. Make a claim from this experiment regarding the effectiveness of different antiseptics.
2. Support your claim by referring to your experimental observations, and include potential sources of error.
3. Explain how the data supports your claim.

Science as a human endeavour 4.2

Relenza

The influenza virus particle contains two essential proteins on its surface: hemagglutinin and neuraminidase. In the 1980s, Australian scientist Peter Coleman and his colleagues at CSIRO determined the three-dimensional structure of the neuraminidase protein. They used this discovery to develop the first antiviral drug against influenza, zanamavir (Relenza®). Relenza is an antiviral medication that interferes with neuraminidase's ability to release new virus particles from host cells, inhibiting the virus from spreading to other cells. Relenza was launched worldwide in 1999 and is used in over 70 countries. It is effective against all influenza strains and earns over $3 billion in yearly sales. Peter Coleman's work paved the way for a new class of antiviral drugs called neuraminidase inhibitors.

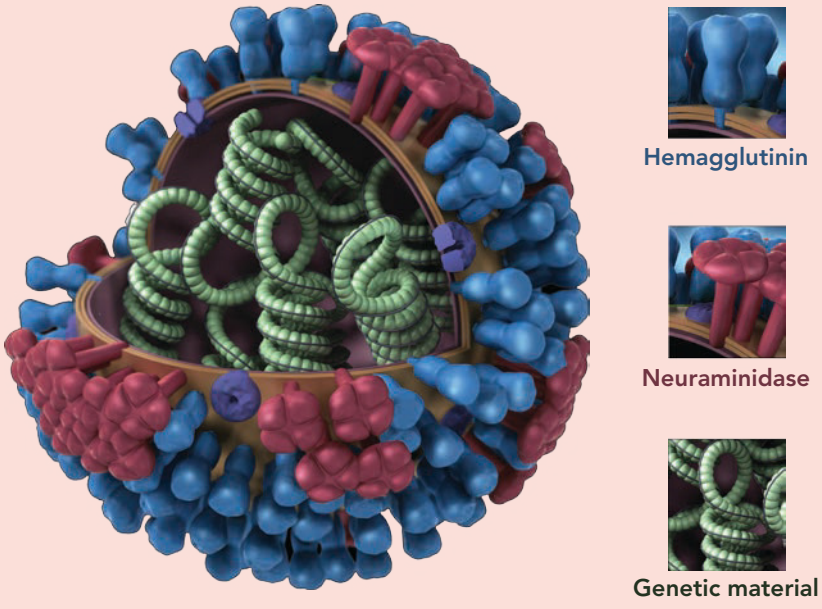


Figure 4.33 Relenza targets the neuraminidase protein on the surface of the influenza virus.

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Section 4.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 4.2 questions

Remembering

1. **Recall** three examples of non-infectious diseases.
2. **Describe** the causes of non-infectious diseases.
3. **Define** 'transmission'.
4. **Describe** one example of direct transmission and one example of indirect transmission.

Understanding

5. **Describe** the difference between direct and indirect transmission.
6. **Explain** the importance of good hygiene when limiting the spread of disease.
7. **Explain** how social distancing can decrease the transmission of disease.
8. **Describe** a method of prevention that can combat diseases transmitted via indirect contact.

Applying

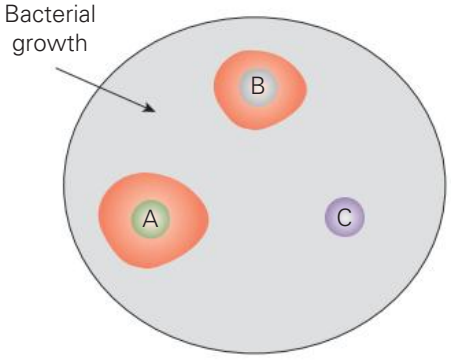
9. **Identify** the mode of transmission in the following scenarios.
   a) Shaking hands with someone who has a cold
   b) Inhaling influenza particles in a classroom that were expelled by a student during the lesson before
   c) Sitting in a doctor's office next to someone who does not cover their mouth when coughing
   d) Stepping on a rusty nail contaminated with *Clostridium tetani*
   e) Sleeping in the same bed as someone with chickenpox
10. A person has an ear infection caused by bacteria. **Explain** whether they are likely to be prescribed antibiotics or antiseptics by their doctor.
11. **Explain** why antibiotics do not work against a viral infection.

Analysing

12. Draw a Venn diagram to **compare** and **contrast** the terms 'outbreak', 'epidemic' and 'pandemic'.

Questions 13 and 14 refer to the following information.

Antimicrobial substances A, B and C were tested for their effectiveness against a strain of bacteria growing on agar. The red areas are called 'zones of inhibition'. This is the area around the antiseptic disc where bacteria were killed. Interpret the results shown here by answering the following questions.



13. Of the antimicrobial substances tested, which was the most effective? **Explain** your reasoning.
14. Of the antimicrobial substances tested, which was the least effective? **Explain** your reasoning.

Evaluating

15. **Evaluate** the claim that all contagious diseases are infectious, but not all infectious diseases are contagious.

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4.3 Response to pathogens

Learning goals

At the end of this section, I will be able to:

1. Describe the role of the immune system.
2. Describe how the first line of defence prevents entry of pathogens.
3. Explain how the second and third lines of defence respond to an infection.
4. Describe what it means to be immune to a disease.
5. Describe how vaccines help build immunity against pathogens.

immune system the system of cells, tissues and organs that enables the body to protect itself against disease

cilia (singular: cilium) hair-like structures that line the respiratory tract and sweep microbes and debris out of the airways

normal flora a population of microbes that permanently inhabits the human body and that do not usually cause disease

We are exposed to pathogens all day, every day. So why are we not constantly sick? Our bodies have a built-in defence mechanism called the **immune system** that prevents and fights diseases. Just like the digestive or respiratory systems, the immune system comprises many different cells and tissues that work together to keep you alive and healthy. The primary cells of the immune system are white blood cells, of which there are many different types with specific jobs. The white blood cells discussed in this chapter have one job in common: to recognise 'self' from 'non-self'. If a cell or molecule is recognised as non-self, an immune response is launched to eliminate the foreign invader. Immune protection consists of three lines of defence. The first two lines of defence are considered non-specific: they respond the same way to every type of pathogen. Additionally, there is no 'memory' of prior infections. The third line of defence is specific, providing a targeted defence depending on the type of pathogen encountered. The responses in this line of defence retain a memory of previously encountered pathogens, protecting you from getting sick a second time.

First line of defence

VIDEO First line of defence

The first line of defence aims to prevent infection: it is the first point of the human body that the pathogen encounters. This line of defence includes physical barriers such as intact skin, hairs, **cilia** and the mucous membranes in the respiratory and reproductive tracts. The hairs that line the entrance of your nostrils are there for a reason! They trap large particles like dust and pollen. The cells that line the respiratory tract secrete a sticky mucus that traps inhaled pathogens, and the cilia beat in an upward motion that pushes mucus and any foreign bodies away from the lungs. If a pathogen does not gain access to the host's cells and tissues, it cannot disrupt normal physiological functions and cause disease. An additional set of barriers are chemical in nature and act to restrict the growth of pathogens in the body. Stomach acid and molecules called lysozymes found in sweat and tears, for example, have the ability to destroy bacteria. Remember the helpful microbes colonising our bodies discussed in section 4.1? These friendly bacteria, called our **normal flora**, also play an important role in preventing infection.

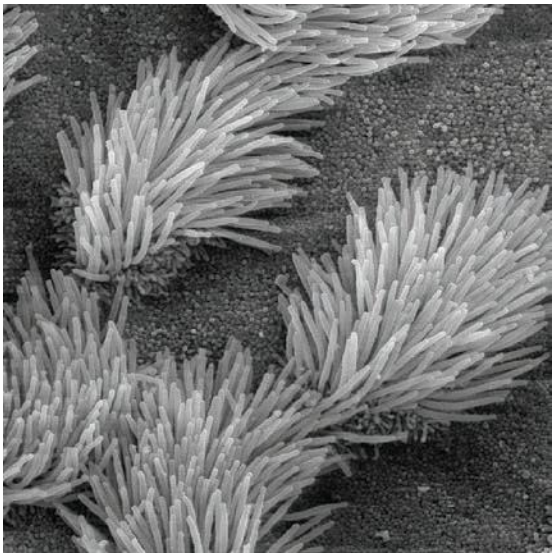


Figure 4.34 A SEM of cilia lining the respiratory tract

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Our skin, gastrointestinal and reproductive tracts are covered in bacteria that usually do not harm us and that out-compete pathogenic bacteria and fungi for space and nutrients, preventing their colonisation of our body. For this first line of defence to work effectively, is important that our skin is intact. If we have a cut or a graze, this creates a pathway of entry into the body, giving bacteria or viruses access to living tissue.

Did you know? 4.5

Mucociliary escalator

The cilia and mucus that line your respiratory tract are called the mucociliary escalator. This is because the cilia move the mucus, with any pathogens or particles trapped in it, upwards like an escalator. The mucus is then swallowed, and any pathogens present are killed by your stomach acid.

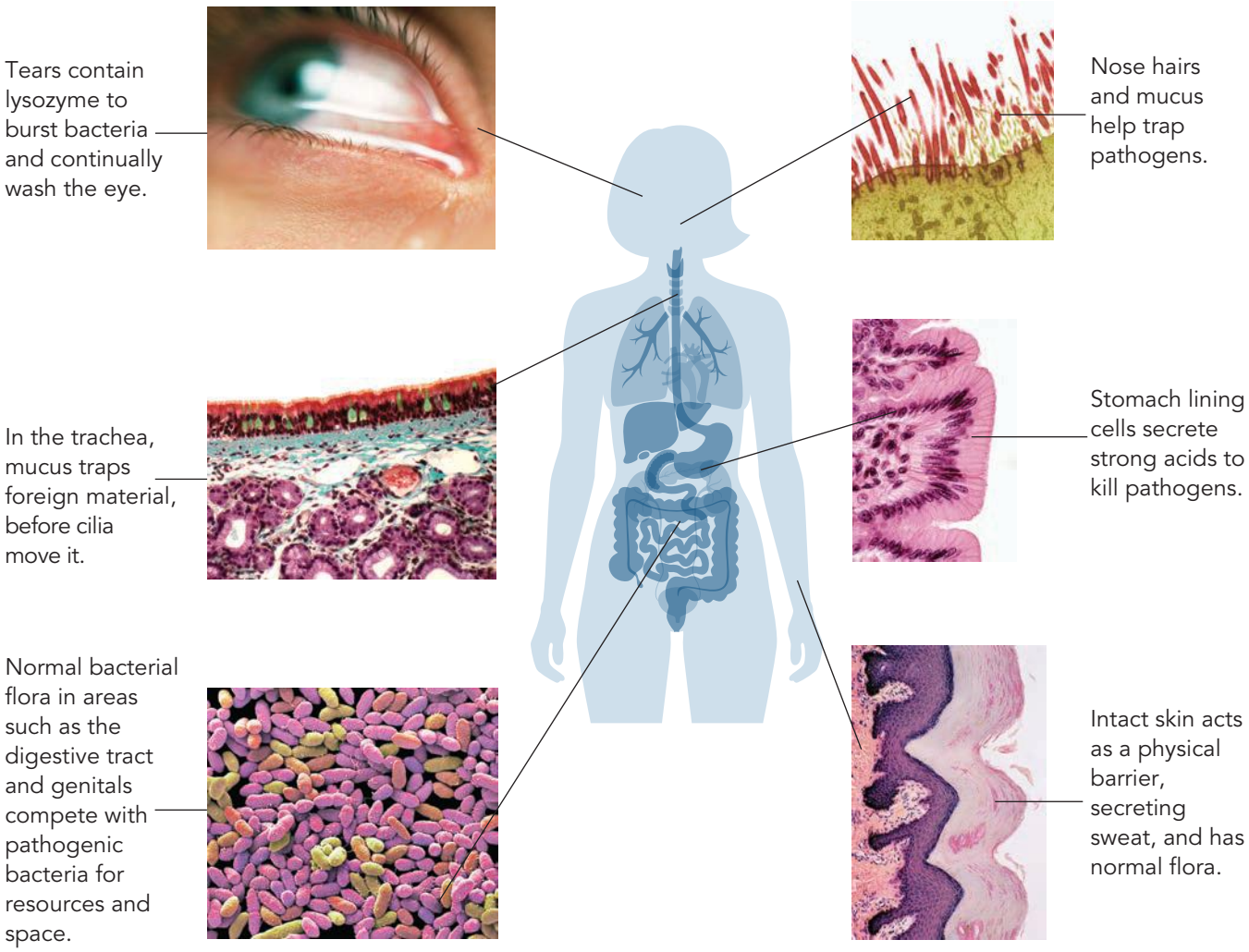


Figure 4.35 Some of the physical, chemical and microbiological barriers in the human body to prevent a pathogen from entering

Quick check 4.5

1. **Compare** the non-specific and specific immune responses.
2. **Describe** one chemical and one physical barrier of the first line of defence.
3. **Explain** how friendly bacteria help prevent disease.

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VIDEO
Second line of defence

Second line of defence

If a pathogen gets past our first line of defence and starts to reproduce inside our cells or tissues, the second line of defence is activated. The second line of defence against infection is another non-specific response that works in the same way against different types of pathogens. Specialised white blood cells called macrophages and neutrophils are constantly circulating in your bloodstream on a search-and-destroy mission. Their role is to change the shape of their membrane to surround and then ingest dead cells and pathogens. This process is called **phagocytosis**. These specialised cells can also activate the inflammatory response, resulting in increased blood flow to the site of infection. Have you ever fallen over and cut or grazed your skin? If the wound became infected, you would have noticed the damaged area becoming swollen, red, hot and painful. This is due to the increase in blood flow to the area, which promotes healing and brings more white blood cells to the area of infection. You may have also noticed pus covering the wound, an accumulation of dead white blood cells and bacteria.

phagocytosis
a cellular process in which a white blood cell wraps around and ingests a cell or large particle to break it down using enzymes

WORKSHEET
Non-specific lines of defence



Figure 4.36 The process of phagocytosis

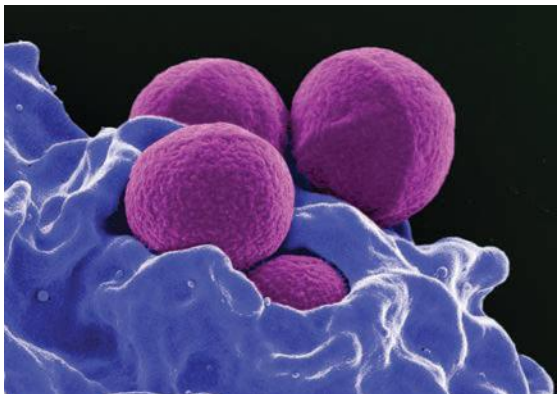


Figure 4.37 A colourised SEM of a neutrophil (blue) phagocytosing *Staphylococcus aureus* bacteria (purple)



Figure 4.38 A healing wound is red from inflammation.

When a pathogen causes tissue damage, chemicals that cause the brain to raise the core body temperature above 37°C are released. This is called a fever; you have probably experienced this unpleasant symptom during a cold or flu. Rest assured, it serves a purpose! During a fever, the brain sets the body's thermostat to 38°C or 39°C, causing you to feel chills. Recall from Chapter 3 that in order to maintain homeostasis, the body will use muscle contractions to shiver and warm your body to this set temperature. The purpose of a fever is to activate heat-shock proteins and suppress pathogen growth. Our bodies work best at 37°C, so a fever that is too high (e.g. over 40°C) or lasts for too long can cause organ damage or death. This is why, as soon as the infection is cleared, the brain resets the thermostat to 37°C. When this happens, you will feel hot and start to sweat in order to cool back down.

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Figure 4.39 A young child with a fever

Quick check 4.6

1. **Recall** whether the second line of defence is specific or non-specific.
2. **Recall** the two cells that perform phagocytosis.
3. **Describe** what occurs during inflammation.
4. **Explain** why you get chills during a fever.

Third line of defence

The third line of defence includes two main groups of specialised white blood cells known as **lymphocytes** – the B cells and the T cells (also known as B lymphocytes and T lymphocytes). These develop in the bone marrow and their letter indicates where they mature (B = bone marrow and T = thymus gland).

There are 25 million to a billion T cells in your body, with children having more T cells than adults. There are two main types of T cells in your body: cytotoxic T cells and helper T cells. Cytotoxic T cells help to eliminate viral infections by differentiating between infected and non-infected cells. To do this, they identify a special molecule called an **antigen**. Each T cell has a unique receptor that can only bind with one kind of antigen, like a lock that can fit with a specific size and shape of key. Healthy cells have self-antigens on the surface of their membranes that the T cells can identify as a regular part of that cell. Self-antigens do not activate T cells. However, suppose a cell is infected with a virus. In that case, the cell will contain viral antigens on its surface that will signal the cytotoxic T cell to identify it as foreign and destroy it. Once a virally infected cell is recognised and destroyed, a macrophage or neutrophil will phagocytose the dead cells to prevent the spread of the virus.

VIDEO
Third line of defence

lymphocyte
a white blood cell that is involved in fighting disease; some produce antibodies

antigen
a substance that induces an immune response in the body

WORKSHEET
Specific lines of defence

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The other type of T cell is the helper T cell (see Figure 4.40). These cells act like team leaders and provide specific chemical instructions to other cells. These chemical instructions allow B and cytotoxic T cells to replicate and make thousands of clones of themselves to fight infection. Without helper T cells, B cells and cytotoxic T cells would be unable to keep infections under control.

antibody a Y-shaped molecule that binds to specific antigens

memory cell a lymphocyte formed after exposure to a pathogen; it can produce a faster and stronger immune response upon re-infection

B cells fight infection by making special proteins called **antibodies**. Again, working like a lock-and-key, antibodies are designed with specific binding sites that can only attach to certain antigens with the matching shape and size (see Figure 4.41). Antibodies cause pathogens to clump together, attracting the white blood cells to perform phagocytosis and kill the pathogen. B and T cells can also form **memory cells**, which allow the immune system to mount a faster and stronger response when encountering a specific pathogen again. Sometimes, the second and subsequent responses are so effective that you might not even feel unwell or know you have been infected (see Figure 4.42).

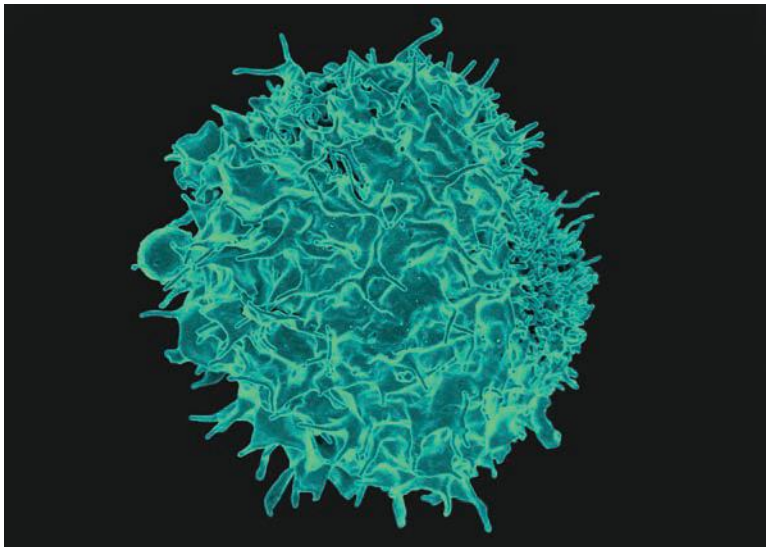


Figure 4.40 A colourised SEM of a T cell

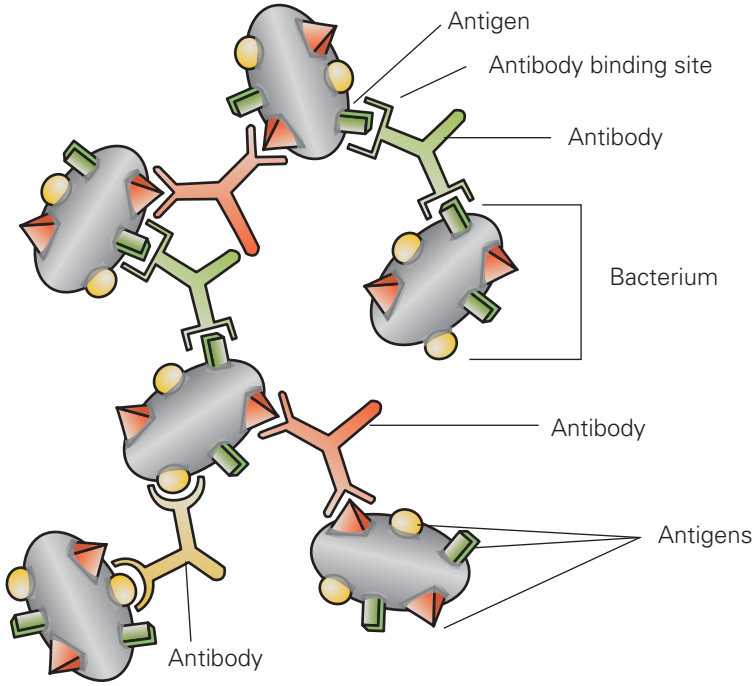


Figure 4.41 Different antibodies (here, green, red or yellow) bind only with their matching antigens. The antibodies clump the pathogenic bacteria together, making them easier to destroy.

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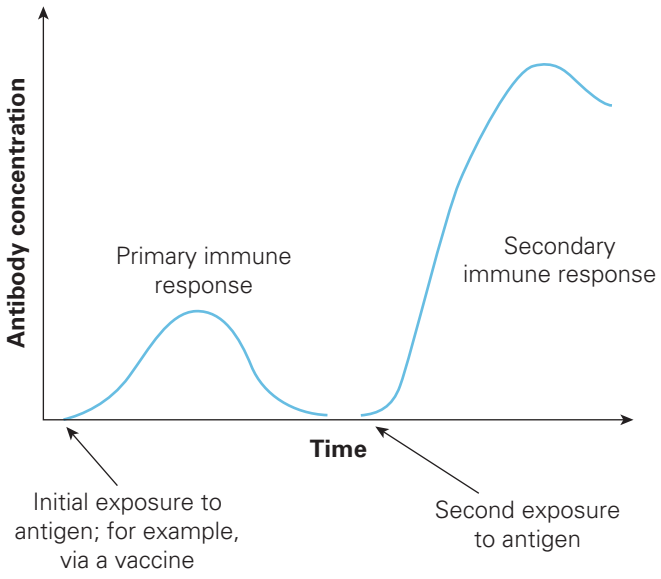


Figure 4.42 The secondary immune response to a previously encountered antigen on the surface of a pathogen is faster and stronger than the primary immune response.

Making thinking visible 4.3

Connect, extend, challenge

Now you have learned about how the immune system fights disease, write a few sentences about how the ideas and information are connected to what you have experienced during illness.

Write down any new ideas that broadened your thinking or extended it in different directions after reading about the three lines of defence.

Write one challenge or puzzle that emerged for you.

The *Connect, extend, challenge* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Quick check 4.7

1. **Recall** the two types of lymphocytes that carry out the third line of defence.
2. **Explain** the difference between B cells and T cells.
3. **Describe** how antibodies work.

Immunisation and vaccines

Vaccines enable you to produce memory cells specific to a particular pathogen without ever being unwell! Vaccination involves injecting a dead or weakened pathogen (complete with all its identifying antigen flags) into your body. The altered version of the pathogen cannot cause an infection. However, the immune system still recognises it as a threat (because of the antigens) and produces antibodies and memory B and T cells in response. After the supposed threat has passed, the antibodies break down, but the memory cells remain in the body for years, granting immunity to that pathogen. If you encounter that pathogen again, the memory cells are activated, producing larger amounts of antibodies in less time. This faster and stronger response often eliminates the pathogen without you even noticing you were infected. This also means you are less likely to transmit the pathogen to other people.

vaccine
a chemical substance composed of a dead or weakened version of a pathogen that is injected into the body to make a person immune against that pathogen

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Figure 4.43 Vaccines prevent people from getting sick and limit the spread of pathogens through a population.

Science as a human endeavour 4.3

Cervical cancer vaccine

Almost all cervical cancers are caused by infection with human papilloma virus (HPV). HPV is transmitted via sexual intercourse and often shows no symptoms, so most infected individuals do not even know they have it. It can only be detected through cervical screening tests, such as a pap smear, which are recommended for anyone with a cervix. There are different types of HPV and these are categorised as low- or high-risk based on their ability to cause cancer. A persistent HPV infection can cause the cells of the cervix to become abnormal and eventually develop into cancer. HPV can also cause anal cancers, vaginal cancers, penile cancers and genital warts.

In the 1990s, University of Queensland researcher Professor Ian Frazer and his colleague, the late Dr Jian Zhou, started developing a HPV vaccine. Their vaccine, Gardasil, was approved in 2006, and Australia subsequently became the first country to add it to the National Immunisation Program. Gardasil-9 protects against seven of the high-risk types of HPV and is free for anyone aged 12–25 in Australia. In the first 5 years of the National HPV Vaccination Program, there was a 77% decrease in HPV-related disease among people with cervixes aged 18–24. Additionally, for those aged 20–24, the incidence of precancerous cervical cells decreased by 34%. If vaccination rates continue to be high, it is estimated that cervical cancer could be considered eliminated within the next 15 years.



Figure 4.44 The Gardasil vaccine is primarily provided through school immunisation programs.

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Did you know? 4.6

European diseases

In 1770, Lieutenant James Cook mapped the eastern coast of Australia. The First Fleet followed, arriving in Sydney in 1788. Prior to European settlement/invasion, Aboriginal and Torres Strait Islander Peoples had developed bush medicines and practices to combat disease. However, they had no immunity to the infectious diseases that were common in Europe. The most immediate consequence of colonisation by Europeans was a wave of epidemic diseases, including smallpox, typhoid, pneumonia, whooping cough, venereal diseases, measles and influenza, to name a few. Many of the European colonist populations had resistance to diseases like measles, bronchitis and scarlet fever, as they had already been exposed to the causative pathogens before arriving in Australia. However, these diseases were introduced by colonisers and spread rapidly through Aboriginal and Torres Strait Islander communities, killing many who had never been exposed before and devasting communities.

Section 4.3 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Go online to access the interactive section review and more!

Section 4.3 questions

Remembering

1. **Recall** how many lines of defence against pathogens humans have.
2. **State** which lines of defence are non-specific and which are specific.
3. **List** examples of two physical barriers in the first line of defence.
4. **Recall** which two cells perform phagocytosis.

Understanding

5. **Explain** how the second line of defence fights pathogens.
6. **Draw** a labelled diagram of an antibody to show how it can help combat pathogens.
7. **Explain** why you cannot get sick from a vaccine.
8. **Describe** how inflammation is useful in clearing infection.

Applying

9. **Explain** why it is dangerous to have a fever for too long.
10. Sauerkraut and kimchi are two examples of probiotics (friendly microbes) in food. People who consume these foods claim that it helps with their digestive health.
    a) **State** which line of defence the consumption of kimchi or sauerkraut would assist.
    b) **Explain** how eating these foods could potentially protect an individual against getting ill.

Analysing

11. **Compare** and **contrast** the second and third line of defence.
12. Acquired immune deficiency syndrome (AIDS) is a disease that kills off helper T cells. **Infer** why becoming infected by a pathogen is much more dangerous for a person living with AIDS.

Evaluating

13. **Discuss** the importance of achieving high coverage of vaccinated individuals in societies where infectious diseases are major health problems.

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Chapter review

Chapter checklist

Success criteria		Linked questions
4.1	I can define 'pathogen'.	1
4.1	I can describe the different types of pathogens.	2, 19a
4.1	I can list examples of common pathogens.	3, 4
4.2	I can distinguish between infectious and non-infectious diseases.	7
4.2	I can describe how infectious diseases can spread between people.	6, 19b
4.2	I can describe methods for limiting the spread of infectious diseases.	11, 13, 17, 18
4.3	I can describe the role of the immune system.	12, 15, 20
4.3	I can describe how the first line of defence prevents entry of pathogens.	14
4.3	I can explain how the second and third line of defence responds to an infection.	5, 9, 10
4.3	I can describe what it means to be immune to a disease.	16
4.3	I can describe how vaccines help build immunity against pathogens.	8, 21

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Define** 'pathogen'.
2. **Recall** the four different types of pathogens.
3. **Provide** an example of a pathogenic bacterium.
4. **Recall** a virus that causes disease in humans.
5. A lymphocyte is a special type of white blood cell. **Name** the two different types of lymphocytes.
6. **Recall** four ways in which an infectious disease can be transmitted between people.

Understanding

7. **Explain** the difference between an infectious and a non-infectious disease.
8. **Describe** how vaccination can prevent individuals from being infected by a disease.
9. **Explain** the difference between non-specific immunity and specific immunity.
10. **Explain** the role of antibodies.

Applying

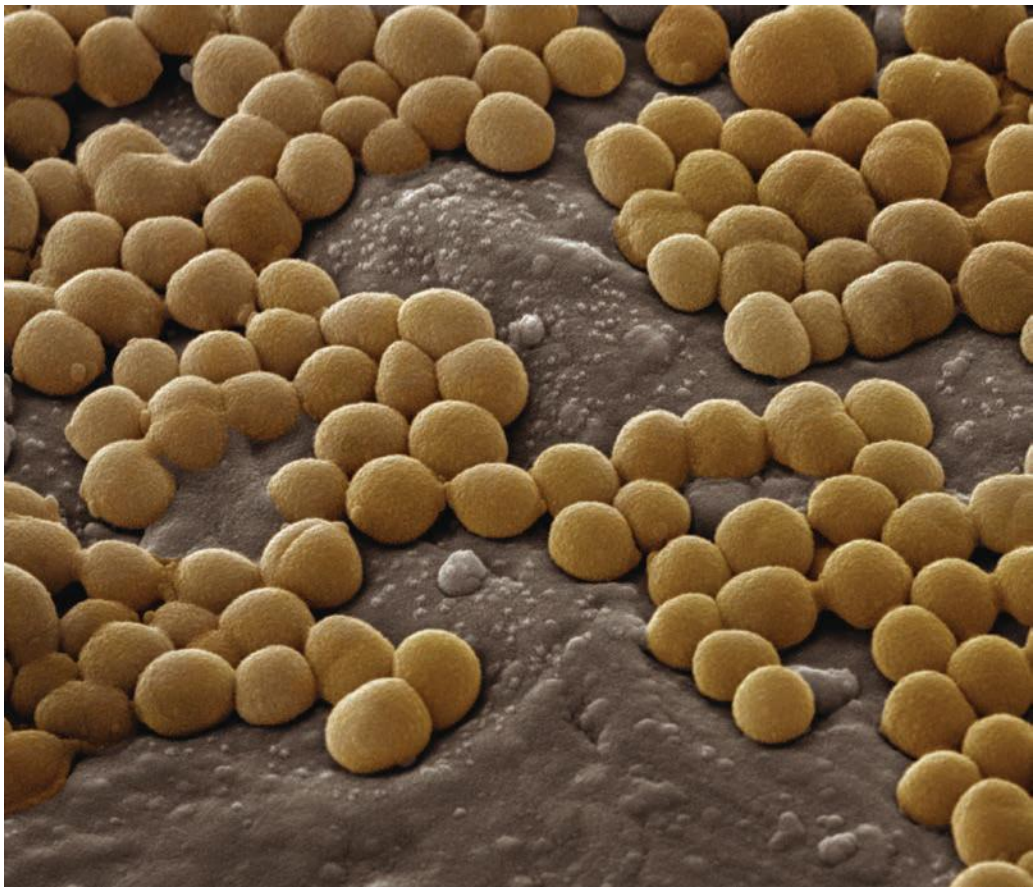
11. **Explain** why viruses cannot be treated with antibiotics.
12. The body's immune system may sometimes start to recognise 'self' antigens as foreign and 'non-self'. **Propose** what might happen in this case.
13. If a virus is spread through respiratory droplets, **describe** two ways to prevent transmission of the virus.

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14. **Explain** why intact skin is important for the first line of defence.
15. A child has had a fever above 40°C for 3 days. **Explain** why this happens and why it is dangerous.

Analysing

16. **Suggest** what is meant by the term 'immune memory'.
17. **Compare** the role of antibiotics and antiseptics.
18. 'Superbugs' are strains of bacteria that have adapted and become resistant after coming into contact with an antibiotic. **Explain** why superbugs are a significant problem in society.
19. The following image shows MRSA bacteria. The MRSA bacteria can survive on a healthy person's skin or in their lungs without causing any symptoms or ill effects; however, in an immune-compromised person, MRSA can be life-threatening.



a) **Suggest** the scientific name for this type of bacteria.
b) **Suggest** two ways it can spread from one individual to the next, along with possible ways spread can be prevented.

Evaluating

20. The role of security in an airport is sometimes used as an analogy for the immune system, with non-self antigens compared to dangerous or illegal items and white blood cells acting as security officers. **Evaluate** the accuracy of this analogy.
21. Herd immunity describes a population's resistance to a particular disease if a high proportion of individuals within the population are immune to the disease, usually through vaccination. Based on this information and what you have learned about how vaccination works, formulate and **evaluate** positive and negative viewpoints towards the compulsory vaccination of children.

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Data questions

To consider a disease eradicated, the agent that causes the disease must no longer be present anywhere in the world. Disease eradication is a permanent achievement, making control measures no longer necessary. Only smallpox, in 1980, and rinderpest, in 2011, have been eradicated. In theory, many diseases could be eradicated, but given current knowledge and technology, the International Task Force for Disease Eradication (ITFDE) has listed seven that are potentially eradicable in practice. These diseases are polio, Guinea worm disease, lymphatic filariasis, cysticercosis, measles, mumps and rubella.

Polio is an infectious disease that has no treatment and can lead to the permanent paralysis of body parts. It is close to being eradicated. Vaccines for polio have been used since the 1950s, which has led to the elimination of the disease from many developed countries. Two out of the three poliovirus types have been eradicated, with one remaining.

Figure 4.45 shows the estimated number of polio cases worldwide from 1980 to 2023, and Figure 4.46 shows the polio vaccine coverage worldwide from 1980 to 2021.

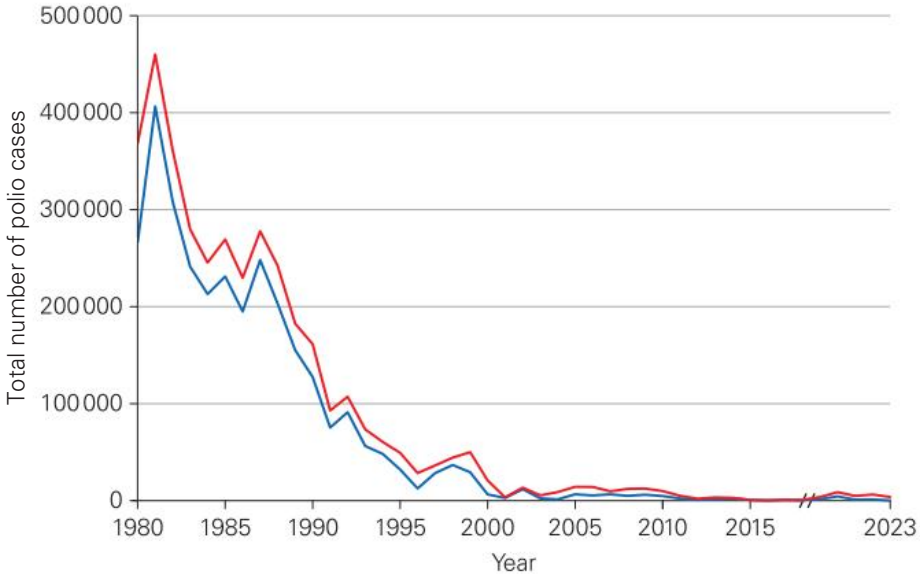


Figure 4.45 A graph showing the global numbers of polio cases in the world from 1980 to 2023
Data source: World Health Organization (2019, 2024); Tebbens et al. (2010)



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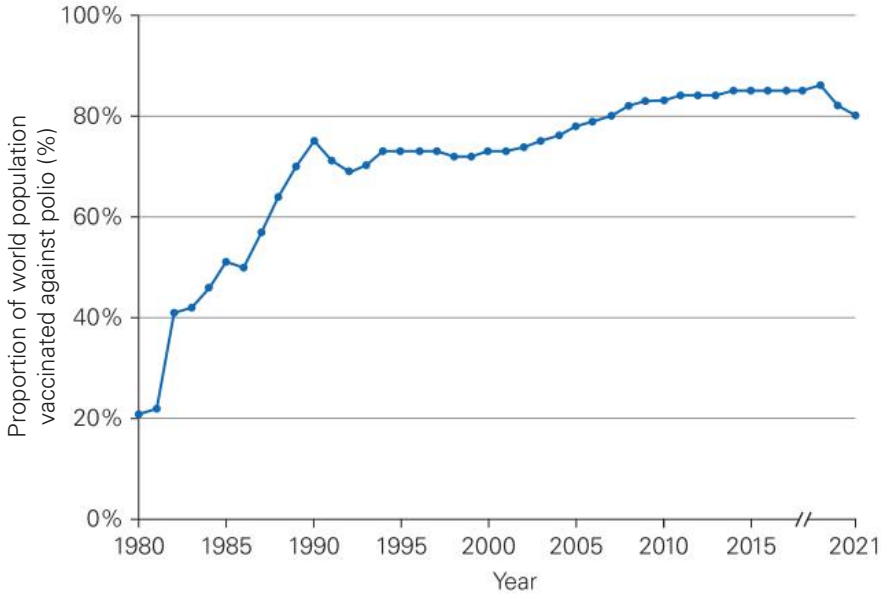


Figure 4.46 A graph showing polio vaccine coverage worldwide from 1980 to 2021
Data source: WHO & UNICEF (2024)

Applying

1. **Identify** the year in which the highest number of polio cases worldwide was recorded.
2. **Identify** the year in which polio cases fell below 100 000.
3. **Calculate** the change in the vaccinated proportion of the world population between 1981 and 1982.

Analysing

4. **Describe** the trend in the data for polio vaccine coverage from 1980 to 2021.
5. **State** which years saw the steepest decline in polio cases and compare this to the number of polio cases for those years.
6. **Analyse** the data in both figures and explain whether there is a relationship between vaccine coverage and the number of people affected by polio.

Evaluating

7. **Propose** a reason why the data in Figure 4.46 would underestimate the number of polio cases recorded.
8. **Evaluate** the data above for its effectiveness in showing the progress that is being made towards polio eradication.
9. **Suggest** further pieces of data that would be helpful in analysing the current situation with polio.



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STEM activity: Designing a public awareness campaign

Background information

COVID-19, caused by the SARS-CoV-2 virus, emerged in late 2019 and quickly led to a global pandemic, significantly impacting health, society and economies worldwide. The virus spreads primarily through respiratory droplets and aerosols when an infected person coughs, sneezes or speaks. Symptoms range from mild (fever, cough, fatigue) to severe (difficulty breathing, organ failure), with the elderly and those with underlying conditions at higher risk.

In Australia, cities like Melbourne experienced some of the strictest lockdowns globally to curb the spread of the virus, with public health measures including mask mandates, social distancing and, later, widespread vaccination campaigns. While these measures were effective in reducing infections, the pandemic also highlighted challenges, such as the rapid spread of misinformation on social media, which made it harder for some people to access accurate guidance on preventing and managing the virus.

Scientific advancements, such as the development of vaccines in record time, played a crucial role in controlling the pandemic. Public health messaging also emphasised simple but effective strategies, like handwashing, mask-wearing and vaccination, to reduce the spread. However, to ensure that people understood and followed these guidelines, it was essential to have clear and engaging public awareness campaigns, particularly to address myths and educate diverse communities.

DESIGN BRIEF

Design a public awareness campaign with the aim of reducing the spread of COVID-19.



Figure 4.47 COVID-19 testing sites were set up across the country to help stop the spread of the disease.

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Activity instructions

Your task is to use your knowledge of the spread of disease to create a public awareness campaign based on the COVID-19 pandemic. The audience for your campaign is the people in your school community. You can present your work to the class through a poster, a social media post, an advertisement or any other relevant media.



Figure 4.48 Many shop owners were forced to shut their doors during COVID-19 lockdowns.

Research and feasibility

1. Investigate COVID-19 by reviewing reliable sources, such as government health websites, scientific articles and information from public health organisations.
2. Identify the key messages your campaign will focus on, such as prevention, vaccination or combating misinformation.
3. Consider your audience: What information is most relevant to your school community's students, teachers and parents?
4. Assess the resources available to you, such as materials, digital tools and time, to ensure your campaign is practical and achievable.

Design and sustainability

5. In your group, decide on the format of your campaign.
6. Think about sustainability: How will your campaign have a lasting impact? Can it be updated or adapted for future use?
7. Develop a clear and concise plan, including sketches, storyboards or outlines for your materials.

Create

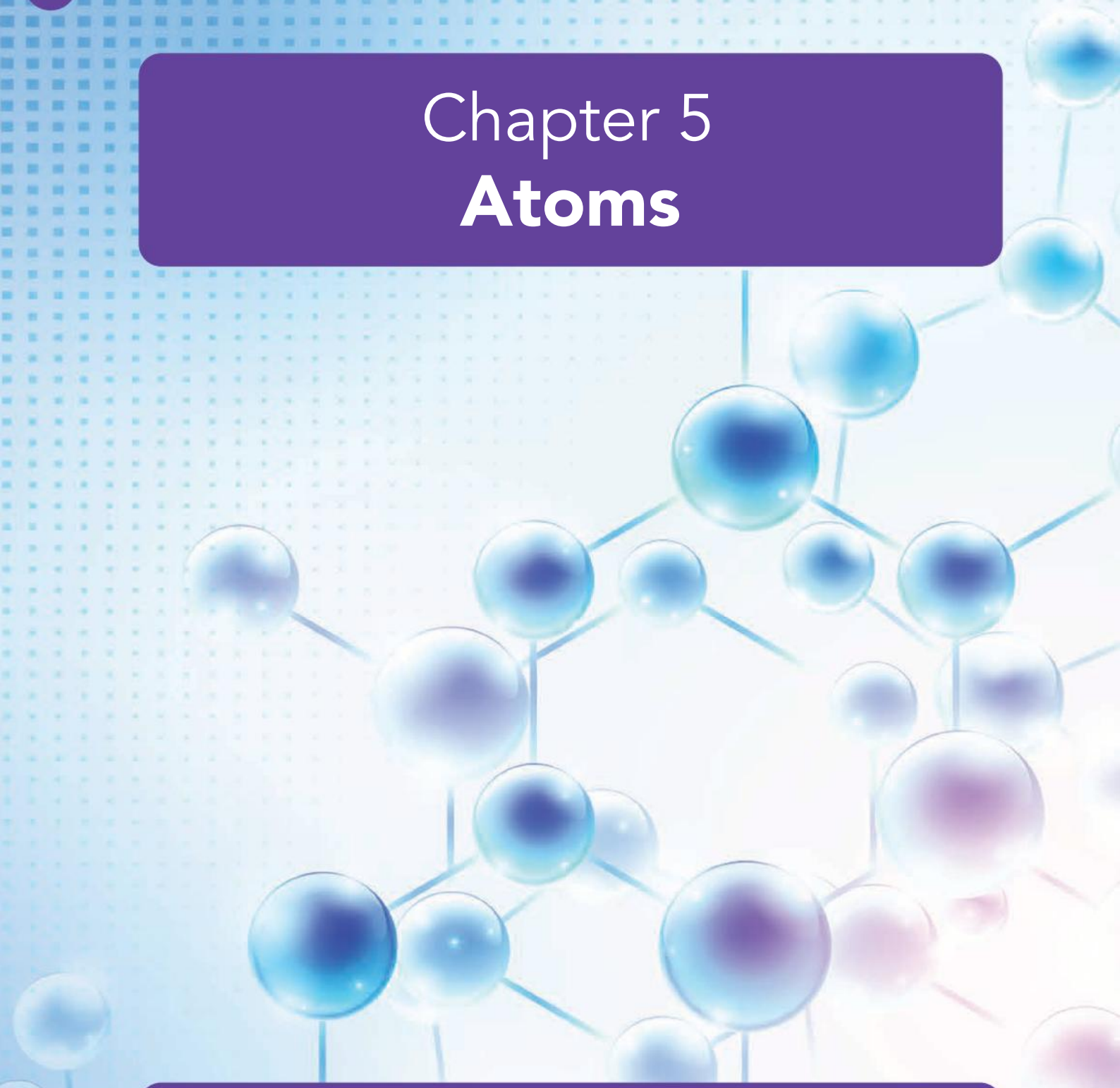
8. Develop your campaign materials based on your designs. Use tools such as:
   - Canva or similar graphic design software for posters or infographics
   - video-editing tools like iMovie or Adobe Premiere for video content
   - social media templates for Instagram posts or reels.
9. Ensure the content is accurate, engaging and visually clear. Use plain language where possible to ensure accessibility and consider multicultural communities, with a particular focus on Aboriginal and Torres Strait Islander Peoples.

Evaluate and modify

10. Gather feedback from your classmates about the effectiveness of the communication in your awareness campaign.
11. Explain any problems that might be encountered when implementing your campaign in the real world today. Could you incorporate technologies to help address these issues (e.g. artificial intelligence)?

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Chapter 5
Atoms



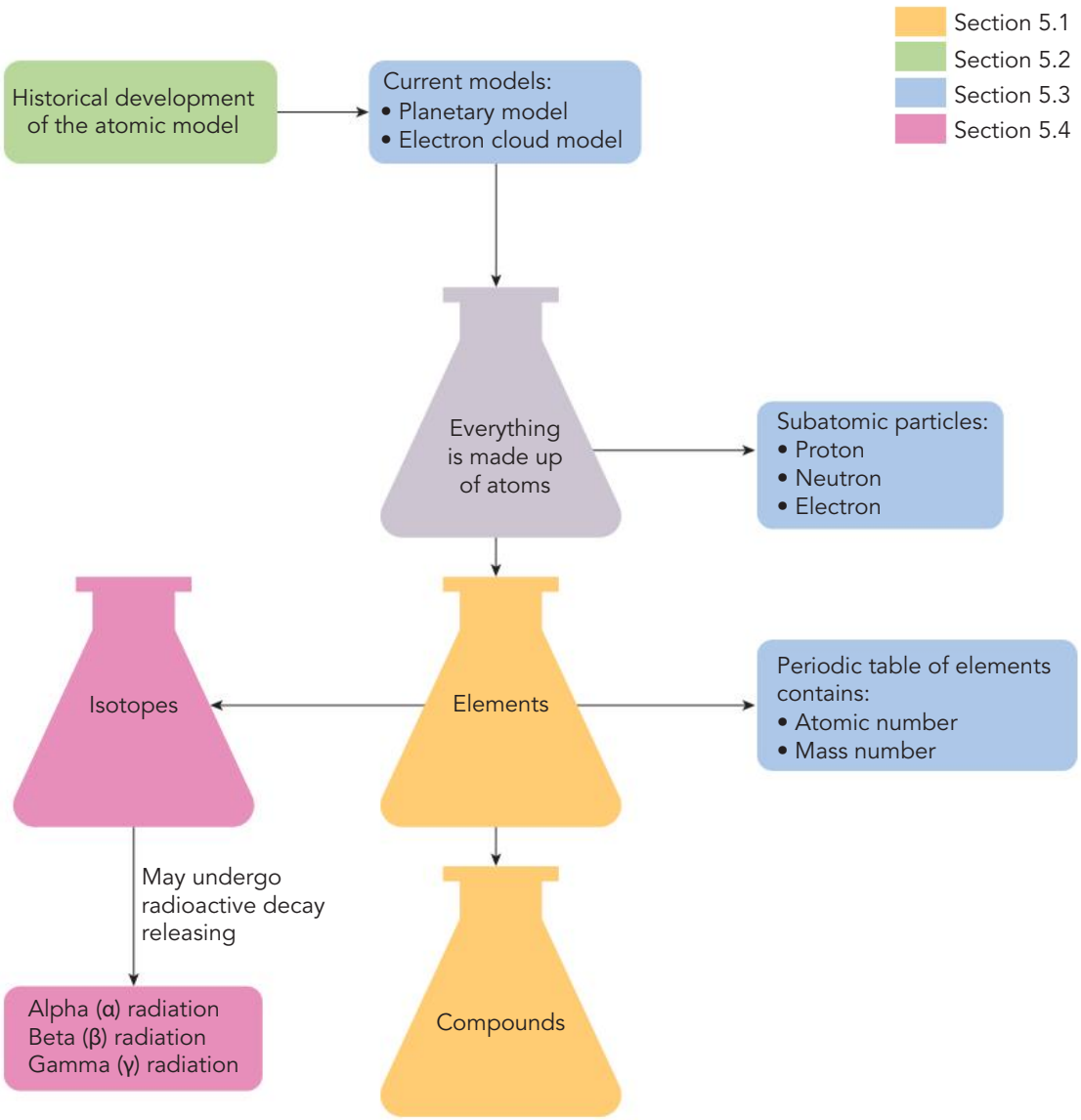
Chapter introduction

This chapter is all about atoms – those teeny particles that make up everything around us. The idea of the structure of the atom was developed by philosophers and scientists over thousands of years. Today, when we talk about the structure of atoms, we can refer to their subatomic particles: protons, neutrons and electrons. In this chapter, we will investigate how these subatomic particles can affect atomic number and atomic mass, and even how atoms of the same element can have different atomic masses. We will consider the formation of isotopes and learn about their stability and radiation, and you will see how different types of radiation can be used for new technologies, including in the medical and materials industries. Science is amazing!

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Concept map



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Curriculum content

the model of the atom changed following the discovery of electrons, protons and neutrons; natural radioactive decay results in a change from unstable to stable atoms (VC2S10U06)	
• comparing the masses and charges of protons, neutrons and electrons, and examining how the discovery of these particles resulted from experimental evidence and answered questions related to properties and behaviours of atoms	5.2, 5.3
• explaining that differences in the number of neutrons in atoms of the same element results in isotopes and that naturally occurring isotopes of some elements are unstable	5.4
• describing in simple terms how different unstable isotopes decay, such as radon-222 emitting an alpha particle, iodine-131 emitting a beta particle and cobalt-60 emitting gamma radiation to form stable atoms	5.4
• defining half-life, examining the timescales of decay of different elements such as carbon-14 and uranium-238, and simulating or using digital simulations to examine radioactive decay, including half-life	5.4
• researching how radiocarbon and other dating methods including optically stimulated luminescence have been used to establish that Aboriginal and Torres Strait Islander Peoples have been present on the Australian continent for at least 65,000 years	5.4
• identifying where applications of radioactivity are used in medicine and industry, such as in diagnosing and treating cancer, and when checking for faults in materials used in aircraft and spacecraft	5.4
scientific knowledge is contestable and is validated and refined over time through expanding scientific methods, replication, publication, peer review and consensus (VC2S10H01)	
• examining how Marie and Pierre Curie's discoveries of new elements were validated	5.4

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Glossary terms

Alpha particle	Half-life	Nuclide notation
Atoms	Ion	Proton
Atomic number	Ionic compound	Radioactive decay
Beta particle	Isotopes	Radioisotopes
Bioplastic	Mass number	Relative atomic mass
Compound	Molecule	Subatomic particle
Electron	Neutron	
Gamma ray	Nucleus	

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5.1 Atoms, elements and compounds

Learning goal
At the end of this section, I will be able to:
1. Define 'atoms', 'elements', 'compounds' and 'molecules'.

Atoms

You may recall from Year 8 that the word 'atom' comes from the Greek word *atomos*, which means 'indivisible' or 'un-cuttable'. If you cut a silver ring in half and then in half again, and continued to do this, you would eventually be left with an atom of silver (Ag). Scientists have now provided evidence that there are particles even smaller than an atom, and this is something you will explore later on in this chapter.

An **atom** is the smallest possible form of an element, and there is a unique atom for every element. So if a silver atom were cut in half, it would not be silver anymore, but would instead be two new elements.

atoms
the building blocks of matter

Atoms are too small to be visible to the naked eye. A human hair is about as thick as 500 000 carbon atoms stacked over each other. Even with examples like this, it is almost impossible to truly understand the size of an atom.

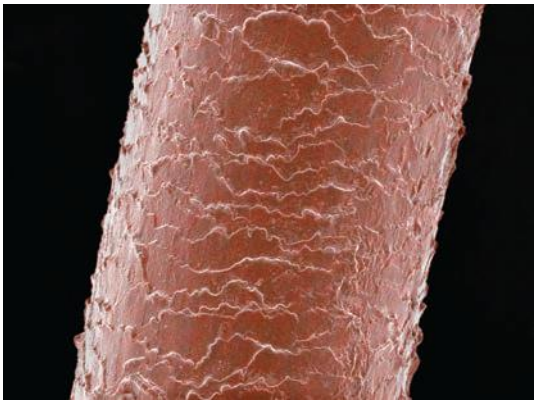


Figure 5.1 Human hair at 750× magnification

You can only visualise an atom with a highly specialised microscope called a scanning tunnelling microscope. The world's first images of atoms were produced by a research team at the International Business Machines Corporation (IBM). In 1981, physicists Gerd Binnig and Heinrich Rohrer developed the first scanning tunnelling microscope. They were awarded the Nobel Prize in Physics in 1986 for their efforts. This discovery allowed scientists to view images of many different atoms that had previously gone unseen.

Science as a human endeavour 5.1

The world's smallest movie

In 2013, researchers at IBM created the world's smallest movie. They used carbon monoxide molecules and moved them by using the small tip of the scanning tunnelling microscope. The movie is called *A Boy and His Atom* – a boy meets an atom and they become friends. It was created using individual frames that were put together using stop-motion software. You can search for this film on the internet. Although it was constructed for fun, it shows just how far science had come in the study of atomic and molecular systems.

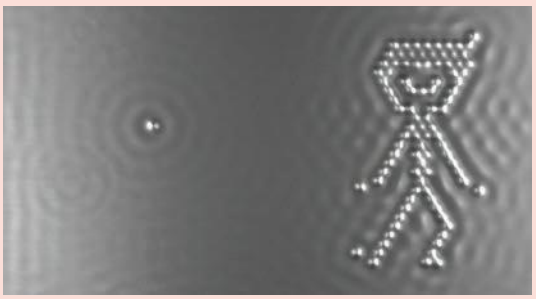


Figure 5.2 *A Boy and His Atom* was created using carbon monoxide atoms.

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Quick check 5.1

1. **Define** 'atom'.
2. **Recall** the name of the microscope that allowed scientists to view atoms.

VIDEO
Elements, compounds and molecules

Elements and compounds

Elements

Recall that all elements are made of only one unique type of atom and these atoms are identical to one another. For example, the element nickel is made up of only Ni atoms. All of the known elements are arranged on the periodic table according to their atomic and chemical properties (see Figure 5.3). They are represented by a symbol using one or two letters.

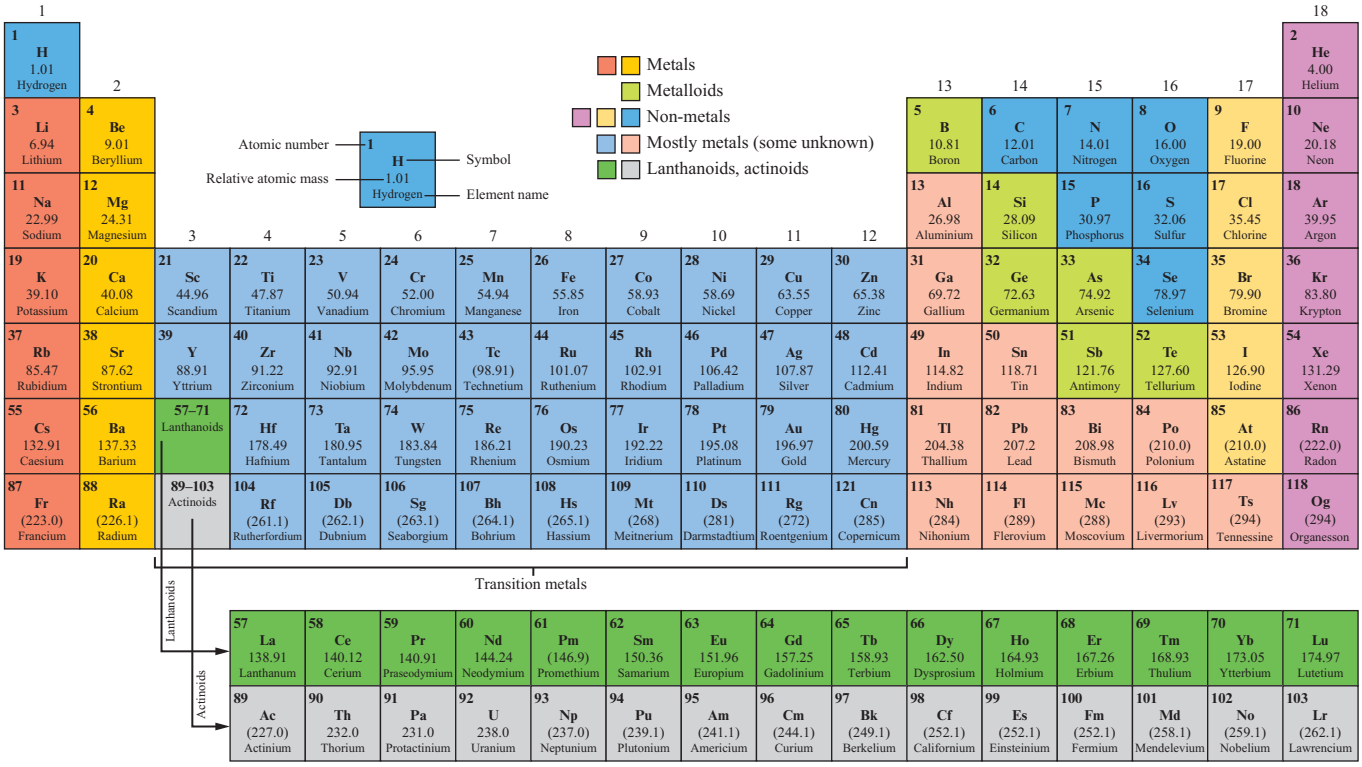


Figure 5.3 The periodic table of elements. See Appendix for a larger version of the periodic table.

Making thinking visible 5.1

Connect, extend, challenge: Element symbols

1. How do element symbols generally relate to their names in English?
2. Eleven element symbols in the periodic table do not match their English names. Can you identify all 11 elements?
3. Why is it important to know the origin of element symbols? How might this knowledge be important to a chemist?

The *Connect, extend, challenge* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.



Figure 5.4 Lead has the symbol Pb, from its Latin name *plumbum*. It was used in Roman plumbing pipes, hence its name.

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Compounds

Compounds are formed when two or more different elements combine in a fixed ratio by chemically bonding. The properties of the individual elements that make up a compound are usually different from the properties of the compound itself. For example, aluminium is a lustrous grey solid and oxygen is a colourless gas, but their compound (aluminium oxide) is a white solid. Compounds consisting of metal and non-metal atoms are often classified as **ionic compounds**.

compound
a substance formed by the chemical combination of two or more different elements in a fixed ratio

ionic compound
a type of compound generally made up of both metal and non-metal atoms

molecule
a chemical species made up of two or more atoms; it can be elemental or a compound

Molecules

The term **molecule** is often used to describe a chemical species made up of two or more atoms. For example, oxygen gas (O_2) is a molecular element, whereas water (H_2O) is a molecular compound. Both are molecules, but one is made up of only one type of element and the other contains different elements.

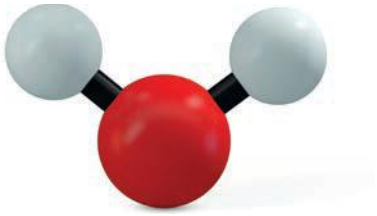


Figure 5.5 In this molecular model of water, there are two hydrogen atoms (white) and one oxygen atom (red).

WORKSHEET
Atoms, elements and compounds

Practical 5.1

Forming a compound from two elements

Be careful
Do not look directly at combusting magnesium.
Ensure general fire safety is followed.

Aim

To show that compounds have different physical properties compared to their individual elements

Materials

- 5 cm strip of magnesium ribbon
- tongs
- crucible
- matches
- Bunsen burner
- heatproof mat
- safety glasses

Method

1. Copy the results table below into your science book.
2. Record your observations of the physical properties of magnesium and oxygen.
3. Set up a Bunsen burner on a heatproof mat.
4. Hold the piece of magnesium ribbon with the tongs and put it into the hottest part of the flame until it catches alight. Avoid looking directly at the reaction.
5. Collect the compound formed in a crucible and observe the contents.
6. Complete the table recording your observations of the physical properties of the compound formed.

Results

Copy and complete the following table.

Table showing the physical properties (appearance) of the substances in the reaction

Substance	Physical properties (appearance)
Magnesium metal	
Oxygen gas (from the air)	
Compound formed	

Discussion: Analysis

1. Predict the name of the compound that was formed in the demonstration.
2. Propose a word equation for the reaction demonstrated.

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Practical 5.2

Splitting molecules into atoms

Aim

To split molecules of water into atoms

Be careful

Make sure connectors of leads are separated and not in contact with each other when attached to the switched-on power pack.

Materials

- baking soda
- distilled water
- 250 mL beaker
- 250 mL measuring cylinder
- stirring rod
- spatula
- power leads × 2
- alligator clips × 2
- power pack (or 9 V battery)
- safety glasses
- 15 cm square of thin cardboard

Method

1. Using the 250 mL measuring cylinder, measure 150 mL of distilled water and pour into the beaker.
2. Add a heaped spatula of baking soda to the beaker and stir it with the stirring rod until the baking soda has dissolved. Note: The baking soda will enhance the conductivity of the solution, but it is not involved in the chemical reaction.
3. Attach each lead to the 9 V battery or the DC terminals of the power pack (setting the voltage to 9 V).
4. To the other end of each lead, attach an alligator clip, making sure the wires do not touch each other.
5. Cut the piece of cardboard to fit over the beaker, then make two holes in the cardboard, approximately 3–4 cm apart.
6. Put the ends of the leads with the alligator clips through the holes in the cardboard and into the beaker of baking soda solution, again making sure the leads do not touch each other at any point.

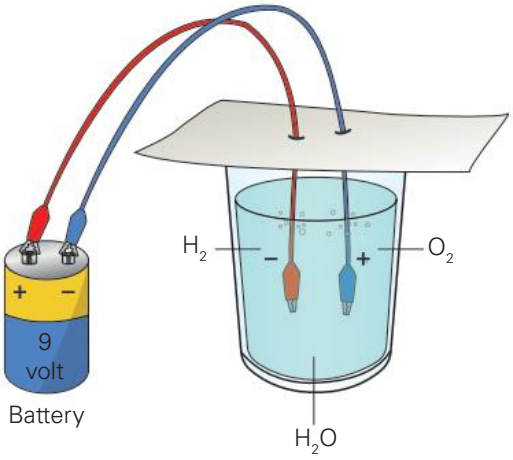


Figure 5.6 Experimental set-up

7. Leave this set up for 10 minutes. During this time you should see bubbles forming at each alligator clip.

Results

Compile a list of the observations that you made from this experiment. Remember, observations are what you can see happening, not an explanation of what is happening.

Discussion: Analysis

1. In this experiment, you split water molecules into their atoms. State which atoms make up water molecules and how many of each single atom there are.
2. Distilled water is water that has undergone a process to remove impurities. Propose why distilled water had to be used in this practical and suggest what, if any, effect this may have had on the outcome.

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Quick check 5.2

1. **Identify** the elements that form each of the following compounds.
   a) Water (H_2O)
   b) Carbon dioxide (CO_2)
   c) Sodium chloride (NaCl)
2. **Determine** whether it is possible to predict if a substance is an element or a compound by its chemical formula or by its chemical name.

Section 5.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 5.1 questions

Remembering

1. **Name** two elements that you might find in the air.
2. **Identify** the different elements present in ethanoic acid (CH_3COOH), which is found in vinegar.

Understanding

3. **Explain** why some elements on the periodic table have symbols that do not match their English names.

Applying

4. **Explain** why carbon dioxide (CO_2) is not found on the periodic table.

Analysing

5. **Compare** an atom, an element and a compound.
6. **Distinguish** between molecules and compounds.

Evaluating

7. **Decide** which of the following substances contain compounds: oxygen, potassium, water, sugar, candle wax, hydrogen, petrol. **Justify** your choice.



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5.2 Development of the atomic model

Learning goal

At the end of this section, I will be able to:

1. Outline the different contributions scientists and philosophers have made to the development of the modern model of the atom.

When did the idea of the atom first come about, and how has it changed over time?

Discussions about the atom and its structure have been going on within the scientific community for hundreds of years. In this section, you will examine the major discoveries that have contributed to our understanding of the atom and highlight how new experimental evidence can lead to a scientific model being updated or replaced. Concepts can be improved or completely changed as new scientific discoveries are made over time.

Democritus (460–370 BCE)

Democritus was the first philosopher to theorise about the atom. In 442 BCE, he hypothesised that if you take an object and cut it into smaller and smaller pieces, eventually you reach a point where you cannot cut it any smaller. You would end up with a piece that was indivisible. Democritus called this piece *atomos*, which means 'indivisible' in Greek. He thought, for example, that water was made of water atoms, bread was made of bread atoms and soil was made of soil atoms. This may sound silly now, but it was quite a sophisticated idea at the time. Keep in mind that Democritus had no modern technology such as microscopes to view these substances.

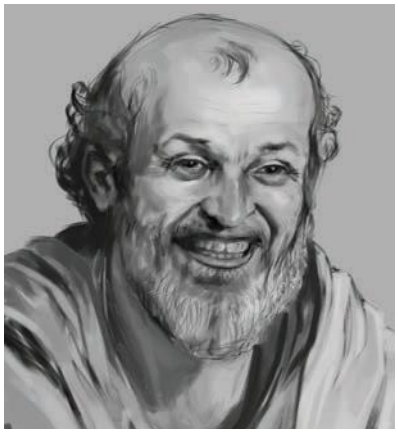


Figure 5.7 The Greek philosopher Democritus theorised about the atom.

Aristotle (384–322 BCE)

Aristotle rejected the ideas of Democritus, instead believing that matter on Earth was made up of four elements – earth, air, fire and water – and the relative amounts of these elements determined how materials behaved. Aristotle had such an influence over people at the time that they forgot all about Democritus' theory.



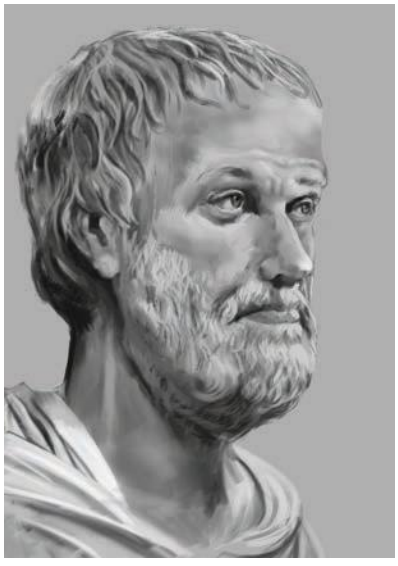


Figure 5.8 The Greek philosopher Aristotle proposed that all matter was made up four elements: earth, air, fire and water.

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John Dalton (1766–1844)

Dalton is credited with initiating research into modern atomic theory in 1803, more than 2000 years after Democritus first proposed his ideas on the atom. Dalton suggested that all elements, which had by then been arranged in the periodic table, contained atoms, and that atoms of the same element would be identical in size, shape and mass. Dalton imagined the atom as a solid sphere, so this theory was called the 'solid sphere model'. He also stated that compounds were a combination of elements. The question he could not answer was why atoms behave the way they do.

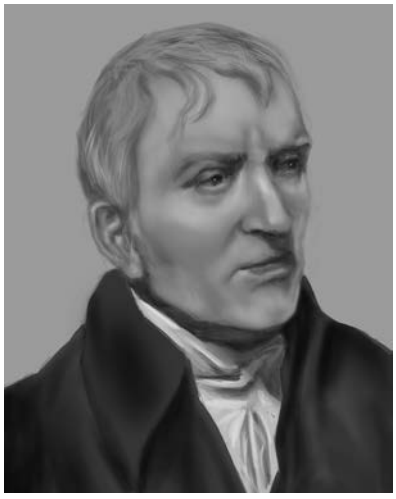


Figure 5.9 John Dalton was an English chemist, physicist and meteorologist. He is best known for initiating research into modern atomic theory.

Joseph John Thomson (1856–1940)

Thomson was the first scientist to discover particles smaller than the atom, disproving Dalton's and Democritus' theories. Surprisingly, the first subatomic particle to be discovered was the lightest – the electron – and Thomson won a Nobel Prize for his work in 1906. By studying 'rays' within a cathode ray tube, Thomson was able to determine that these 'rays' had a mass 1000 times smaller than a hydrogen atom, the lightest piece of matter known to science at the time. He therefore concluded that these 'rays' were not rays at all, but very light particles. These particles were also attracted to a positively charged metal plate, indicating that they were likely to be negatively charged. He named these particles 'corpuscles', but they are now called electrons.

The first model of the structure of the atom was proposed by Thomson, who named it the 'plum pudding' model (see Figure 5.11). Thomson knew that electrons were negatively charged and that atoms were neutral, so he theorised that there must also be positive charge within the atom that equalled the negative charge of its electrons. He imagined the atom as negatively charged electrons (plums) embedded in a large 'sea' of positively charged 'pudding'.



Figure 5.10 Thomson proposed the plum pudding model and is credited with discovering the electron.

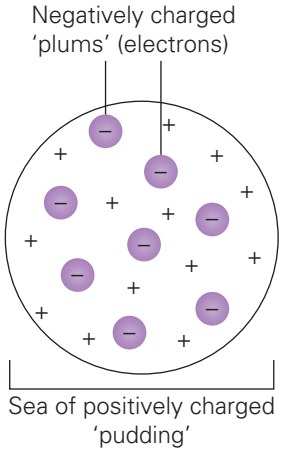


Figure 5.11 The plum pudding model consists of negatively charged electrons (the plums) scattered through a sea of positive charge (the pudding).

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WORKSHEET
The gold foil experiment

Ernest Rutherford (1871–1937)

In 1911, Ernest Rutherford and colleagues Hans Geiger and Ernest Marsden fired **alpha particles** (helium **nuclei**) at a thin piece of gold foil, in the famous gold foil experiment.

alpha particle
a positively charged particle that is emitted from the nucleus of some radioactive elements during the radioactive decay (or disintegration) of an unstable atom

nucleus (plural: nuclei)
the central part of the atom containing its protons and neutrons

Rutherford predicted that if the atom was like Thomson's plum pudding model, then all the alpha particles should pass straight through the atom undisturbed. This is not what happened! As the gold foil experiment showed, although almost all (99.99%) of the alpha particles passed straight through the foil and were detected at the other side, indicating that the atom was mainly empty space, some of the alpha particles bounced back or were deflected as if they had hit something. Rutherford concluded that there must be an area of charge concentrated in the middle of the atom, with enough mass to cause the alpha particles to deflect or bounce back, thus disproving the plum pudding model (see Figure 5.13).

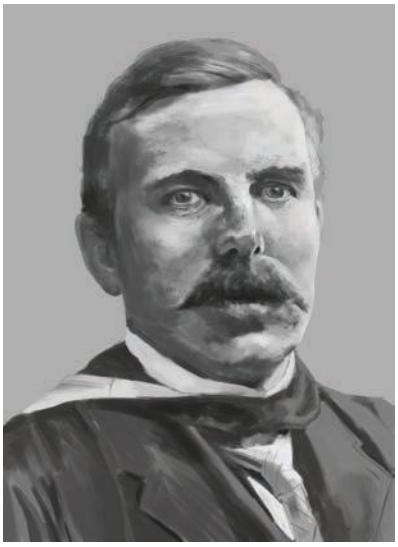


Figure 5.12 Rutherford stated that there was a large concentration of charge and mass situated in the centre of the atom and that most of the atom was empty space.

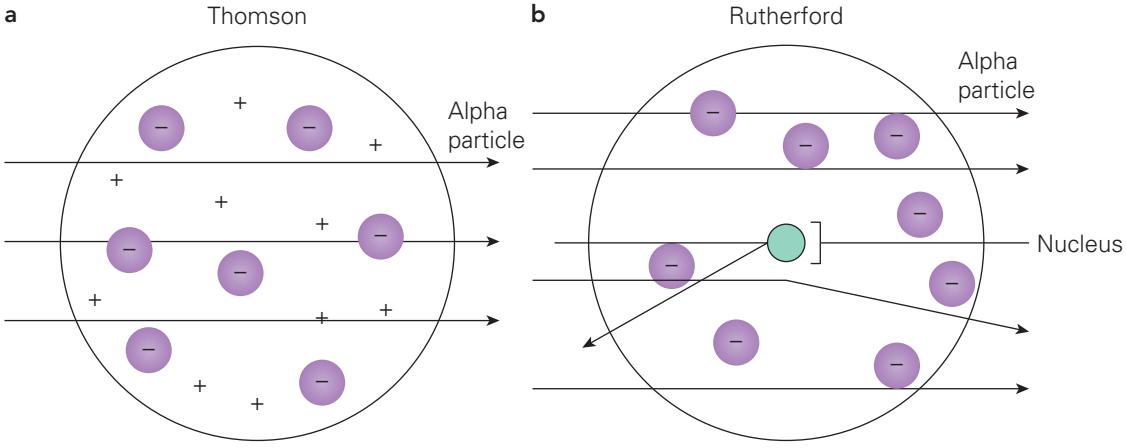


Figure 5.13 Comparison between atomic models: **(a)** Thomson's plum pudding and **(b)** Rutherford's central region of mass and charge

In analysing the results of this experiment, Rutherford devised his own model of the atom. This model depicts a charged area with substantial mass concentrated in the middle of the atom, called the nucleus. Rutherford and many other scientists assumed the nucleus to be positively charged because it repelled the positively charged alpha particles that were fired towards it. Rutherford concluded that the negatively charged electrons orbited around this central region. Rutherford's model is often called the 'nuclear' model of the atom. Although many other scientists contributed to the developing knowledge at the time, it was Rutherford who named the positively charged particles in the nucleus 'protons'.

Try this 5.1

Modelling the development of atomic theory



Consider:

- How is a gumball like Dalton's theory of the atom?
- How is a chocolate chip biscuit like Thomson's model of the atom?
- How could you represent Rutherford's model of the atom using sweet treats?

Interactive digital simulations are also a type of modelling. Take a look at PhET's Rutherford scattering simulation online to see how an animation can help us understand more about science.

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Explore! 5.1

Millikan's oil drop experiment

In 1923, physicist Robert Andrews Millikan won the Nobel Prize in Physics for his now famous oil drop experiment, which provided evidence for the formal charge of the electron.

Use the internet to answer the following questions.

1. What is the Millikan oil drop experiment?
2. How does the experiment provide evidence of the negative charge of the electron?

Millikan's evidence was consistent with evidence from earlier discoveries, including Thomson's discovery of the electron and Rutherford's hypothesis that electrons exist in space around a dense positively charged nucleus. These three key findings were pivotal for the consolidation of knowledge about electricity – the movement of negatively charged electrons through a substance.

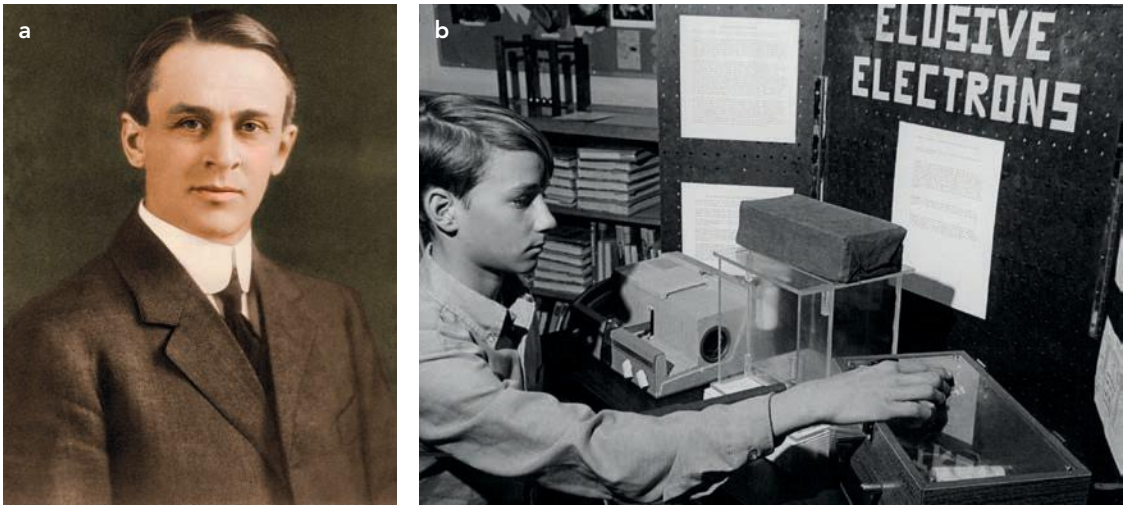


Figure 5.14 (a) Nobel laureate Robert Andrews Millikan and **(b)** a student conducting the Millikan oil drop experiment

Quick check 5.3

1. **Recall** the four elements that Aristotle believed made up all matter on Earth.
2. **State** the name of the subatomic particle that Thomson discovered and the name of his atomic model.
3. **Complete** the sentences below using the word list.

alpha	empty space	plum pudding model
nucleus	passed through	

Rutherford conducted the gold foil experiment, firing _____ particles at a thin piece of gold foil. Most of these particles _____; however, a small number were deflected back. Rutherford hypothesised that the reason for this was that the particles were either passing through a region of _____ or hitting a central region of concentrated mass and positive charge, which he called the _____. His findings disproved the _____.

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By the early twentieth century, scientists had a good idea about atomic structure; they just needed to identify where the electrons were actually situated in the atom.

Niels Bohr (1885–1962)

Niels Bohr proposed his model of the atom (a modification of Rutherford's theory) in 1913 after observing the behaviour of electrons. Bohr was trying to compare the behaviour of electrons and the behaviour of light. He said electrons moved in fixed circular orbits around the nucleus in structures called shells, and that these shells were specific distances away from the nucleus and the same for all atoms. Bohr's model is often called the 'planetary model' because it resembles how planets orbit a central star.

Electrons located in shells that were further away from the nucleus had higher energies than those closer to it. He stated that when electrons absorb energy, or get excited, they jump to the next energy level or shell. When they fall back to their original level, they emit some light, which matches the amount of absorbed energy.

Scientists now know that Bohr's model has some flaws, but it provided some important understanding about the behaviour of electrons. This model, built off the work of Dalton, Thomson and Rutherford, is the model you will recognise and use the most in your studies.



Figure 5.15 Bohr proposed that electrons were not randomly spread across the atom but were arranged in discrete energy levels or shells.

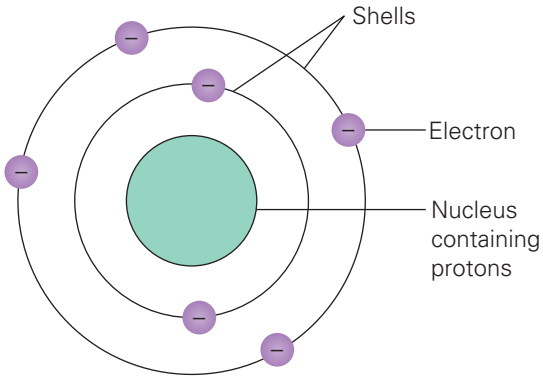


Figure 5.16 Bohr's model of the atom is sometimes called the planetary model. It shows electrons in fixed shells around a central nucleus.

Erwin Schrödinger 1887–1961

Although Bohr's model proposed that electrons existed in 'shells' around the nucleus, scientists knew very little about the position and behaviour of the electrons in the 'shells'. Erwin Schrödinger stated that it is impossible to predict where a specific electron will be situated in the atom at any given time. The only thing you can predict is where in the atom you are most likely to find an electron. This contradicted Bohr's idea of electrons being in fixed shells around a central nucleus. Schrödinger proposed the electron cloud model, which shows the locations in the atom with the greatest probability of containing an electron. This relates to the wave properties of the electron (quantum, or wave, mechanics).

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Figure 5.17 Schrödinger proposed the electron cloud model, contradicting Bohr's model of fixed electron shells.

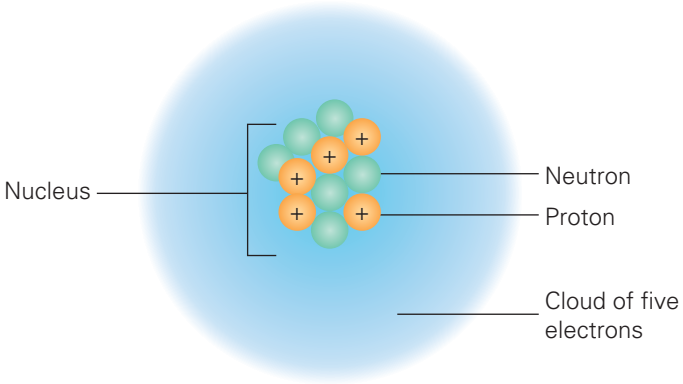


Figure 5.18 The electron cloud model of a boron atom

James Chadwick (1891–1974)

The last of the three subatomic particles to be discovered was the neutron. Since it has no charge and does not repel the protons in the nucleus, this subatomic particle was relatively undetectable. This was until James Chadwick started working with beryllium atoms and alpha particles in 1932. When he collided these two particles together, an unknown radiation made up of neutrally charged particles was released. He named these particles neutrons.

In high school, although we use the Bohr model (protons in the nucleus and shells of electrons), we also include neutrons in the nucleus in our diagrams, even though Bohr did not.



Figure 5.19 Chadwick discovered the neutron, the last subatomic particle to be discovered. This completed the atomic model in use today.

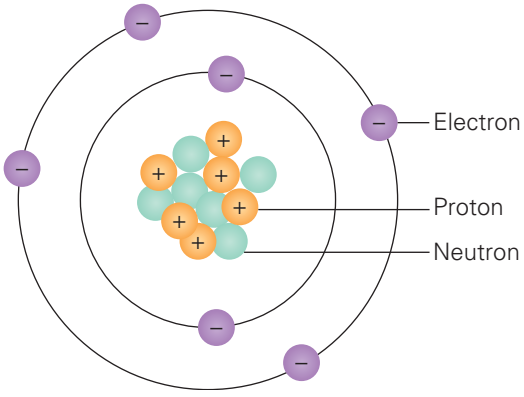


Figure 5.20 We use the Bohr model, also showing neutrons, because it is a simplification of the electron cloud model.

Quick check 5.4

1. a) **Recall** the name Bohr gave to the structures that contained electrons.
   b) **Describe** how Bohr's explanation of these structures differed from Rutherford's model.
2. **Identify** the subatomic particle that Chadwick discovered.

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WORKSHEET The development of the atomic model

The evolution of the atomic model is an excellent example of how individual scientists contributed to and continue to revise our understanding of atomic structure. However, it is important to note that this is still a model and there may be new discoveries to come. After all, at one time scientists thought that the plum pudding model was the correct model of atomic structure. It is important that scientists continue to ask questions, conduct experiments and critique other people's work to increase our understanding of atomic structure.

Science as a human endeavour 5.2

The Higgs boson

Our understanding of the structure of the atom and the particles within it did not stop with James Chadwick in 1932. In 1964, British-born theoretical physicist Professor Peter Higgs proposed the existence of another subatomic particle, which was later named after him: the Higgs boson. The detection of this particle became his goal and the goal of many other theoretical physicists.



Figure 5.21 Professor Peter Higgs (1929–2024) proposed another subatomic particle, the Higgs boson. The existence of this particle was confirmed in 2012.

In 2012, the European Organization for Nuclear Research (CERN) announced they had conducted experiments on the Large Hadron Collider (LHC), a particle accelerator built in a ring-shaped tunnel with a 27-kilometre diameter underneath the Franco–Swiss border. The experiments showed promising results of a particle that could be a Higgs-like boson.

You can imagine the excitement Professor Higgs must have felt after all this time! In 2013, after almost 55 years of research, CERN finally had enough evidence to confirm that they had recorded the presence of a Higgs boson. Professor Higgs was awarded a Nobel Prize in Physics in the same year.

This is a great example of how, with hard work and persistence, you can achieve your goals!



Figure 5.22 Engineers working on a part of the LHC at CERN where the Higgs boson was discovered

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The Matilda Effect

The 'Matilda Effect' refers to the systematic denial or minimisation of women's scientific contributions, with their work often attributed to male colleagues. This phenomenon has led to the historical erasure of many women scientists' achievements, perpetuating gender biases in the recognition and rewarding of scientific work.

The following examples underscore the challenges women have faced in the scientific community. Throughout the development of atomic theory, numerous women made significant contributions that were often overlooked, marginalised, or attributed to their male counterparts due to systemic misogyny.

Marie Curie (1867–1934)

Marie Curie's pioneering work in radioactivity was foundational to our understanding of atomic structure. She discovered the elements polonium and radium and coined the term 'radioactivity'. Despite her monumental contributions, she faced substantial gender-based discrimination. In 1903, when the Royal Institution in London invited the Curies to speak on radioactivity, only her husband, Pierre Curie, was permitted to speak.

Lise Meitner (1878–1968)

An Austrian Swedish physicist, Lise Meitner played a crucial role in the discovery of nuclear fission, the process that powers nuclear reactors and atomic bombs. Despite her significant contributions, it was her collaborator Otto Hahn who received the Nobel Prize in Chemistry in 1944 for this discovery, while Meitner's role was largely overlooked, exemplifying the systemic biases that lead to the erasure of women's contributions in science.

Charlotte Froese Fischer (1929–2024)

A Canadian American applied mathematician and computer scientist, Charlotte Froese Fischer developed the Multi-Configurational Hartree-Fock (MCHF) approach to atomic-structure calculations. Her theoretical prediction of the existence of the negative ion of calcium was experimentally confirmed, marking the first known anion of a Group 2 element. Despite her significant contributions, she faced challenges in a male-dominated field, reflecting the broader systemic issues that often led to the underrepresentation and undervaluation of women's work in science.

Did you know? 5.1

Neutrinos

In this section, you have learned that the atom is made up of three different subatomic particles. However, there are actually a few more, including the Higgs boson. Another subatomic particle is the neutrino, which is hypothesised to act like an electron but have a neutral charge. Neutrinos don't exist in an atom but are produced and emitted when two or more atoms fuse together under extremely high temperature and pressure, such as the



Figure 5.23 Nobel Laureates Professors Arthur B. McDonald and Takaaki Kajita in 2015

continued …

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conditions on the Sun. These neutrinos then travel through space, with some reaching Earth. In 2015, Professors Takaaki Kajita and Arthur B. McDonald were awarded the Nobel Prize in Physics for their work showing that neutrinos have mass, just like electrons.



Figure 5.24 Professor Janet Conrad studies neutrinos.

Professor Janet Conrad is an American physicist and a leading expert on neutrinos. She has played a key role in the Main Injector Neutrino Oscillation Search (MINOS) experiment, which was designed to study the behaviour of neutrinos as they travelled through Earth. She led a team that developed the software and algorithms used to analyse the data collected by the experiment. The MINOS experiment provided important evidence for the phenomenon of neutrino oscillation, which is the process by which neutrinos change their identity as they travel.

Go online to access the interactive section review and more!

Section 5.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 5.2 questions

Remembering

1. **Recall** what the Greek word *atomos* means in English. How does this relate to the word 'atom'?
2. **Recall** who discovered the neutron.

Understanding

3. **Summarise** what Rutherford predicted would happen, according to Thomson's plum pudding model, when he fired alpha particles at gold foil.
4. **Identify** why some alpha particles bounced back towards the detector in Rutherford's gold foil experiment.

Applying

5. **Compare** Rutherford's model of the atom with the plum pudding model.

Analysing

6. **Analyse** the differences between Schrödinger's and Bohr's models of the atom.

Evaluating

7. **Discuss** the evidence that led to Rutherford concluding that most of the mass and all the positive charge of the atom were concentrated in the centre.

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5.3 The modern structure of the atom

Learning goals

At the end of this section, I will be able to:

1. Compare the relative mass and charge of protons, neutrons and electrons.
2. Define 'ion', 'atomic number' and 'mass number'.
3. Determine the number of protons and electrons in the atom of an element.
4. Calculate the mass of an atom from the number of protons and neutrons.

VIDEO
Subatomic particles

Subatomic particles

Despite having a long history, it was only in the twentieth century that the idea of atoms became widely accepted. As new technologies developed, physicists discovered that the atom is made up of three main **subatomic particles**: **protons**, **neutrons** and **electrons**. There are different numbers of these subatomic particles in each element, which we will explore shortly.



Figure 5.25 The Large Hadron Collider (LHC) is used by scientists to accelerate particles and then smash them together.

subatomic particle one of the particles that make up an atom

proton a subatomic particle with a positive charge found in the nucleus of an atom; it has a relative mass of 1

neutron a subatomic particle with a neutral charge found in the nucleus of an atom; it has a relative mass of 1

electron a subatomic particle with a negative charge, found outside the nucleus of an atom; it has a relative mass of $\frac{1}{1836}$ of a proton or neutron

Since 2008, physicists have learned a lot more about particles within atoms from studies using CERN's LHC. Here, subatomic particles are smashed together at speeds close to the speed of light. The remains are then analysed. When the LHC was first built, some scientists believed it would create many miniature black holes that might even swallow Earth. Luckily, despite being the world's biggest machine, the LHC currently cannot produce nearly enough energy for this to occur.

Did you know? 5.2

Ordinary hydrogen: An unusual element

Hydrogen is the only element that does not contain all three subatomic particles. Most hydrogen atoms only contain one proton and one electron. It is missing a neutron!

Modern atomic models

Even with the most powerful microscopes, scientists cannot see inside the atom, so they create models of the atom to represent ideas that cannot be observed. To help visualise the structure of the atom, you can model it as a mini solar system. In the middle of our solar system is the Sun and orbiting the Sun are the planets, with most of the rest of the solar system being empty space.

The atom has a similar kind of structure. In the middle of the atom is a structure called the nucleus, which is where the protons and neutrons are situated. Orbiting the nucleus in shells (also known as orbitals) are the electrons. The shells are drawn as circles and are at different energy levels depending on how far they are away from the nucleus.

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The first shell can 'hold' up to two electrons, and the second shell up to eight electrons before it is full. Each lower shell must be filled before electrons begin occupying the next shell.

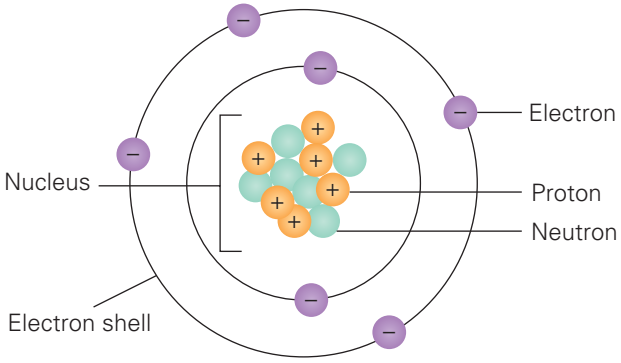


Figure 5.26 A Bohr diagram shows the positively charged nucleus (containing both protons and neutrons) in the middle, with the negatively charged electrons orbiting in shells around it.

Just like the solar system, most of the atom is made up of empty space. To give you an idea of how empty the atom is, if the atom was the size of an Olympic athletics track, then the nucleus would only be the size of a pea!

Did you know? 5.3

Maria Goeppert Mayer

Maria Goeppert Mayer was a pioneering physicist whose work on the nuclear shell model revolutionised our understanding of the behaviour of subatomic particles. Born in Germany in 1906, Goeppert Mayer moved to the United States in the 1930s and began working on the physics of the atomic nucleus. Her research on the behaviour of protons and neutrons led to the development of the nuclear shell model, which explained the stability and behaviour of atomic nuclei based on the arrangement of their protons and neutrons.

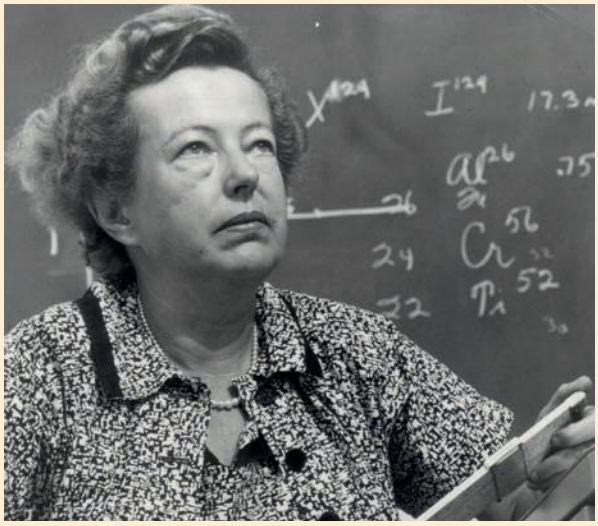


Figure 5.27 Despite her groundbreaking work, Goeppert Mayer struggled to find paid academic positions due to gender discrimination. Her achievements were finally recognised when she became the second woman to receive the Nobel Prize in Physics in 1963, decades after her initial contributions.

Quick check 5.5

1. **Name** the structure at the centre of the atom and **state** what it contains.
2. **Identify** the location of the electrons in modern atomic models.

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Properties of subatomic particles

To understand more about atoms and how they behave, we need to know more about the three subatomic particles within them.

Charge

You may be wondering what keeps the electrons inside the atom. If they are whizzing around at enormous speeds inside the atom, why don't they just fly off into space? The reason they remain has to do with the electrical charges of the subatomic particles. The protons in the nucleus in the middle of the atom have a positive charge (+1 each). Electrons orbiting the nucleus have a negative charge (–1 each). Positive and negative charges follow two basic rules of electrostatics: opposite charges attract and like charges repel. This means that the protons and electrons in an atom are attracted to each other, and this is what stops the electrons from flying off into space. Neutrons are electrically neutral, which means they have relatively no charge (0).

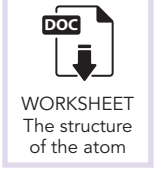
Mass

Protons and neutrons have very similar masses: a proton has a mass of 1.673×10^{-24} grams (g) and a neutron has a mass of 1.675×10^{-24} g. These numbers are very small and almost the same, so for practical reasons, both protons and neutrons are assigned a relative mass of 1 atomic mass unit (amu). These values are much easier to remember and work with. Electrons have a relative mass $\frac{1}{1836}$ of a proton or a neutron.

Quick check 5.6

1. Copy and complete this table to **summarise** the differences in charge and relative mass of the three subatomic particles.

Subatomic particle	Symbol	Location	Relative charge	Relative mass
Proton	p^+			
Neutron	n^0			
Electron	e^-			



WORKSHEET
The structure of the atom

Explore! 5.2

Particles smaller than the electron

Scientists once thought that the atom was the smallest particle that existed. Now we know that protons, neutrons and electrons make up the atom, but is there anything that makes up these subatomic particles? Because of its wavelike properties, it is extremely hard to define or measure the size of an electron. Some quantum physicists think that an electron could even be in two places at one time.

Research the particles that make up protons, neutrons and electrons, also known as quarks. What are their names? What is known about them?

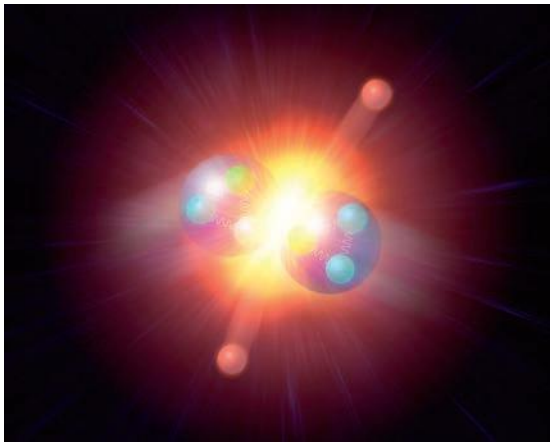


Figure 5.28 Two protons collide to emit two Higgs bosons. The protons are each made up of three smaller quarks.

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The number of subatomic particles in an atom depends on the type of element being considered. Look at the periodic table in Figure 5.29 and you will notice that each element has a symbol and two numbers. These numbers provide information about the number of protons, neutrons and electrons in each atom of that element.

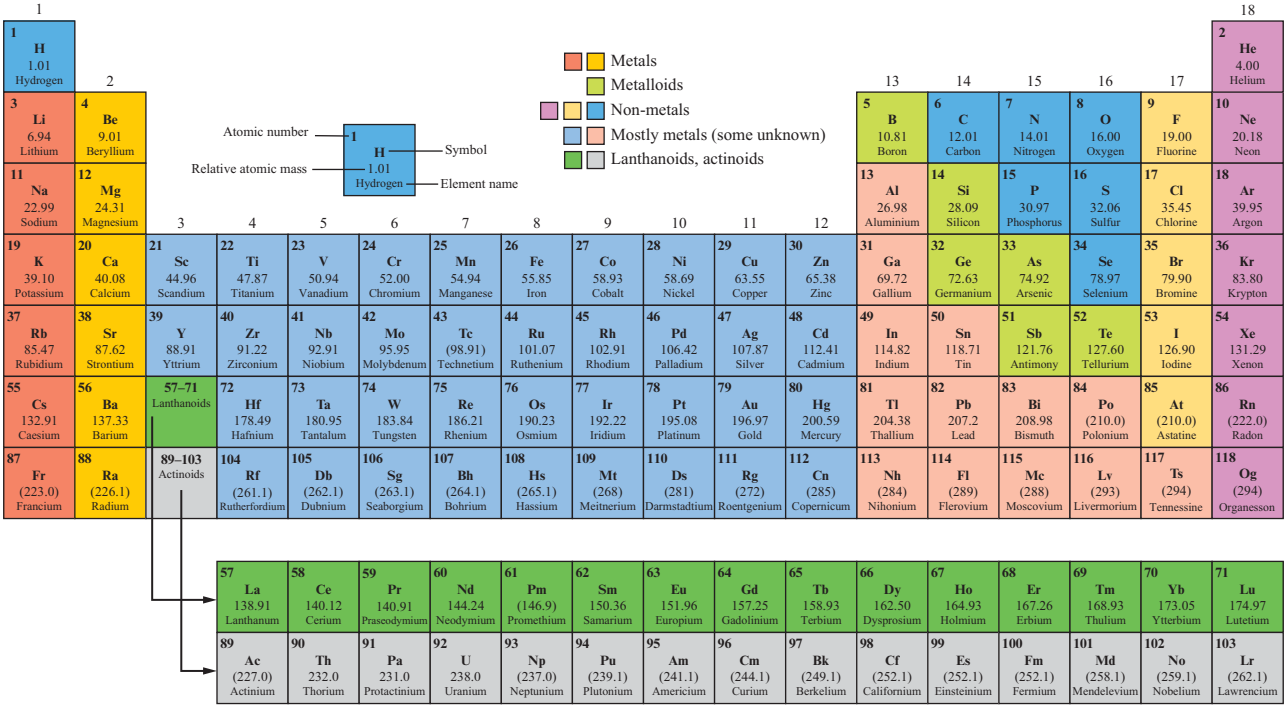


Figure 5.29 The periodic table gives you information about each element's atoms. See Appendix for a larger version of the periodic table.

Atomic number

atomic number the number of protons in an atom of an element

The number on the top left above the element symbol is called the **atomic number**. The atomic number is sometimes called the *proton number*, as it tells you how many protons are in an atom of that element. For example, the atomic number of carbon is 6; therefore, a carbon atom has six protons.

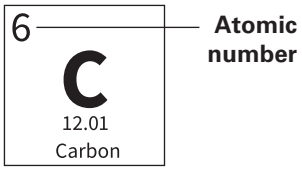


Figure 5.30 For the element carbon, the atomic number is 6. Therefore, you can conclude that it has six protons.

The atomic number defines the element. Any atom that contains six protons will always be carbon, no matter how many neutrons or electrons it contains. If another proton is added to carbon, then a different element with seven protons is formed – otherwise known as nitrogen. Carbon is a black solid and nitrogen is a colourless gas; one proton can make a big difference to an element's properties!



Figure 5.31 Carbon is a black solid with an atomic number of 6.



Figure 5.32 Nitrogen is a colourless gas with an atomic number of 7. It can be converted to a liquid by cooling it to –196°C.

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This is the same for any other element on the periodic table. Hydrogen has one proton so any other substance with one proton will also be the element hydrogen.

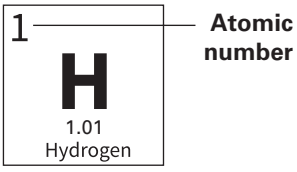
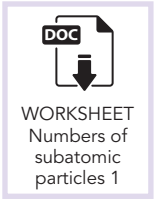


Figure 5.33 For the element hydrogen, the atomic number is 1, so you can conclude that it has one proton.

Quick check 5.7

1. Using an element of your choice as an example, **explain** what the atomic number tells you about the atom.

Number of electrons and formation of ions



The atomic number also gives you information about the number of electrons in an atom of an element. Recall that protons have a positive charge and electrons have a negative charge. An atom is neutral, meaning that it has an overall charge of zero. For the overall charge to equal zero (neutral), an atom must have the same number of positive protons and negative electrons. Carbon has an atomic number of 6, meaning it has six protons (six positively charged particles). Therefore, for the atom to have zero charge, it must also have six electrons (six negatively charged particles).

Unlike changing the number of protons, changing the number of electrons in an element will not change the type of element but it will change the chemical properties of the element. If the number of electrons in an atom changes, the atom becomes charged, and is referred to as an **ion**. Ions can be:

- positively charged, if they lose one or more of their negatively charged electrons. This is denoted by a superscript plus (+) sign after the chemical symbol.
- negatively charged, if they gain one or more negatively charged electrons. This is denoted by a superscript minus (–) sign after the chemical symbol.

ion
a charged version of an atom that has either gained electrons (and become negatively charged) or lost electrons (and become positively charged)

For example, Mg^{2+} denotes a magnesium atom that has lost two electrons and now has an overall charge of 2+ (see Figure 5.34).

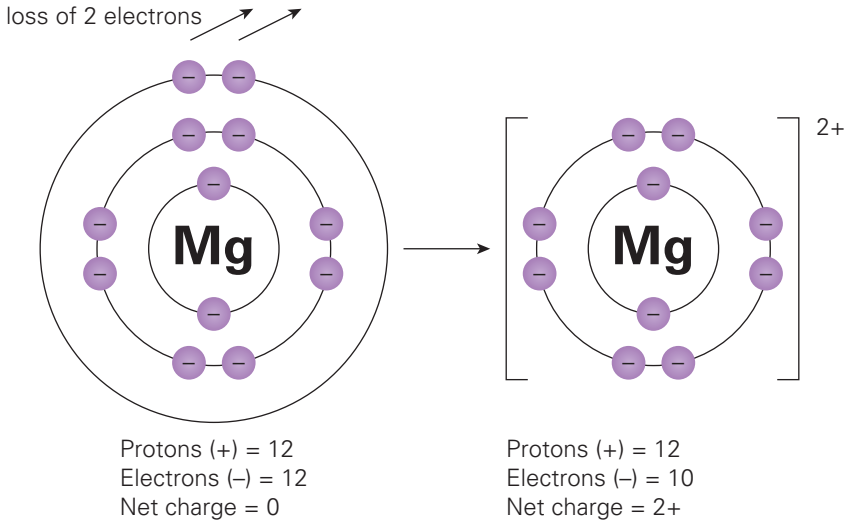


Figure 5.34 If a magnesium atom loses two electrons from its outer shell, it has lost two negative charges. This gives the resulting magnesium ion an overall positive charge of 2+.

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Practical 5.3

Investigating which ions cause water hardness

Aim

To investigate the effect of different ions on water hardness (Note: Water 'hardness' refers to the amount of dissolved calcium and magnesium ions present in water.)

Materials

- test tubes × 8
- test-tube corks/bungs × 8
- test-tube rack
- dropping pipettes
- 100 mL beaker
- marker pen
- 50 mL soap solution in industrially denatured alcohol (This can be made by dissolving soap flakes or shavings from a bar of soap in industrially denatured alcohol.)
- 10 mL each of
  - distilled or deionised water
  - 0.1 mol L^{-1} sodium chloride
  - 0.1 mol L^{-1} calcium chloride
  - 0.1 mol L^{-1} magnesium chloride
  - 0.1 mol L^{-1} potassium nitrate
  - 0.1 mol L^{-1} sodium sulfate
  - 0.1 mol L^{-1} iron(II) sulfate
  - 0.1 mol L^{-1} magnesium sulfate

Method

1. Write a rationale about water hardness, what influences it and what problems hard water can cause.
2. Identify the independent and dependent variables for this experiment.
3. Identify as many variables that need to be controlled as possible, and describe how you will control them.
4. Develop a hypothesis to predict which ions will cause the hardest water.
5. Complete a risk assessment for this practical that includes how the risks will be controlled.
6. Set up eight labelled test tubes in a test-tube rack. Place 1 cm depth of distilled water in one of the test tubes and place 1 cm of each of the seven different ion solutions in the remaining test tubes.
7. Use a dropping pipette to transfer approximately 1 cm depth of soap solution to each test tube.
8. Seal the test tubes with a bung or cork and shake them well.
9. Record which test tubes contain a lather (mass of bubbles) at the end of the shaking. If a lather is present, record its depth.

Results

Draw a results table that will allow the collection of sufficient and relevant raw data.

Discussion: Analysis

1. Identify the ion(s) that cause the hardest water. Justify your answer using your data.

Discussion: Evaluation

1. Discuss the purpose of the test tube containing distilled water. Explain how this may contribute to the reliability of the experiment.
2. Identify any potential sources of error in this experiment.
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 would improve the data quality.

Conclusion

1. Make a claim from this experiment about ions and water hardness.
2. Support your claim by referring to your experimental observations.
3. State whether your hypothesis was supported or not supported by the results.

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Explore! 5.3

Charged particles

When the number of electrons in an atom changes and an ion forms, the properties of the element are affected. You are going to conduct some research on some different elements, their structure and properties, and the ions they form.

1. When fluorine atoms become negatively charged ions, they can combine with other elements, forming fluorides such as sodium fluoride (NaF). Conduct some research on the properties of fluorine and compare this with the properties of sodium fluoride.
2. The elements in the last group (column) of the periodic table are known as the noble gases. They all have a full outer shell of electrons and do not form ions readily. The elements in the second last group of the periodic table (group 17) are known as the halogens, and all are one electron short of a full outer shell. Conduct some research and compare what type of ions noble gases and halogens form.
3. The elements in the first group of the periodic table are known as the alkali metals. They all have one electron in their outer shell. Conduct some research on what type of ions they form.
4. The elements in the second group of the periodic table are known as the alkaline earth metals. They all have two electrons in their outer shell. Conduct some research on what type of ions they form.
5. Predict the charge of ions formed from:
   a) sulfur
   b) barium
   c) iodine.



Quick check 5.8

1. **Explain** how an atom becomes positively or negatively charged.
2. An atom of oxygen gains two electrons and becomes an ion. **State** the ion formed, using the atomic symbol for oxygen and its charge.

Mass number

The **mass number** of an atom is the whole number sum of the protons and neutrons in the nucleus. For a single atom, the mass number can be calculated by the following equation:

Mass number = number of protons + number of neutrons

Electrons are not considered when calculating an atom's mass number, because their mass is so small that it is considered negligible. Note that the mass number is not the second number you see included in the periodic table.

The second number listed for each element in the periodic table is called the **relative atomic mass** (see Figure 5.35). Every element consists of a mixture of atoms that have the same number of protons but different numbers of neutrons. Such atoms are called **isotopes** and will be discussed in the next section. The relative atomic mass is rarely a whole number because it shows the average mass of an element's atom when considering all natural isotope masses and their abundances.

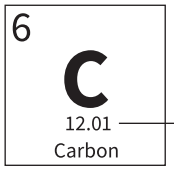


Figure 5.35 The atomic symbols for carbon showing the atomic number of 6 and relative atomic mass of 12.01. These numbers can be used to estimate the number of neutrons in a carbon atom.

WORKSHEET
Numbers of subatomic particles 2

mass number
the sum of the protons and neutrons in the nucleus of an atom

relative atomic mass
the average mass of an atom when considering all natural isotope masses and their abundances

isotopes
atoms of the same element with the same number of protons but a different number of neutrons

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Worked example 5.1

Determining the number of neutrons in an atom

An oxygen atom has an atomic number of 8 (eight protons) and a mass number of 16. Calculate the number of neutrons.

Solution	Explanation
Mass number = number of protons + number of neutrons 16 = 8 + number of neutrons	Substitute the known values (mass number and number of protons) into the equation.
Number of neutrons = mass number – number of protons Number of neutrons = 16 – 8 = 8	Rearrange the equation to solve for the missing value (number of neutrons).

Try this 5.2

Model making

Using plasticine, make models to represent atoms of different elements (e.g. lithium, carbon and fluorine). Take photos of each model you make and label the:

- protons, neutrons and electrons
- nucleus and electron shells
- atomic number and mass number

Alternatively, you could use PhET's Build an Atom interactive tool. Here you can practise applying your understanding of atomic structure, atomic number, mass number and forming ions by adding and removing electrons.

Quick check 5.9

1. Locate the following elements on the periodic table. Using their atomic numbers and relative atomic masses (rounded to the nearest whole number), **state** the number of protons, neutrons and electrons in each atom.

	Atomic number	Relative atomic mass	Number of protons	Number of neutrons	Number of electrons
Nitrogen					
Sodium					
Sulfur					
Gold					

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Section 5.3 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Section 5.3 questions

Remembering

1. **Name** the three subatomic particles that make up the atom.
2. **Identify** which subatomic particle has the smallest mass.
3. **Recall** the name of the structure at the centre of an atom where the protons and neutrons are located.

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4. **State** the names of the two numbers that accompany each element on the periodic table.
5. **Identify** which of the numbers you named in Question 4 is always the largest.
6. **Name** the element that has an atomic number of 20.

Understanding

7. **Illustrate** a labelled diagram that shows the Bohr (or planetary) model of a beryllium atom that contains four protons, five neutrons and four electrons.
8. **Illustrate** a diagram of the electron cloud model of the atom.
9. An atom has a mass number of 45 and an atomic number of 16. **Calculate** how many neutrons it has. Show your working.
10. **Identify** the subatomic particles that have nearly the same mass.

Applying

11. **Explain** why the number of electrons is not included in the mass number equation.
12. Copy and complete the table below, using the information in the periodic table to **summarise** the structure of the different elements.

Name	Atomic number	Relative atomic mass	Number of protons	Number of neutrons	Number of electrons
Oxygen					
Helium					
Fluorine					

13. Copy and complete the table below to **summarise** the ions formed by different elements.

Element	Atomic number	Number of electrons	Loss/gain electrons	Ionic charge	Ionic notation
Aluminium (Al)	13		Loss of 3		Al^{3+}
Lithium (Li)		3		+1	Li^{+}
Nitrogen (N)	7		Gain of 2		
Calcium (Ca)	20			+2	
Chlorine (Cl)		17			Cl^{-}

Analysing

14. **Compare** the properties of protons, neutrons and electrons.
15. **Compare** the position of the electrons in the planetary and electron cloud models.
16. **Compare** the mass number and the atomic number of an element.

Evaluating

17. 'The mass number determines the identity of the element.' **Propose** whether this statement is true or false. Justify your answer.
18. **Propose** several reasons why models are useful in science. Explain the limitations of using models.
19. **Justify** why no two elements on the periodic table have the same atomic number.
20. **Evaluate** the statement: 'Atoms are always neutral.'

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5.4 Isotopes

VIDEO
Uses of isotopes

Learning goals

At the end of this section, I will be able to:

1. Define 'isotope' and 'radioactive half-life'.
2. Define 'radioactive decay' and describe the three types of nuclear radiation.
3. Compare the ionising and penetrating power of alpha, beta and gamma radiation.
4. Outline applications of radioactivity, such as radioactive dating and medical treatments.

Earlier in this chapter, you learned how changing the number of protons in an atom of an element changes that atom into a different element. You also saw how changing the number of electrons results in a charged atom called an ion. Now you will learn what happens when the number of neutrons in an atom is altered.

What are isotopes?

Two atoms that have the same atomic number (so are the same element) but different mass numbers are called isotopes. Since these isotopes must have the same number of protons as each other (since they are the same element), the difference in their mass numbers must come from having a different number of neutrons. (Remember: The mass of electrons is negligible.)

The discovery of isotopes

The presence of isotopes was first proposed by Frederick Soddy in 1913. He noticed that atoms of the same element could have different atomic masses but behave in the same way. He named these elements 'isotopes', which means 'same place', referring to their location on the periodic table. Scientists could not explain why this occurred until James Chadwick discovered the neutron.

Let's look at an example. Carbon exists naturally in three forms: carbon-12, carbon-13 and carbon-14 (see Figure 5.36). These are all the element carbon because they all have an atomic number of 6 (six protons).

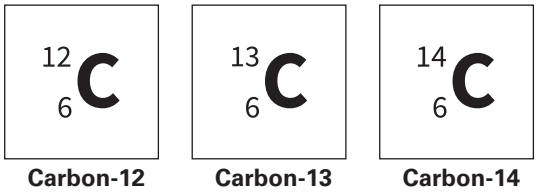


Figure 5.36 The three naturally occurring isotopes of carbon

However, they have different mass numbers (12, 13 and 14), which can be explained by them having different numbers of neutrons. Remember that the number of neutrons in an atom is calculated by subtracting the atomic number from the mass number. Therefore, carbon-12 has six neutrons, carbon-13 has seven neutrons and carbon-14 has eight neutrons. As they have different numbers of neutrons but the same atomic number, these are isotopes of carbon.

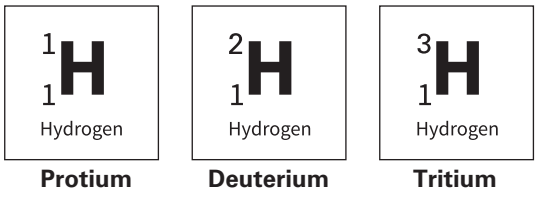
The relative atomic mass of an element shown on the periodic table is the average mass of all naturally occurring isotopes of that element. For example, the relative atomic mass of carbon is 12.01, which tells us that, in nature, carbon-12 is by far the most common carbon isotope. Indeed, 98.89% of all carbon atoms are carbon-12, with the second-most common carbon isotope being carbon-13 at 1.1%

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Naming isotopes

Isotopes are named by writing the element name first and then the mass number. For example, the three isotopes of hydrogen are hydrogen-1 (H-1, also known as protium), hydrogen-2 (H-2, known as deuterium) and hydrogen-3 (H-3, known as tritium).

Another way of representing isotopes is to use **nuclide notation**. To do this, write the mass number at the top left of the element symbol and the atomic number at the bottom left of the element symbol (see Figure 5.37).



Protium **Deuterium** **Tritium**

Figure 5.37 The three naturally occurring isotopes of hydrogen, represented using nuclide notation

WORKSHEET Naming isotopes

nuclide notation a symbol notation in which the mass number is shown at the top left of an element symbol and the atomic number is shown at the bottom left

radioisotopes the radioactive isotopes of an element

radioactive decay when an unstable nucleus emits radiation (alpha and beta particles or gamma rays) and breaks down to form another element

Stable and unstable isotopes

The stability of an isotope depends on how likely it is to break down or decay into other elements. Heavy isotopes (i.e. those that have many more neutrons than protons) tend to be unstable, whereas lighter isotopes (i.e. those with a similar number of neutrons and protons) tend to be stable.

Unstable isotopes, such as the isotopes of the element uranium, are called **radioisotopes**. In these types of isotopes, **radioactive decay** occurs to achieve a stable nucleus (as discussed later in this section). Stable isotopes are not radioactive, or are radioactive to a much lesser extent, because their nucleus is stable and therefore not prone to radioactive decay. Elements can have more than one stable isotope, such as carbon-12 and carbon-13. Table 5.1 summarises the differences between stable and unstable isotopes.

Stable isotopes	Unstable isotopes
Have a stable nucleus	Have an unstable nucleus
Not radioactive	Radioactive

Table 5.1 A comparison between stable and unstable isotopes

Explore! 5.4

Unusual mass numbers

The mass number of chlorine on the periodic table is 35.45. Using this number to calculate the number of neutrons gives 18.45 neutrons. This cannot be correct because it is not a whole number. (You cannot have 0.45 of a neutron.) Conduct some research to answer the following questions.

1. Why is the mass number of chlorine recorded as 35.45 on the periodic table?
2. Chlorine has two naturally occurring stable isotopes, Cl-35 and Cl-37. What is the difference between Cl-35 and Cl-37?
3. Given the mass number of chlorine, which isotope of chlorine do you think is more abundant in nature?

Quick check 5.10

1. **Define** 'isotope'.
2. **Determine** the name of an isotope of magnesium with a mass number of 25.
3. **Recall** the characteristics of unstable isotopes.

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Did you know? 5.4

Mass numbers in parentheses

Look at francium (Fr) on the bottom left of the periodic table. It has parentheses around its relative atomic mass (223.0). Elements written like this are radioactive, which means they are very unstable and that most of their isotopes decay into other elements quickly. The relative atomic mass in parentheses represents the most stable isotope of that element – the one that exists the longest. Can you find other radioactive elements on the periodic table?



Figure 5.38 Marguerite Perey, a French physicist, discovered the element francium, which is one of the rarest and most unstable elements on the periodic table. Perey was the first woman to be elected to the prestigious French Academy of Sciences.

Radioactive decay

When unstable atoms undergo the process of radioactive decay, the atom's nucleus becomes more stable, and radiation is emitted or released (see Figure 5.39). The radiation can be in the form of energy or particles, and there are three main types:

- alpha (α)
- beta (β)
- gamma (γ).

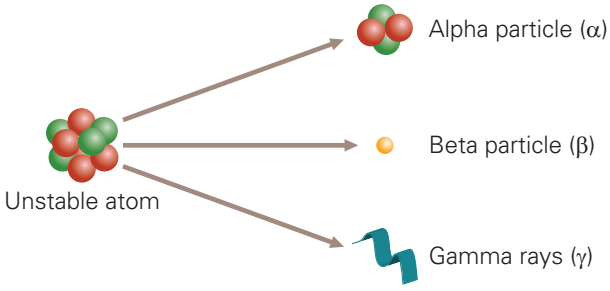


Figure 5.39 As an unstable atom decays and tries to become stable, the nuclei release energy in the form of ionising radiation (alpha particles, beta particles and gamma rays).

Alpha decay

An alpha particle consists of two protons and two neutrons, which is the same as the nucleus of a helium atom (without electrons). Therefore, when an atom undergoes alpha decay, its atomic number decreases by 2 and its mass number decreases by 4. When the atomic number changes, a new element is formed. In this case, the element has two fewer protons.

The equation in Figure 5.40 shows what happens when an atom of radon-222 undergoes alpha decay. Note that an alpha particle can be shown as either $^{4}_{2}\text{He}$ or $^{4}_{2}\alpha$ and has a charge of 2+. As a helium nucleus is emitted, the radon-222 atom loses two protons and therefore becomes a polonium atom. The mass number also decreases by 4 from 222 to 218.

$$^{222}_{86}\text{Rn} \rightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\text{He} \qquad ^{222}_{86}\text{Rn} \rightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\alpha$$

Figure 5.40 When a radon-222 atom undergoes alpha decay, it becomes a polonium-218 atom. The atom of radon has changed into an atom of polonium.

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Beta decay

Beta particles are simply fast-moving electrons emitted from the nucleus. During beta decay, a neutron is transmuted (changed) into a proton and an electron. Consequently, the atomic number increases by one, which changes the identity of the element. The mass number of the remaining atom is not affected because it has lost a neutron but gained a proton.

beta particle
a negatively charged particle (electron) that is emitted from the nucleus of some radioactive elements during radioactive decay (or disintegration) of an unstable atom

gamma ray
a type of electromagnetic radiation; it has high energy and a very short wavelength; it is produced when certain radioactive atoms decay

The equation in Figure 5.41 shows what happens during beta decay. The iodine-131 atom gains a proton and loses a neutron to become a xenon atom, and a high-energy beta particle (electron) is emitted. Note: A beta particle can be shown as either $^{0}_{-1}e$ or $^{0}_{-1}\beta$.

$$^{131}_{53}I \rightarrow {}^{131}_{54}Xe + {}^{0}_{-1}e \qquad {}^{131}_{53}I \rightarrow {}^{131}_{54}Xe + {}^{0}_{-1}\beta$$

Figure 5.41 When an iodine-131 nucleus undergoes beta decay, it becomes a xenon-131 atom and emits a beta particle.

Gamma decay

Gamma decay is different from alpha and beta decay in that the atom undergoing gamma decay is not changed; that is, the mass and atomic numbers are not altered. This is because gamma decay involves the emission of a high-energy wave (**gamma ray**) rather than a particle.



WIDGET
Nuclear equations

The equation in Figure 5.42 shows the gamma decay of radioactive cobalt-60. As the cobalt-60 nucleus is unstable, it is said to contain more nuclear energy than is required for stability, and an asterisk (*) is included next to the mass number in the nuclide notation. The * indicates that the nucleus is excited or has more energy. A gamma ray is a wave of energy with no mass or charge, so the cobalt-60 atom is unchanged. However, the * is removed to denote that the nucleus is no longer excited.

$$^{60*}_{27}Co \rightarrow {}^{60}_{27}Co + {}^{0}_{0}\gamma$$

Figure 5.42 When an excited cobalt-60 nucleus decays, a gamma ray is emitted.

As mentioned, a gamma ray (sometimes called a photon) is a high-energy wave and unlike the emissions from alpha and beta decay. You might be surprised to learn that this emission is a form of electromagnetic radiation with properties similar to light!

Explore! 5.5

Marie Curie

Marie Curie was the first woman to be awarded a Nobel Prize and is the only person to have been awarded two Nobel Prizes in different scientific fields: Physics in 1903 (with her husband, Pierre Curie, and Henri Becquerel) and Chemistry in 1911.

Marie Curie's daughter, Irène Joliot-Curie, was the second woman to win a Nobel Prize after discovering artificial radioactivity with her husband in 1934.

Conduct some research on the work of Marie and Pierre Curie that led to their scientific discoveries in radiation as well as the experiments that validated their discoveries.



Figure 5.43 Marie Curie discovered the radioactive elements radium and polonium.

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Ionising and penetrating powers

How dangerous a type of radiation is depends on its ability to penetrate materials and how much damage it can do (how ionising it is). Figure 5.44 and Table 5.2 summarise the properties of the three types of radiation.

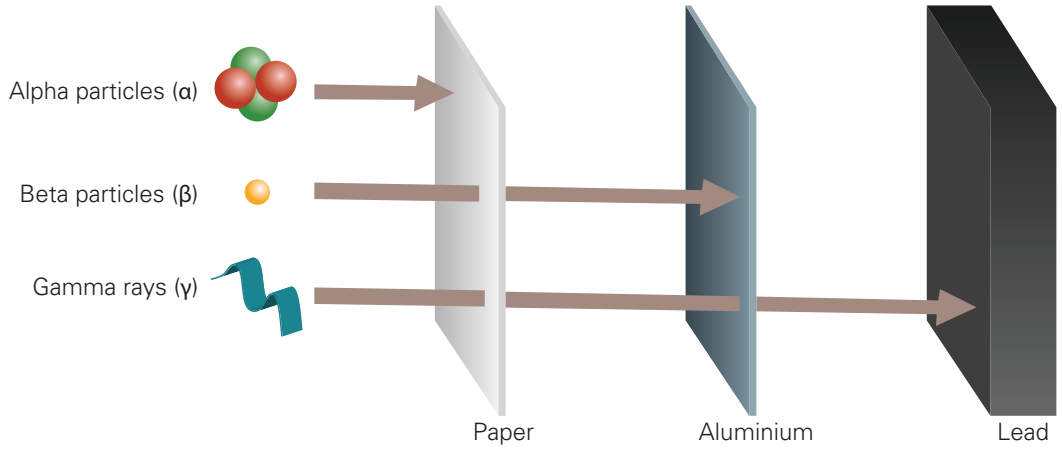


Figure 5.44 The penetrating powers of alpha, beta and gamma radiation

WORKSHEET Radioactive decay

Type of radiation	Penetrating power	Ionisation power
Alpha	Least penetrating. Can be stopped by a sheet of paper.	Very strongly ionising because it is a $^{4}_{2}He^{2+}$ ion. Can cause the most damage, especially if inside the body.
Beta	Can penetrate paper but is stopped by a thin aluminium sheet.	Not as ionising as alpha particles but more ionising than gamma rays.
Gamma	The most penetrating. Can only be stopped by thick pieces of lead or concrete.	Not very ionising so causes the least damage. Can penetrate the body, and high-energy gamma rays are used to kill cancer cells.

Table 5.2 Properties of the three types of radiation

Quick check 5.11

1. **Summarise** the information about the types of radioactive decay in the following table.

Type of decay	Alpha	Beta	Gamma
Symbol			
Description			
Charge			
Change in atomic number			
Change in mass number			
Penetrating ability			
Ionising effect			

2. **Complete** the following equations using your knowledge of radioactive decay.
   a) $^{226}_{88}Ra \rightarrow$ _____ + $^{4}_{2}He$
   b) $^{14}_{6}C \rightarrow {}^{14}_{7}N +$ _____
   c) $^{131}_{53}I \rightarrow$ _____ + $^{0}_{-1}e$

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Practical 5.4: Self-design and teacher demonstration

Investigating the penetration of alpha, beta and gamma radiation

You have been provided with the following materials. Suggest an experiment that could be done using this equipment to show the penetrating properties of alpha, beta and gamma radiation. You may wish to draw a diagram or write a method to demonstrate that you have done this task.

Aim

To investigate the penetrative strengths of ionising radiation

Materials

- alpha radiation source
- beta radiation source
- gamma radiation source
- Geiger–Müller tube (detects radiation)
- absorbing materials: sheet of paper, aluminium sheet and lead sheet

Method

Your teacher will demonstrate the experiment. This experiment emits dangerous radiation, so it can only be performed by a teacher and under strictly controlled conditions.

Results

Copy and complete the following table.

Table showing the penetrating power of the three forms of radiation

Radiation	Material that stops most of the radiation from passing through	Penetrating power
Alpha		
Beta		
Gamma		

Discussion: Analysis

1. Identify the most penetrating radiation and justify your choice.
2. Propose which type of radiation you think could cause the most damage if it gets into our bodies.
3. Conduct some research on the effects that radiation can have on the body to explain why it is so damaging.

Discussion: Evaluation

1. Discuss how the experiment could be modified to show the effect of different distances and thicknesses of absorbing materials.

Science as a human endeavour 5.3

Ionisation chamber smoke detectors

Radioactivity is used in novel technologies, even in your own home! Ionisation chamber smoke detectors can detect very small amounts of smoke in a domestic household, even before occupants can smell smoke in the air.

An ionisation chamber in the smoke detector contains a very small amount of americium-241 (Am-241) foil. This radioactive element decays, emitting alpha and gamma radiation as shown in the following equations:

$$^{241}_{95}\mathrm{AM} \rightarrow {}^{237}_{93}\mathrm{Np} + {}^{4}_{2}\alpha$$

$$^{241*}_{95}\mathrm{AM} \rightarrow {}^{241}_{95}\mathrm{AM} + {}^{0}_{0}\gamma$$

continued ...

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The alpha particles emitted are very strongly ionising and ionise the air in the chamber. This means the air in the chamber conducts electricity. If smoke particles enter the chamber, the electrical current is disrupted and the smoke detector sounds an alarm.

While this nuclear reaction might be happening in your own home, there is no need to worry. The radiation emitted by domestic smoke detectors is less than 40 kBq, which is considered safe under state regulation.

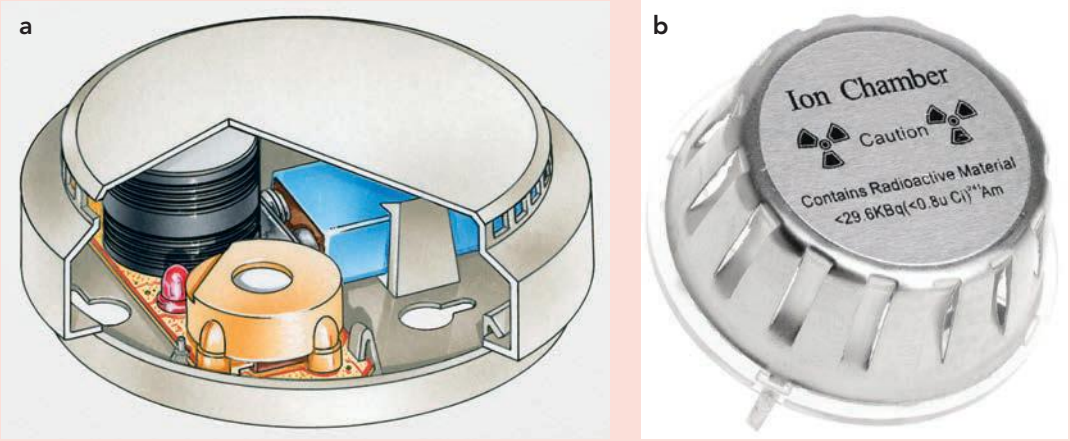


Figure 5.45 (a) A cross-section of an ionisation chamber smoke detector. It shows a battery (blue), a piezoelectric sounder (yellow) and an ionisation chamber (black). **(b)** An americium-241 ionisation chamber.

Radioactive half-life

half-life
the time taken for half of the atoms in a sample of radioactive material to decay

Some radioactive elements decay extremely quickly – over seconds, minutes or hours – while others decay steadily over thousands or millions of years. The time taken for half of the atoms in a sample of radioactive material to decay is known as its **half-life**. This is a useful value for comparing radioactive elements as well as predicting the age of radioactive materials.



Carbon-14 is a radioactive isotope of carbon with a half-life of approximately 5730 years (see Figure 5.46). This means that a pure sample of carbon-14 should take about 5730 years for half of its atoms to decay, in this case usually by beta decay to nitrogen-14. The abundance of carbon-14 and nitrogen-14 in a fossil can be analysed over time to identify the possible age of the fossil.

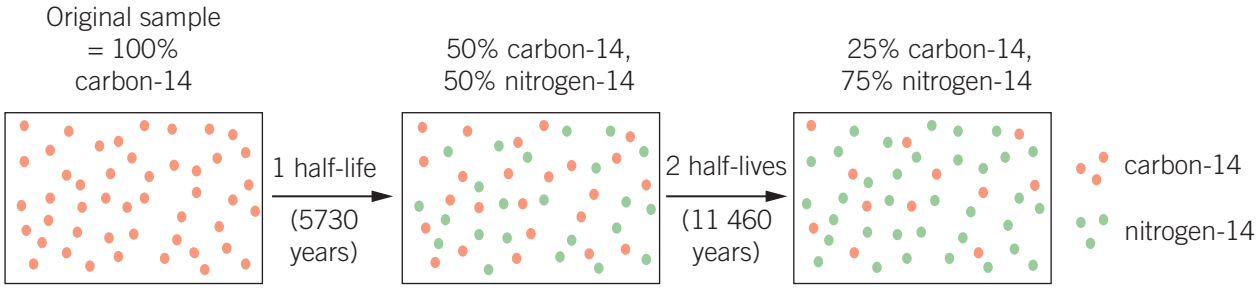


Figure 5.46 A radioactive material's half-life is the time taken for half the atoms in a sample of that radioactive material to decay. For example, it takes 5730 years for half of a sample of carbon-14's atoms to decay into nitrogen-14.

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Try this 5.3

Modelling radioactive half-lives

Place 100 five-cent coins (alternatively, counters with different markings on each side, or M&Ms) in a sealable plastic bag. Shake the bag, then pour the contents onto a white sheet of paper. Count and record the number of 'undecayed' coins (heads up) and put those coins back into the bag. The coins showing tails are 'decayed' and should be put to the side. Shake the bag again and then pour the contents out a second time. Again, count and record the number of 'undecayed' coins (heads) and put those coins back into the bag. Repeat until you either run out of coins or finish 10 trials. Graph your results.

Look at your graph and consider what this activity shows about radioactive half-lives.

Let's look at an example. The remains of a First Nations ancestor, known as Mungo Man, were found in a dry lakebed in Mungo National Park, a place of deep cultural and spiritual significance to Muthi Muthi, Ngiyampaa and Paakantyi Aboriginal Peoples. Dating methods such as carbon-14 and thermoluminescence have been used to estimate the age of these remains, aligning with First Nations oral traditions that speak to the long-standing presence of their peoples on this continent. Scientists analysed samples from the remains to identify the amount of carbon-14 and nitrogen-14. As the half-life of carbon-14 is known, they could then use this information to calculate the amount of time that had passed since Mungo man died (see Figure 5.47).

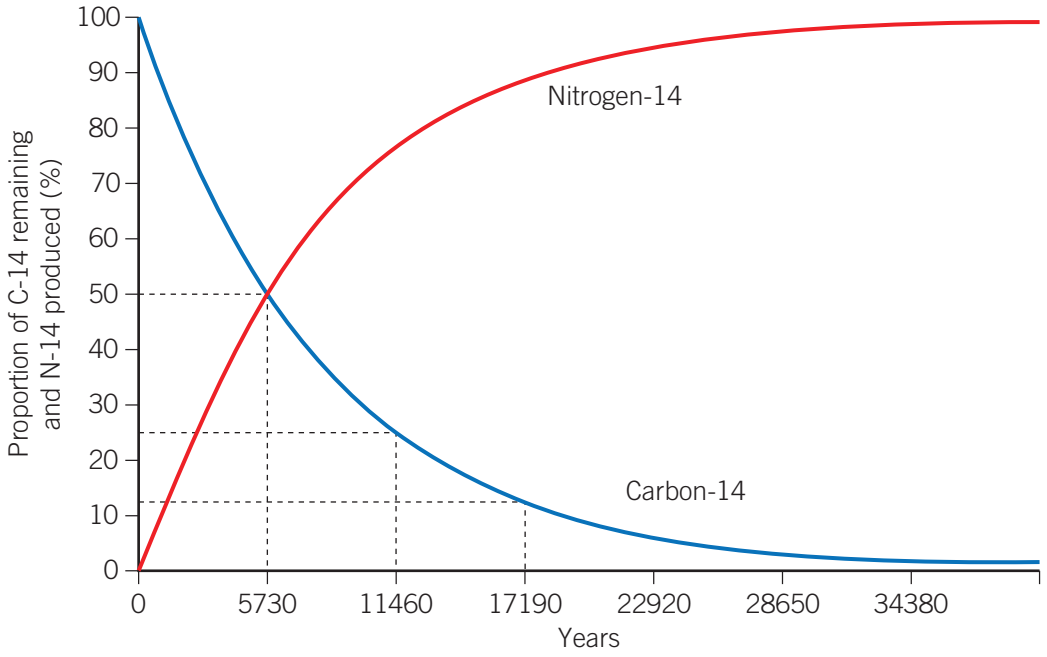


Figure 5.47 Carbon-14, an unstable isotope, radioactively decays into nitrogen-14, a stable isotope. Therefore, as the amount of carbon-14 in a sample falls, the amount of nitrogen-14 rises. The point of intersection on the graph (5730 years) marks the half-life, the time by which exactly half of the carbon-14 has decayed.

In 2003, however, a panel of experts used a more contemporary and advanced range of optically stimulated luminescence dating methods, which revealed that the Lake Mungo remains were probably close to 40 000 years old! Scientific dating methods have been used alongside Aboriginal and Torres Strait Islander knowledge to affirm the long history of First Nations Peoples on this continent, which extends beyond 65 000 years. These methods do not replace the deep time histories held in First Nations oral traditions, but provide additional ways of understanding time and environmental changes.

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But what if the sample to be analysed is thought to be millions of years old? Carbon dating is only useful on samples up to around 60 000 years old. For older samples, other isotopes with longer half-lives can be used (see Table 5.3). For example, uranium-238 is a naturally occurring isotope with a very long half-life of about 4.5 billion years, making it useful for dating samples that are much older.

Original isotope (unstable)	Isotope formed through decay (stable)	Half-life (years)	Dating range (years)
Carbon-14	Nitrogen-14	5730	Up to 60 000 years ago
Potassium-40	Argon-40	1.3 billion	500 000 years and older
Uranium-238	Lead-206	4.5 billion	10 million – 4.6 billion

Table 5.3 Isotopes commonly used for radioactive dating

Did you know? 5.5

Budj Bim: A living cultural landscape and UNESCO World Heritage Site

Budj Bim is a sacred and living cultural landscape of Gunditjmara people, located in southwestern Victoria. For tens of thousands of years, Gunditjmara people have carefully managed this land, engineering an intricate system of stone channels, weirs and ponds to sustainably farm eels (kooyang). This sophisticated aquaculture system ensured a reliable food source, supporting permanent settlements and demonstrating deep scientific knowledge of water management, ecological balance and sustainable food production.



Figure 5.48 The Gunditjmara people managed the water flow from Lake Condah, shown above, forming one of the oldest aquaculture systems in the world.

Western scientific dating methods, including carbon dating, estimate that aquaculture practices at Budj Bim began at least 6700 years ago. However, this timeframe only scratches the surface of Gunditjmara people's enduring connection to this landscape.

Recognising its importance, Budj Bim was inscribed on the World Heritage List as a UNESCO World Heritage Site. It is the first in Australia to be listed exclusively for its First Nations cultural values.

Quick check 5.12

1. **Define** radioactive 'half-life'.
2. **Write** a nuclear equation for the:
   a) beta decay of C-14
   b) alpha decay of U-238.
3. If an organism was known to exist 550–250 million years ago, **state** which radioactive isotope would be best to use to determine its accurate age.
4. You have 100 g of a radioactive isotope and its half-life is 10 years.
   a) **State** how much of the isotope you will have left after:
      i) 10 years
      ii) 20 years.
   b) **Determine** how many half-lives will occur in 40 years.

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Explore! 5.6

Affirming First Nations' deep time presence on Country

In 2017, excavations at a rock shelter near Kakadu National Park, on Mirarr Country, provided further scientific evidence of Aboriginal presence at Madjedbebe for at least 65 000 years. This aligns with Aboriginal knowledge that has long asserted an unbroken connection to Country. Western dating techniques, including radioactive dating, thermoluminescence and optically stimulated luminescence, were used to estimate this timeframe, reinforcing what Aboriginal communities know.

Similar techniques have also been applied at Moyjil in southwest Victoria, a site containing evidence such as charred rocks and weather-worn shells. Some researchers suggest this may indicate Aboriginal occupation dating back 120 000 years.

First Nations knowledge holders, Elders and researchers continue to lead efforts to deepen our understanding of these ancient histories.

Investigate how thermoluminescence and optically stimulated luminescence work, and how they complement other dating techniques such as carbon-14 dating in measuring time on Country.

Applications of radioactivity



There are 94 naturally occurring elements with around 250 stable isotopes and 3200 unstable radioisotopes. Stable isotopes and radioisotopes both have important uses.

Besides dating fossils and ancient rock art and providing evidence of human existence, perhaps the most well-known use for isotopes is in medicine to diagnose and treat illnesses. Cobalt-60 (Co-60) is used in radiotherapy to treat cancer cells; strontium-90 (Sr-90) is used in the treatment of skin cancer in pets; and gamma rays are produced when radioisotope decay is used to kill bacteria that may be present on medical equipment.

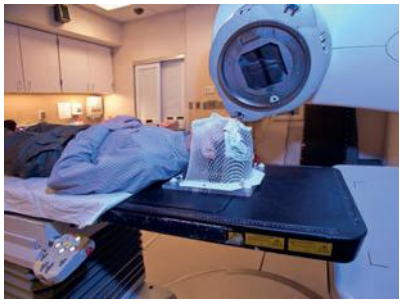


Figure 5.49 A patient undergoing radiotherapy for cancer

Knowing the half-life of the radioisotopes used in medicine is very important. For example, an isotope of fluorine-18, used in medical imaging, has a half-life of about 109 minutes. That means fluorine-18 must be prepared at the medical facility and used very quickly because it will all decay in a few hours!

Another interesting application of radioisotopes is in the materials industry. For example, iridium-192 is a useful radioisotope with a half-life of about 74 days, which also gives it some longevity for application. It can be used as a diagnostic tool for finding faults in materials such as in pipelines, aircraft and spacecraft. Iridium-192 primarily decays by beta decay and gamma decay. These emissions penetrate materials to a different extent and thus the emissions can be used to image the inside of materials by detecting radioactive emissions that can pass through different materials.

Making thinking visible 5.2

Generate, sort, connect, elaborate

1. Generate a list of terms that come to mind when you think about sections 5.1 to 5.4.
2. Sort your terms according to how central or tangential they are. Place central ideas or key terms near the centre of your paper and more tangential ideas towards the outside of the page.
3. Connect your terms by drawing connecting lines between the terms that have something in common. Write a short sentence to explain how the terms are connected.
4. Elaborate on any of the terms you have written so far by adding new terms that expand, extend or add to your initial terms.

You may like to view this as a revision tool that brings all of the concepts in this chapter together.

The *Generate, sort, connect, elaborate* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

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Go online to access the interactive section review and more!

Section 5.4 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Section 5.4 questions

Remembering

1. **Name** three important uses of radioisotopes.
2. **Name** a radioisotope useful in treating human cancer.

Understanding

3. **Describe** the relationship between the mass of an isotope and its stability.
4. If an atom emits beta radiation, **state** what particle it gives off and how the atom is changed as a result.

Applying

5. **Determine** the name of an isotope of barium with a mass number of 130.
6. **Determine** the name of an isotope of potassium with 22 neutrons.
7. **Summarise** what happens to the nucleus of an element during alpha decay.
8. **Complete** the following equations to demonstrate your understanding of the types of radiation produced during radioactive decay.
   a) $_____ \rightarrow {}^{0}_{-1}e + {}^{60}_{28}Ni$
   b) ${}^{210}_{82}Pb \rightarrow _____ + {}^{206}_{80}Hg$
   c) ${}^{184}_{74}W \rightarrow {}^{4}_{2}He + _____$

Analysing

9. **Contrast** stable isotopes and radioisotopes.
10. **Compare** these isotopes of sodium: Na-23 and Na-24.
11. a) If you have 16 g of radioactive substance, **calculate** how much will remain after three half-lives.
    b) If you have 120 atoms of a radioactive substance, **calculate** how many atoms will remain after two half-lives.
12. An archaeologist finds an old bone and takes it for carbon-14 dating. She tells the scientist it is around 2000 years old. After testing, it is found that the bone is 25% through its first half-life. Do these findings support the archaeologist's theory about the bone's age? **Explain**.

Evaluating

13. **Construct** an equation to show the alpha decay of uranium-235 to thorium-231.
14. An element undergoes radioactive decay, but its atomic number and mass number are not affected. **Deduce** the type of decay.
15. During the radioactive decay of an isotope, a high-energy electron is released. **Deduce** the type of decay.

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Chapter review

Chapter checklist

Success criteria		Linked questions
5.1	I can define 'atoms', 'elements', 'compounds' and 'molecules'.	1, 4, 14
5.2	I can outline different contributions scientists and philosophers have made to the development of the modern model of the atom.	7, 9, 11, 21
5.3	I can compare the relative mass and charge of protons, neutrons and electrons.	2, 15
5.3	I can define 'ion', 'atomic number' and 'mass number'.	8, 10
5.3	I can determine the number of protons and electrons in the atom of an element.	5, 13
5.3	I can calculate the mass of an atom from the number of protons and neutrons.	5
5.4	I can define 'isotope' and 'radioactive half-life'.	3, 12
5.4	I can define 'radioactive decay' and describe the three types of nuclear radiation.	6, 17, 20
5.4	I can compare the ionising and penetrating power of alpha, beta and gamma radiation.	18, 19
5.4	I can outline applications of radioactivity; for example, radioactive dating and medical treatments.	16

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Remembering

1. **State** the names of the three subatomic particles within the atom.
2. **Recall** the relative charge of each subatomic particle:
   - **a)** proton
   - **b)** neutron
   - **c)** electron.
3. **Define** 'radioactive half-life'.
4. **State** where the protons and neutrons are located within the atom.
5. a) If a neutral atom has 18 protons, **state** how many electrons it has.
   b) If the atom also has 22 neutrons, **state** the mass number.
6. **Recall** the type of particle that is released during beta decay.

Understanding

7. **Describe** the planetary model of the atom.
8. **Outline** how atomic number and mass number are different.
9. **Explain** how Rutherford's gold foil experiment led to the discovery of the nucleus.

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Applying

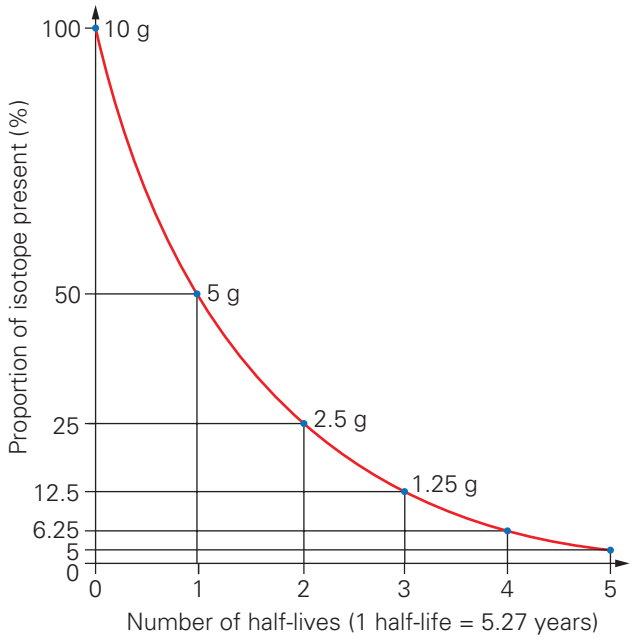
10. Apply your knowledge of the overall charge of an atom to **explain** what would happen to an oxygen atom if it had an extra electron (nine electrons).
11. **Explain** why the neutron was difficult to discover.
12. **Describe** the differences between isotopes of the same element.
13. Copy and complete the table below to **summarise** the three main isotopes of neon.

Isotope	Mass number	Number of protons	Number of neutrons	Number of electrons
$^{20}_{10}Ne$				
$^{21}_{10}Ne$				
$^{22}_{10}Ne$				

Analysing

14. **Contrast** an element and a compound.
15. **Compare** the properties of the subatomic particles in terms of their mass.
16. Cobalt therapy is a medical treatment that uses the decay of cobalt-60 to treat diseases such as cancer. Cobalt-60 is a radioisotope that decays into the stable isotope nickel. The gamma rays produced by cobalt-60 decay are directed to a specific part of a patient's body to kill tumour tissue.

    The decay of cobalt-60 is shown in the following half-life graph.



    Explain why the cobalt-60 in a machine that directs gamma rays into a patient's body must be regularly replaced.

Evaluating

17. **Deduce** the relationship between the mass of an element and how stable it is.
18. Ionising radiation is used in smoke detectors. **Decide** which type of radiation you would choose for this use and why.
19. **Propose** why radioactive sources in schools must be stored in lead-lined boxes.
20. **Write** a nuclear equation for the beta decay of iridium-192.
21. **Discuss** whether you expect the atomic model to change significantly in the future. **Justify** your answer.

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Data questions

The isotope carbon-14 decays by beta radiation to form nitrogen-14 atoms, following the decay curve in Figure 5.50. Scientists can predict the age of a fossil by analytical techniques that measure the relative abundance decay curves of carbon-14 and nitrogen-14 in the fossil.

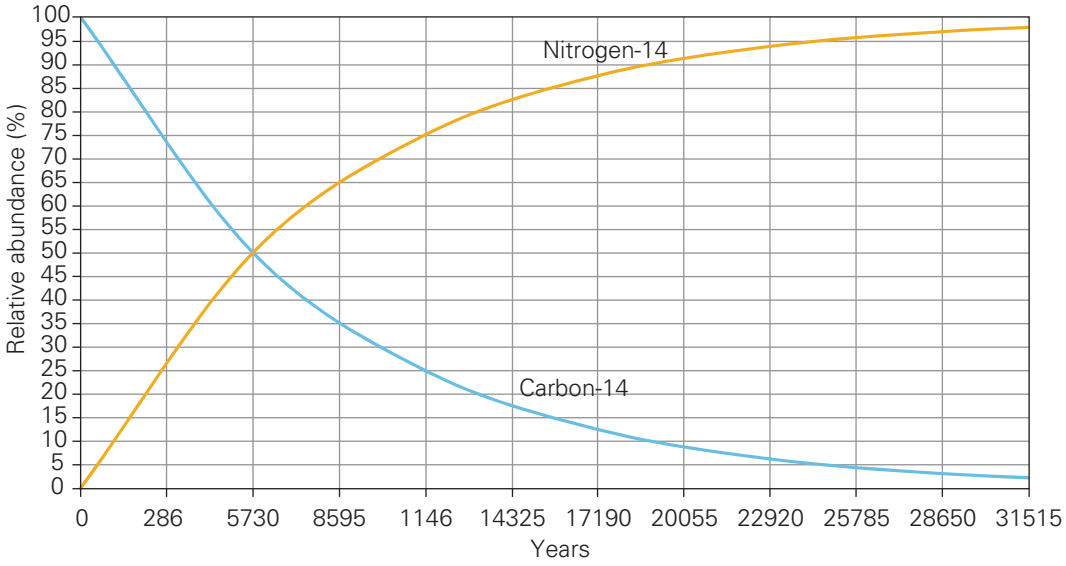


Figure 5.50 The relative abundance of carbon-14 (blue line) and nitrogen-14 (orange line) in an initial sample of carbon-14 over 31 515 years

Applying

1. A scientist has measured the relative abundance of carbon-14 in a sample of Aboriginal Australian rock art at 25% compared to nitrogen-14. **Determine** the age of the rock art.
2. The relative abundance of nitrogen-14 in a kangaroo fossil sample is 40%. **Calculate** the relative abundance of carbon-14.
3. **Identify** the relative abundance of nitrogen-14 in a fossil dated at 8595 years old.

Analysing

4. **Contrast** the two curves and comment on the relative rate of decay of carbon-14 and growth of nitrogen-14.

Evaluating

5. **Deduce** the half-life (time taken for half of the carbon-14 to decay to nitrogen-14) of carbon-14.
6. After 28 650 years, the relative abundance of carbon-14 is 3.125%. **Predict** the relative abundance of nitrogen-14 after another 5730 years (34 380 years total).
7. **Predict** and explain whether it would be possible to find a fossil with a relative abundance of carbon-14 of 0%.
8. The use of radiocarbon dating is most efficient with fossils less than 20 000 years old. **Compare** the carbon-14 decay curve before and after 20 000 years and elaborate on this comment.



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STEM activity: Designing and creating a product using bioplastics

Background information

Plastic is one of the most commonly used substances today. It is used for everything from food packaging to toys, building materials to clothing, and even medical implants. Plastic was invented in 1907 and has revolutionised the manufacturing of a multitude of different products because of its versatility. Plastic can be hard, soft, stretchy, bendable, strong or durable.

Molecules are atoms that are bonded together. Chemically, plastic consists of long chains of molecules called polymers. This is why the names of many plastics start with 'poly'. The polymers are made up of carbon and hydrogen, and sometimes oxygen, nitrogen, sulfur, phosphorus, fluorine or silicon.

H H H H H H H H

C C C C C C C C

H H H H H H H H

Figure 5.51 Polyethylene is the simplest plastic. It consists of a long chain of carbon atoms and hydrogen atoms.

There are two main problems with the amount of plastic that is used. First, most plastic is made from crude oil, a limited resource that is harmful to the environment to extract. Second, because of its molecular structure, plastic is very difficult to biodegrade (break down). Plastic litter builds up in waterways and kills wildlife, as well as leaching harmful toxins into the environment.



Figure 5.52 Plastic litter builds up on beaches.



Figure 5.53 An oil refinery in Melbourne

bioplastic
a type of plastic made from renewable resources, such as plants

Bioplastics are a type of plastic made from renewable resources, such as plants. They can easily be made at home with readily available ingredients. Although they cannot solve the plastic problem alone, they can reduce carbon dioxide emissions, and some have the potential to biodegrade more easily than traditional plastics.

DESIGN BRIEF

Design and create a product using bioplastics.

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Activity instructions

In groups of two or three, your task is to think of a product that is made of plastic and find a way of making it out of bioplastic.

Be careful



Wear safety glasses.
Be very careful when working around the hotplate and handling the hot mixture.
Ensure the hotplate is cool before moving it.

Suggested materials

- corn starch
- vinegar
- glycerine
- water
- food dye (optional)
- saucepan
- wooden spoon
- hotplate
- non-stick paper (or aluminium foil) and tray
- cookie cutters or moulds to shape the plastic
- safety glasses

Research and feasibility

1. In your group, discuss different plastic products you use in your everyday life, and list all the benefits to manufacturing these products as a bioplastic.
2. List all the restrictions you must consider in your design based on the materials and space you have available.
3. Conduct some research on how you would use the suggested materials (or other materials safe for use in a school science laboratory) to manufacture the bioplastic.

Design and sustainability

4. Decide on a plastic product that you could make using a bioplastic. Justify your choice as a group by considering your constraints.
5. Design the method for manufacturing the bioplastic.
6. Design the mould you will use for making your product.

Create

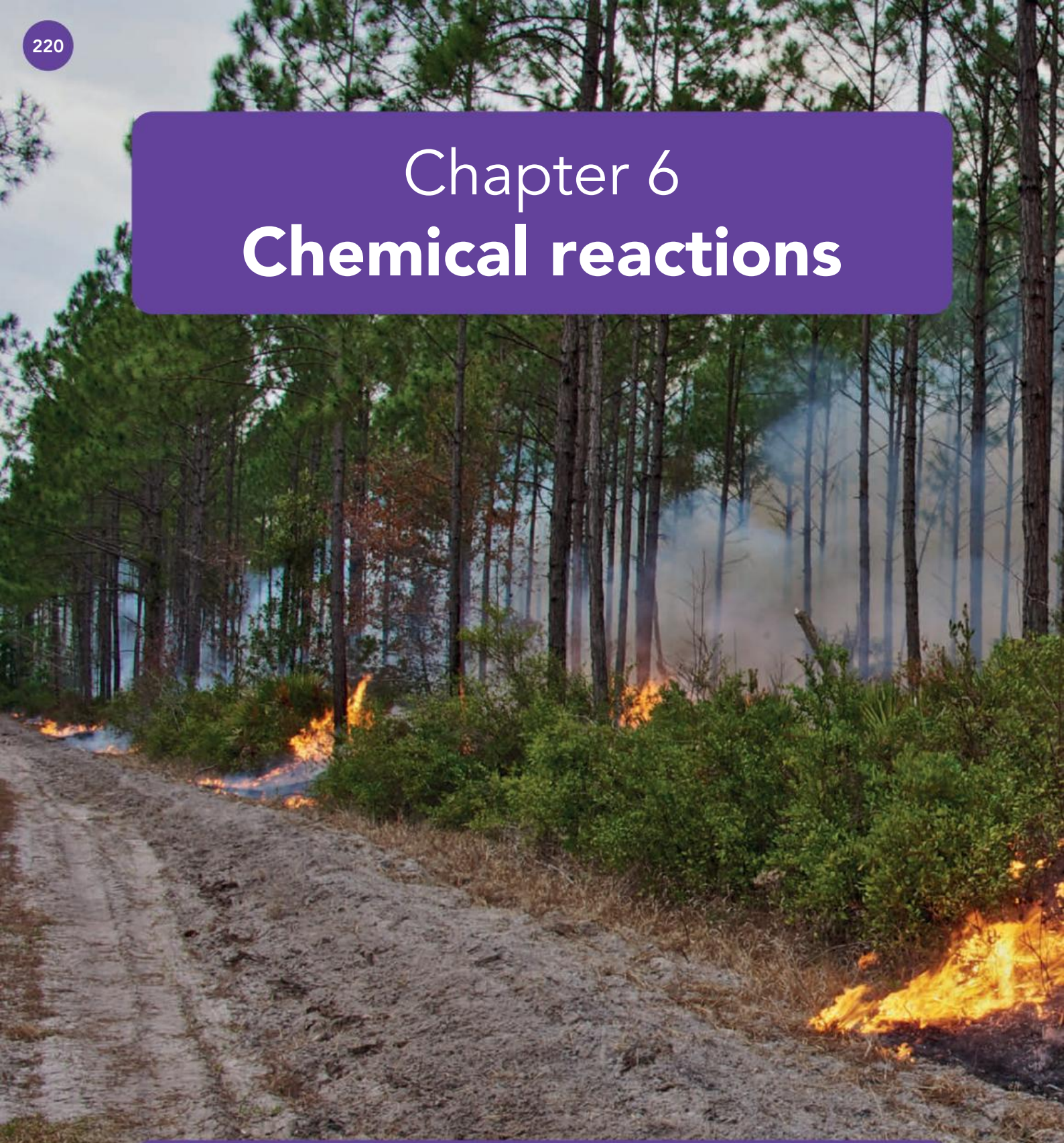
7. Create the mould you will use for your bioplastic product.
8. Follow your design method and construct your bioplastic product solution. Remember it may take a week for your bioplastic to set.

Evaluate and modify

9. Describe any difficulties you encountered when creating your product out of bioplastic.
10. Suggest ways that the design of your product could be improved.
11. List the physical properties of your bioplastic and comment on how appropriate these properties were for your product.
12. Test your product by using it for its intended purpose under different conditions.
13. Evaluate the effectiveness of your product.

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Chapter 6
Chemical reactions

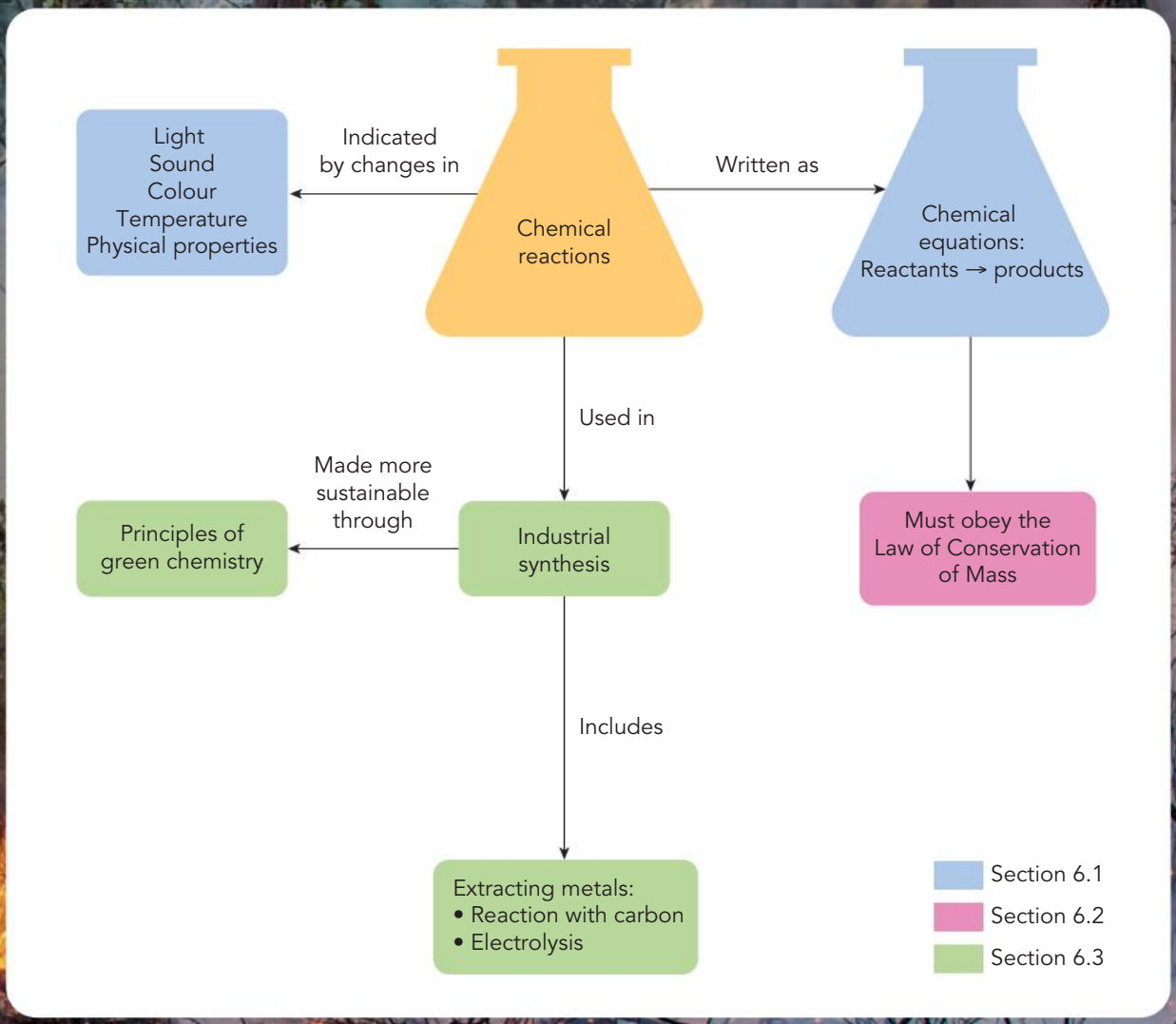
Chapter introduction

Chemical reactions occur when the atoms in reactants are rearranged, resulting in the formation of new products. The Law of Conservation of Mass states that mass cannot be created nor destroyed during a chemical reaction. In this chapter, you will learn about how this law is crucial for manufacturers because it allows them to predict and plan useful chemical syntheses. By considering green chemistry principles in chemical manufacturing, companies can benefit by meeting consumer and regulatory demands, reducing costs and being more environmentally sustainable.

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Concept map



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Curriculum content

chemical reactions are described by the Law of Conservation of Mass and involve the rearrangement of atoms; they can be modelled using a range of representations, including word and simple balanced chemical equations (VC2S10U08)	
• identifying reactants and products in chemical reactions	6.1
• using models and representations to show the rearrangement of atoms in chemical reactions and to illustrate the Law of Conservation of Mass	6.1, 6.2
• investigating chemical reactions in closed and open systems and relating data obtained to the Law of Conservation of Mass	6.2
• writing symbol equations that are easy to balance and explaining the rationale for balancing chemical equations with reference to the Law of Conservation of Mass	6.2
• investigating why most elements are not found in their elemental state	6.3
• explaining how implementing ideas related to green chemistry principles, such as minimising the amount of unusable waste products, energy use and using more environmentally friendly chemical processes, will affect the environment	6.3
scientific knowledge may be interpreted in different ways by individuals and groups in society; the values and needs of society can influence the focus of scientific research (VC2S10H04)	
• examining why many manufacturers are adopting green chemistry processes	6.3

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Glossary terms

Balanced	Green	Rearrange
Catalyst	Law of Conservation of Mass	Subscript
Chemical change	Native metal	Sustainable
Chemical reaction	Open system	Symbol equation
Closed system	Product	Word equation
Coefficient	Reactant	
Electrolysis	Reaction conditions	

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6.1 Chemical reactants and products

Learning goals

At the end of this section, I will be able to:

1. Recall the evidence of chemical change.
2. Define 'chemical reaction'.
3. Identify reactants and products in a chemical equation.
4. Write a word equation.

Many areas of modern life require chemical reactions. The components of a lunchtime sandwich, the ink in a pen and the screen of a smartphone have all been carefully produced using chemical reactions. But what are chemical reactions? Do they have anything to do with chemical change?



Figure 6.1 All the ingredients in your sandwich, from bread to salt, were made by chemical reactions.

Making thinking visible 6.1

Chalk talk: Chemical reactions

Your teacher has placed several pieces of butcher's paper, each with a different prompt on it, around the room. You will walk around the room and respond to the different prompts by recording the following.

- What ideas come to mind when you think about this prompt? Can you explain what the prompt is saying? Can you provide examples?
- What connections can you make to the responses of others? Can you elaborate on the ideas of others?
- What questions arise as you think about the prompts and comments of others?

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

Chemical change

In Year 8 you learned about physical change and **chemical change**.

chemical change a rearrangement of atoms that is often irreversible

Recall that a chemical change occurs when chemical substances react to form new chemical substances with different chemical compositions. In contrast, a physical change involves a change in size, shape or state of matter without any alteration in the chemical composition. While both types of changes can be reversible, some chemical changes require a significant amount of energy to reverse, making them 'irreversible' in practical terms. In contrast, physical changes, such as the boiling and freezing of water, are typically easily reversible.

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Table 6.1 lists some observable evidence or indicators of a chemical change.

Indicator	Example
Sound produced	Hydrogen and oxygen reacting together to make water creates a loud bang.
Change in colour	A grey-coloured iron nail reacting with oxygen and water forms red rust (iron oxide).
Change in physical properties	Sodium (a soft metal) reacting with water (a colourless liquid) produces sodium hydroxide (a colourless solution) and hydrogen gas, which is observed as rapid bubbling, also referred to as effervescence.
Light produced	The production of fire is a chemical reaction called combustion, which involves the rapid oxidation of a fuel in the presence of heat and oxygen, which produces heat, light and by-products such as smoke and ash. Light is produced as a result of the excited atoms emitting photons as they return to their ground state.
Change in temperature	Magnesium metal reacting with an acid releases heat, which can be measured with a thermometer.

Table 6.1 Indicators of a chemical change

Quick check 6.1

1. **Recall** examples of a chemical change.
2. 'All chemical changes are irreversible.' **Propose** whether this statement is true or false and explain your answer.
3. **Classify** each of the following as a physical or chemical change.
   - **a)** Vegetable scraps breaking down in the compost bin
   - **b)** Separating sand from gravel
   - **c)** Cutting fingernails
   - **d)** Drilling a screw into wood
   - **e)** Trees growing new leaves in spring
   - **f)** A stock cube dissolving in hot water
   - **g)** Fruit on the ground going mouldy
   - **h)** Breakfast cereal going soggy



Chemical reactions

chemical reaction a process or chemical change that transforms one set of substances (the reactants) into another set of substances (the products)

rearrange move things into a different order

When we see evidence that a chemical change has occurred, we can say that a **chemical reaction** has taken place. During chemical reactions, the atoms in the starting substances are **rearranged** to make new substances. For this to happen, chemical bonds holding the atoms together in the starting substances must be broken and new bonds must form in different arrangements to make the new substances.

Figure 6.2 shows a chemical reaction in which a made-up compound named AB is reacting with element C to make a new compound, BC, and element A. In this reaction, the bond between A and B in compound AB is broken and a new bond is formed between B and C to form compound BC – the atoms have been rearranged. The new substances are different from the starting substances; therefore, a chemical reaction has taken place.

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Figure 6.2 Rearranging atoms in a chemical reaction

VIDEO
Chemical reactions

Notice the arrow in the chemical reaction in Figure 6.2. It separates the starting substances that react together from the new substances formed by the reaction. The arrow indicates that a reaction is occurring; when reading the equation aloud, read the arrow as 'yields'. For example, 'AB plus C yields A plus BC'. Equals signs are not used for chemical reactions as it implies the reaction can go forwards and backwards.

Let's look at a real-life example. Figure 6.3 shows the chemical reaction between carbon and oxygen. In this chemical reaction, the bond between the two oxygen atoms is broken, the atoms are rearranged, and new bonds are formed between each oxygen atom and the carbon atom. The new substance formed is called carbon dioxide.

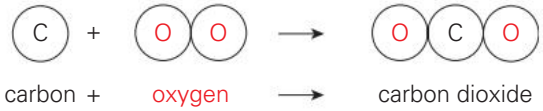


Figure 6.3 The formation of carbon dioxide is a chemical reaction. The atoms in the starting substances are rearranged to make new substances.

The rearrangement of the atoms can affect the properties of the substances in chemical reactions. Carbon is a solid at room temperature and oxygen is a gas. The compound formed in this reaction, carbon dioxide, is a gas at room temperature. The arrangement of the atoms within a compound determines the properties of a substance, which is why the properties of the compound formed in Figure 6.3 are so different from the starting substances.

Quick check 6.2

1. **Explain** how new substances are formed during a chemical reaction.
2. **Describe** what is happening to the substances in the following equation.



Chemical equations

A chemical equation is a way of representing what happens in a chemical reaction. It shows the substances that are reacted together and the substances that are made from the rearrangement of the atoms.

Reactants and products

In a chemical reaction, the substances doing the reacting are called **reactants**. Reactants are always written on the left-hand side of a chemical equation (before the arrow). The new substances that are formed are called **products**. Products are always written on the right-hand side of an equation (after the arrow). Figure 6.4 shows a word equation for the reaction between magnesium and hydrochloric acid. A **word equation** shows the reactants and the products written in words with an arrow between them to represent the chemical change.

reactant
a substance that is reacting in a chemical reaction

product
a substance that is formed in a chemical reaction

word equation
a chemical reaction written using the names of the reactants and products involved

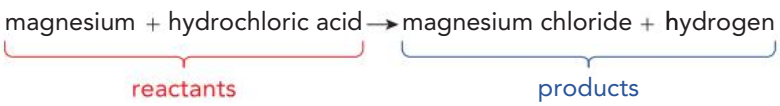


Figure 6.4 A word equation for the chemical reaction between magnesium and hydrochloric acid

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Reaction conditions

catalyst
a chemical that speeds up a chemical reaction; it is not a reactant and is not used up during the reaction

reaction conditions
the conditions required for a chemical reaction to proceed

Not all chemical reactions happen spontaneously (i.e. without us having to do anything). Some reactions require heat or light energy to get started, some require high pressures and some need a chemical called a **catalyst** to speed up the reaction. Sometimes catalysts are not necessary for the reaction to occur, but are used to increase the speed of the reaction. This makes catalysts very useful for industries where the desired products should be made quickly and efficiently.

These factors are examples of **reaction conditions**. When special reaction conditions are required, they are written above (and sometimes below) the arrow in a chemical equation. This shows that these conditions are required for the reaction, but that they are not directly involved in the reaction. For example, fertilisers are made from ammonia, a source of nitrogen. The ammonia in fertilisers is produced by the Haber process, where the reaction involves the use of a catalyst, high temperatures and high pressure. Figure 6.5 shows how these reaction conditions are included in the chemical reaction.

$$\text{nitrogen} + \text{hydrogen} \xrightarrow[450\text{–}500^\circ\text{C, 150–200 atmospheres (pressure)}]{\text{iron catalyst}} \text{ammonia}$$

Figure 6.5 A word equation for the reaction that produces the ammonia in fertiliser, showing the reaction conditions required

Quick check 6.3

1. **State** on which side of a chemical equation the products are written.
2. **State** on which side of a chemical equation the reactants are written.
3. **Identify** where the reaction conditions should be written in a chemical equation.
4. **Identify** what the arrow indicates in a chemical reaction.

Did you know? 6.1

Special effects

You might have seen movies where fire and explosions occur. This is the work of specialised scientists called pyrotechnicians. Pyrotechnics is the science of using chemical reactions for the production of heat, light and sound. On a movie set, the effects have to be carefully controlled and easily extinguished! A commonly used effect in movies is the production of flame using a 'flame projector'. A combustible gas like propane (reactant) is ignited with an electric match and may be mixed with small amounts of other fuels that add soot (product) and colour. The colour of the flame is determined by the use of different metals from the periodic table.

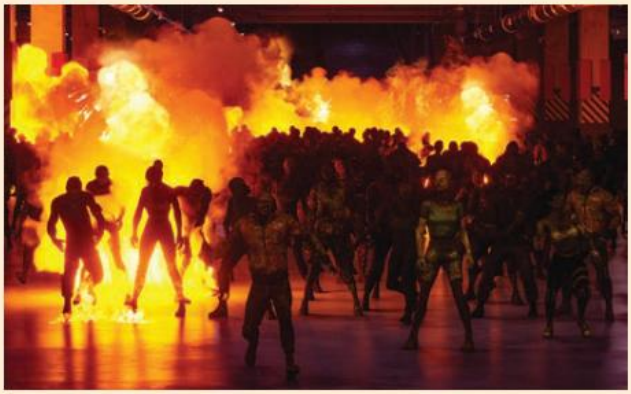


Figure 6.6 In this zombie movie, the flames produced by chemical reaction need to be carefully controlled by pyrotechnic experts.

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Representing chemical equations

Chemical equations can be presented in different ways.

1. Word equations show the names of the reactants and products. (We saw an example in Figure 6.4.)
2. **Symbol equations** show the chemical formulas of the reactants and products.
3. Particle representations use circles to represent the atoms, ions or molecules in a substance, such as their relative concentrations and how they react. (We saw an example in Figure 6.3.)
4. Chemical structures (as shown for caffeine in Figure 6.7) give shape and chemical bonding structure information; however, you will not use this type of presentation in Year 9.

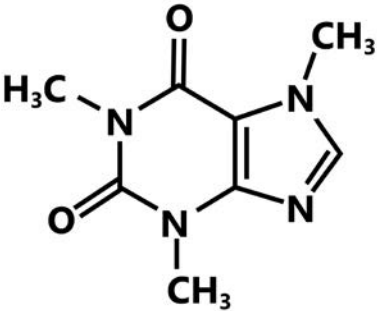


Figure 6.7 A caffeine molecule can be represented using a structural formula to provide more information about chemical bonding.

Regardless of the type of chemical equation used, there is always an arrow separating the reactants on the left and the products on the right. The different types of equations only differ in the way the reactants and products are represented.

Word equation:

methane + oxygen ⟶ carbon dioxide + water

Symbol equation:

$CH_4 + O_2 \longrightarrow CO_2 + H_2O$

Figure 6.8 Chemical reactions can be represented using word equations (top) and symbol equations (bottom).

WORKSHEET
Chemical reactions

symbol equation
a chemical reaction written using the symbols and formulas of the reactants and products involved

Try this 6.1

Writing word equations

Practise writing some word equations for each of the following scenarios.

1. Copper and silver nitrate react to make copper nitrate and silver.
2. Calcium carbonate powder reacts with a solution of dilute hydrochloric acid to produce a solution of calcium chloride, liquid water and carbon dioxide gas.
3. When the methane reacts with oxygen in a Bunsen burner, the products are usually carbon dioxide and water.
4. Aluminium sulphate solution and calcium hydroxide solution produce a precipitate of aluminium hydroxide and solid calcium sulphate.
5. Water vapour reacts with sodium metal to produce solid sodium hydroxide and hydrogen gas.
6. Plants take in carbon dioxide and water, and in the presence of the sunlight make glucose sugar and oxygen.
7. Hydrogen peroxide naturally decomposes to produce water and oxygen gas, but the reaction is very slow. Adding the catalyst manganese (IV) oxide makes it occur very quickly.



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Section questions 

Teachers can assign tasks and track results 

Section 6.1 questions

Remembering

1. **State** what the arrow '→' represents in a chemical reaction.
2. **Identify** the reactants in the following reactions.
   a) Sodium hydroxide + iron carbonate → iron hydroxide + sodium carbonate
   b) Propane + oxygen → carbon dioxide + water
   c) Hydrogen + oxygen → water
   d) Calcium carbonate → calcium oxide + carbon dioxide
3. **Identify** the products of each of the reactions in Question 2.

Understanding

4. **Select** the correct definition from the table for each keyword.

Keyword	Definition
Reactants	The substances formed in a chemical reaction
Products	The type of environment that the reaction needs for it to happen (e.g. temperature or pressure)
Reaction conditions	The substances that are reacting in a chemical reaction

5. **Describe** what happens to the atoms in the reactants during a chemical reaction.

Applying

6. Nitrogen and oxygen gas exist in the atmosphere, but they do not react together. However, at the high temperatures and pressures in car engines, they will react with each other. **Identify** the reaction conditions needed to cause nitrogen and oxygen to react with each other.
7. **Determine** the word equations for the following scenarios.
   a) Magnesium and chlorine react to make magnesium chloride.
   b) When iron and oxygen react, they change to a new substance: iron oxide (rust).
   c) The platinum catalyst in a car's catalytic converter changes carbon monoxide and oxygen to carbon dioxide.

Analysing

8. **Compare** physical changes and chemical changes.
9. **Categorise** the following examples as physical changes or chemical changes.
   a) Sugar dissolving in a cup of tea
   b) Iron nail rusting
   c) Ice melting to form water
   d) Frying an egg
   e) Toasting bread

Evaluating

10. The following equation shows what happens during respiration, during which glucose and oxygen (reactants) react to make carbon dioxide and water (products). **Deduce** the three mistakes that have been made and rewrite the equation correctly.

carbon dioxide and water = glucose + oxygen

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6.2 The Law of Conservation of Mass

Learning goals

At the end of this section, I will be able to:

1. Define the 'Law of Conservation of Mass'.
2. Explain the outcome of experiments based on the Law of Conservation of Mass.
3. Identify a balanced chemical equation for a chemical reaction.

WORKSHEET Conservation of mass 1

VIDEO Law of Conservation of Mass

In the late 1700s, scientists thought that for something to burn, it had to contain the element phlogiston (later known as oxygen). Antoine Lavoisier, a French scientist, was burning red precipitate (mercury oxide) in a closed environment, meaning that no substances could escape, and noticed that the mass of the substances at the end was the same as the mass of the substances at the start. In 1789, he called this Lavoisier's law – it was later renamed the **Law of Conservation of Mass**. This is one of the fundamental laws of chemistry.

Law of Conservation of Mass
a scientific law that states that matter can be neither created nor destroyed

The Law of Conservation of Mass

The Law of Conservation of Mass states that matter can neither be created nor destroyed – but what does this mean? Imagine you have two clear solutions. Solution A contains 50 grams (g) of sodium chloride dissolved in water and solution B contains 50 g of silver nitrate dissolved in water. You can see that the mass of the solutions or reactants, before being mixed, is equal to 100 g. When the two solutions are mixed and a chemical reaction occurs, according to the Law of Conservation of Mass, the mass of the products should equal the mass of the reactants, as matter cannot be created nor destroyed. And indeed, this is the case. When you mix these two solutions together in a beaker, a white solid called silver chloride forms as a precipitate and the contents of the beaker still weighs 100 g (see Figure 6.10).



Figure 6.9 Antoine Lavoisier proposed the Law of Conservation of Mass.



Figure 6.10 The mass of the reactants should equal the mass of the products according to the Law of Conservation of Mass.

Let's consider another example. If you take the mass of all the ingredients used to make pikelets (flour, eggs and milk), when the pikelets have been cooked, the mass of all the pikelets made from the batter should equal the mass of the starting ingredients or reactants. This would follow the Law of Conservation of Mass. However, as cooking on the stove top is not a closed or sealed environment, there might actually be a difference between the two masses, as water can evaporate from the batter during cooking. This means matter appears to be lost as the products have less mass than the reactants.

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closed system
an environment from which matter cannot escape

open system
an environment from which matter can escape

This example demonstrates why it is important to observe the conservation of mass in a **closed system** (one from which nothing can escape). In an **open system**, reactions that produce gases will appear to lose mass as that gas moves into the air. Conversely, reactions that take gas from the environment as a reactant will appear to gain mass in an open system.



Figure 6.11 If a chemical reaction, like cooking pikelets, occurs in an open system, it may appear that mass has been lost.

Try this 6.2

Investigating the Law of Conservation of Mass

Complete these activities and consider if the Law of Conservation of Mass has been demonstrated or not. If not, think about why that may be the case. Revisit the terms 'open system' and 'closed system'.

Be careful

Wear appropriate personal protective equipment.

The popcorn bag will be hot after heating. Handle with care.

The steel wool activity generates smoke. Take appropriate precautions.

1. Grab a bag of unpopped microwave popcorn and record the mass. Cook the popcorn in the microwave as per the instructions on the bag. Once the popcorn has finished popping, weigh the bag again and record the mass. Follow the instructions for opening the bag, then weight the bag again and record the mass.
2. Place an unused glowstick on some scales and record the mass. Crack the glowstick so that it starts to glow and place it straight back onto the scales. Weight the glowstick and record the mass.
3. Pull some steel wool apart into thin strips and then bundle it into a loose ball. Place the steel wool in a glass Petri dish or aluminium patty pan and weigh it. Record the mass. Touch a 9-volt battery to the steel wool and watch as it catches alight. Repeat several times until much of the wool has burned. After the steel wool has gone out, allow the Petri dish to cool for 2 minutes. Then weigh the Petri dish and steel wool a second time, and record the mass.

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Quick check 6.4

1. **Identify** who discovered the Law of Conservation of Mass.
2. **State** the definition of the Law of Conservation of Mass.
3. **Determine** the mass of the products if the mass of reactants is 30 g.
4. **Discuss** why it is difficult to observe the Law of Conservation of Mass in an open system.
5. **Explain** why the mass of a glass of water left out on a hot day decreases.

How does the Law of Conservation of Mass relate to chemical equations?

As a scientist, you need to factor in the Law of Conservation of Mass when you write chemical equations. Consider the reaction in Figure 6.12. Here, copper chloride ($CuCl_2$) is being broken down into its elements: copper (Cu) and chlorine (Cl_2).

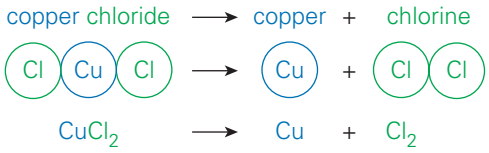


Figure 6.12 A word equation, particle representation and symbol equation showing the decomposition of copper chloride into its elements

For this reaction to obey the Law of Conservation of Mass, there must be the same number of atoms of each element in the reactant and the products.

Let's check:

reactants	→	products
1 copper atom		1 copper atom
2 chlorine atoms		2 chlorine atoms

So, there is the same number of atoms on each side of the equation and therefore the same mass. We say this equation is **balanced** as it follows the Law of Conservation of Mass. The only difference is how the atoms are arranged.

balanced when a chemical equation has an equal number of atoms of each element on both the reactant and product side of the equation

Figure 6.13 shows a word equation, particle representation and symbol equation for the reaction between magnesium (Mg) and oxygen (O_2) to form magnesium oxide (MgO).

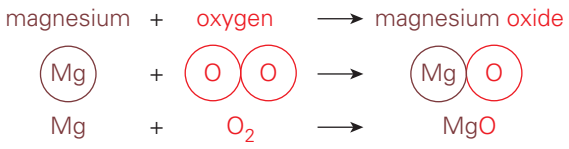


Figure 6.13 The combustion reaction between magnesium and oxygen forms magnesium oxide.

What do you notice about the number of each type of atom in the reactants compared to the product?

reactants	→	products
1 magnesium atom		1 magnesium atom
2 oxygen atoms		1 oxygen atom

The number of each type of atom in the reactants and the product is different. This means that this equation is not obeying the Law of Conservation of Mass and is not balanced.

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How can we make the equation balanced? We cannot change the molecules that are formed or the substances reacting by changing their formula, but we can change how much of them there is. As we need another oxygen on the product side, let us make it 2 MgO, as shown in Figure 6.14.

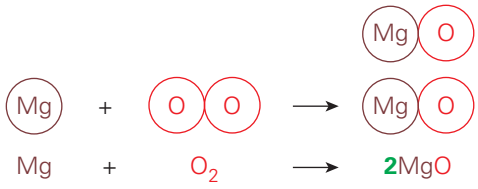


Figure 6.14 This equation now has the correct number of oxygen atoms, but it is still not observing the Law of Conservation of Mass.

Let's check again:

reactants	⟶	products
1 magnesium atom		2 magnesium atoms
2 oxygen atoms		2 oxygen atoms

The equation is *still* not balanced. What if we add one more magnesium atom to the left-hand side (reactants), as shown in Figure 6.15. Does that make the equation balanced?

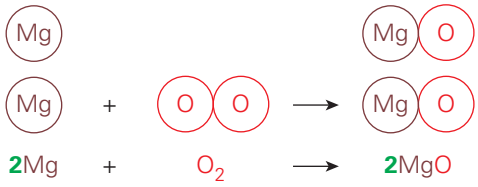


Figure 6.15 The correct balanced equation has the same number of each atom in the reactants and products and therefore observes the Law of Conservation of Mass.

reactants	⟶	products
2 magnesium atoms		2 magnesium atoms
2 oxygen atoms		2 oxygen atoms

coefficient
a number placed in front of a chemical symbol to balance a chemical equation

subscript
a number, letter or symbol written below the line of text (e.g. the 2 in O_2)

Notice the numbers (in green) that have been added to the symbol equation to balance it (see Figure 6.15). They are called **coefficients**. The coefficients do not change the chemical substance, as they do not interfere with the formula by changing the **subscript** numbers. They just change the amount of the substance, in the same way that we might say 1 cup of flour or 2 cups of flour. It is still flour, but the amount has changed.

WORKSHEET
Conservation of mass 2

To show that a chemical reaction obeys the Law of Conservation of Mass, a balanced chemical equation is used. This provides more information than a word equation because the number of reactant and product atoms is shown. For now, you just need to concentrate on identifying whether equations observe the Law of Conservation of Mass and are balanced. In Year 10, you will learn the intricacies of how to balance chemical equations so that they follow this law.

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Try this 6.3

Balancing equations

Using Lego, practise balancing equations. Begin by drawing an arrow in the centre of a piece of paper. For each of the reactions below (a–c), make the reactants and the products. Make sure each element is a different colour (e.g. red for C and blue for O).

a) Reactants: CO and O_2; products: CO_2

b) Reactants: Na and Cl_2; products: NaCl

c) Reactants: Na and H_2O; products: NaOH and H_2



Position your reactants and products on the paper, either to the left or right of the arrow as necessary, and add '+' symbols. Determine how many of each type of atom is on the left (in the reactants) and on the right (in the products). Does the equation demonstrate the Law of Conservation of Mass? If not, can you balance it?

One of PhET's interactive digital simulations looks at reactants, products and leftovers. You may like to have a play around with the sandwiches, molecules and game mode to reinforce your understanding of the Law of Conservation of Mass and balancing chemical equations.

Quick check 6.5

1. **Explain** why it is necessary to balance equations.
2. Two students were doing an experiment in the laboratory. They measured the mass of reactants as 50 g. After the reaction had completed, the mass of the products was 34 g. They noticed that a gas was given off during the reaction, so they wanted to find out the mass of this gas. **Explain** to the students how they could calculate this.
3. In each of the following examples, **identify** the coefficient (which can change) and the subscript (which cannot be changed without affecting the chemical substance).
   a) $3H_2$
   b) $2H_2O$
   c) $2NH_3$
4. **Identify** which of the following symbol equations are balanced and therefore demonstrate the Law of Conservation of Mass. If the equation is not balanced, you could try to balance it.
   a) $Na + Cl_2 \rightarrow NaCl$
   b) $2CuO + C \rightarrow Cu + CO_2$
   c) $N_2 + 3H_2 \rightarrow 2NH_3$
   d) $2H_2O_2 \rightarrow 2H_2O + O_2$

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Practical 6.1

Observing the Law of Conservation of Mass (1)

Be careful
Do not look directly at combusting magnesium. The reaction is very bright and can damage your eyes. Wear safety glasses.

VIDEO Practical 6.1 Observing the Law of Conservation of Mass (1)

Aim
To observe the Law of Conservation of Mass by reacting magnesium and oxygen

Hypothesis
Read through the materials and method and then write a hypothesis for this practical.

Materials
- 5 cm strip of magnesium ribbon
- tongs
- crucible
- matches
- Bunsen burner
- pipeclay triangle
- tripod
- heatproof mat
- safety glasses
- electronic balance
- fine sandpaper

Method
1. Copy the results table below into your science book.
2. Set up a Bunsen burner on a heatproof mat. Place the clay triangle on top of the tripod.
3. Weigh the crucible with its lid.
4. Examine the piece of magnesium. If it is not shiny and clean, gently use the sandpaper to remove any imperfections from the surface.
5. Loosely coil the magnesium ribbon and place it in the crucible. Weigh the crucible again with the lid on.
6. Calculate the mass of magnesium by subtracting the mass of the empty crucible.
7. Heat the crucible over the Bunsen burner on the blue flame, carefully lifting the lid using the tongs to allow sufficient air into the crucible.
8. Continue heating until the magnesium has fully reacted.
9. When the crucible has cooled sufficiently, weigh it and its contents again. Calculate the mass of the new compound by subtracting the mass of the empty crucible.

Results
Copy and complete the following table.

Table showing the mass of different components in the experiment, before and after heating

Item	Mass (g)
Crucible + lid	
Crucible + lid + magnesium before heating	
Magnesium	
Crucible + lid + compound after heating	
Compound	

Discussion: Analysis
1. Describe your observations when the magnesium reacted in the crucible. List the evidence/indicators that a chemical change had occurred.
2. The formula for oxygen is O_2. Write a balanced chemical equation for this reaction, using Figure 6.15 to help you.
3. State if your results demonstrate the Law of Conservation of Mass.
4. Explain why this reaction is a difficult example for showing the Law of Conservation of Mass.
5. Propose how you could have made it easier to demonstrate the Law of Conservation of Mass.

continued

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Discussion: Evaluation

1. Identify any potential sources of error in this experiment and how they have potentially affected the results.
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. Make a claim regarding your experimental findings.
2. Support the claim by referring to your experimental data, including any potential sources of error.
3. State whether your hypothesis was supported or not supported by the data.

Practical 6.2

Observing the Law of Conservation of Mass (2)

Aim

To observe the Law of Conservation of Mass by observing a chemical reaction

Hypothesis

Read through the materials and method, and write a hypothesis for this practical.

Materials

- 20 mL measuring cylinder × 2
- 20 mL 0.1 mol L^{-1} copper(II) sulfate ($CuSO_4$)
- 20 mL of 0.1 mol L^{-1} sodium hydroxide (NaOH)
- 100 mL beakers × 2
- electronic balance

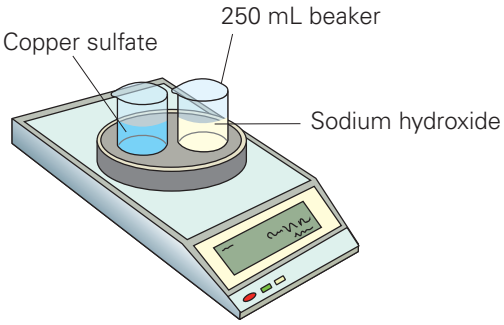


Figure 6.16 Weighing the mass of the beakers with the reactants

Method

1. Measure out 20 mL of 0.1 mol L^{-1} copper(II) sulfate into a 100 mL beaker.
2. Measure out 20 mL of 0.1 mol L^{-1} sodium hydroxide into another 100 mL beaker.
3. Turn on a top-loading electronic balance and zero it.
4. Place both beakers on the electronic balance together as shown in Figure 6.16, and record the mass in the results table.
5. Carefully pour the contents of one of the beakers into the other, taking care not to spill anything on the balance.
6. Replace the empty beaker back on the balance and weigh the mass of both beakers again.
7. Record the mass of the beakers in the table below.

Results

Copy and complete the following table.

Table showing the mass of the beakers before and after mixing

	Mass (g)
Beakers before mixing	
Beakers after mixing	

Discussion: Analysis

1. State the Law of Conservation of Mass.
2. A chemical reaction has taken place. The products of this reaction are copper(II) hydroxide, $Cu(OH)_2$, and sodium sulfate, Na_2SO_4. Write a word equation for this reaction.
3. List the evidence that a chemical reaction has taken place.
4. This experiment was carried out in an open system. Define this term.
5. Is there evidence to suggest that mass is conserved in this chemical reaction? Explain.

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Section 6.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 6.2 questions

Remembering

1. **State** the Law of Conservation of Mass.
2. **Identify** the mass of the products when the following react to completion.
   a) 35 g of reactants
   b) 12 g of reactants
   c) 2 g of one reactant added to 24 g of another reactant
   d) 6 g of one reactant added to 3 g of another reactant

Understanding

3. There are two reactants in a chemical equation and one product. The mass of the product is 30 g. The mass of the first reactant is 17 g. **Describe** how the mass of the second reactant must equal 13 g to obey the Law of Conservation of Mass in a closed system.

Applying

4. Emma carried out an experiment by reacting different amounts of magnesium with oxygen. Her measurements are shown in the following results table. **Explain** how her results support the Law of Conservation of Mass.

Mass of magnesium (g)	Mass of oxygen (g)	Mass of product (g)
5.90	1.74	7.64
2.34	1.83	4.17
6.39	2.36	8.75

Analysing

5. **Analyse** the following chemical equations to find which obey the Law of Conservation of Mass.
   a) $C + O_2 \rightarrow CO_2$
   b) $CaCO_3 \rightarrow CaO + CO_2$
   c) $H_2 + O_2 \rightarrow H_2O$
   d) $Na + Cl_2 \rightarrow NaCl$
   e) $Ba + O_2 \rightarrow BaO$
6. **Rewrite** any chemical equations from Question 5 that did not obey the Law of Conservation of Mass as balanced chemical equations.
7. **Distinguish** between an open system and a closed system.

Evaluating

8. **Decide** whether an open system or a closed system is better to observe the Law of Conservation of Mass. **Justify** your choice.
9. In a chemical reaction, the mass of the reactants was 15 g. The mass of the products was 12 g. **Decide** whether this reaction followed the Law of Conservation of Mass. **Justify** your choice.
10. Ginny and Paul leave a glass of water on their balcony. By the time they realise it has been left there, the volume of water in the glass has reduced. Ginny says that the mass of water molecules has been lost. Paul says there is less water and therefore less mass in the glass because the water has evaporated, and this mass has been added to the mass of the air.
    a) **Decide** who you think is correct and justify your reasoning.
    b) **Design** an experiment to demonstrate who was correct.

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6.3 Industrial synthesis

Learning goals

At the end of this section, I will be able to:

1. Describe how some chemical reactions are used to extract metals and produce elements.
2. Explain how manufacturers can improve chemical synthesis by using green chemistry principles.

Chemical reactions occur naturally to produce a range of naturally occurring chemical compounds (i.e. two or more different elements chemically bonded together). Industrial chemical manufacturers often take such compounds and use chemical reactions to re-form pure elements. This is a major industry in Australia, particularly in mining, in which metal compounds are mined and reacted to re-form pure metals.

Extracting metals

Non-reactive metals

Metals that are very unreactive and can be found in the earth in the elemental form are known as **native metals**. For example, gold, silver and copper (see Figure 6.17) metals can be found in their elemental form.

native metal
a metal that exists in its elemental form in the environment



Figure 6.17 Copper is a less reactive metal, which is why it can be found in its pure form in nature; that is, it is a native metal.

Reactive metals

As most metals in their elemental states are reactive, they are not found in their native state, but rather are found as compounds. This means the metal atoms are combined with other substances. These compounds are called ores.

Reaction with carbon

Most relatively reactive metals exist in nature as compounds that have reacted with oxygen or sulfur to form metal oxide or sulfide mineral ores. The elemental form of the metal can be synthesised by reacting the metal oxides or sulfides with carbon (such as coal) at extremely high temperatures in a blast furnace. The carbon removes the oxygen from the metal ore, producing the products carbon dioxide and the pure form of the metal. The reaction below is an example of how iron is extracted from iron oxide in a blast furnace.

Word equation:	iron oxide + carbon → iron + carbon dioxide
Symbol equation:	$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$

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Practical 6.3

Extracting iron using a matchstick

Be careful
Wear appropriate personal protective equipment.



Aim

To extract iron from iron oxide

Materials

- red iron(III) oxide powder
- sodium carbonate powder
- 100 mL beaker filled with water
- watchglasses
- crucible tongs
- weighing boat
- spatula
- Bunsen burner
- bench mat
- magnet
- safety match



VIDEO
Practical 6.3
Extracting iron using a matchstick

Method

1. Copy the results table below into your science book.
2. Place a small amount of sodium carbonate powder in a watchglass. Do the same with the iron(III) oxide powder.
3. Run the magnet underneath the watchglasses containing the iron(III) oxide powder and the sodium carbonate powder, and over the match head. Record whether they are magnetic.
4. Check the rubber tubing for the Bunsen burner is intact and the air hole is closed, then set up and light the Bunsen burner.
5. Moisten the head of the match by dipping it into a beaker of water.
6. Roll the head of the match in the sodium carbonate powder and then in the iron(III) oxide powder.
7. Using the pair of tongs, hold the head of the match in a blue Bunsen burner flame – only let it burn halfway down the match.
8. Turn off the Bunsen burner and allow the match to cool.
9. Use the spatula to crush the charred head of the match into the weighing boat.
10. Run the magnet underneath the weighing boat and record what you see.

Results

Copy and complete the following table.

Table showing the magnetic nature of the different substances observed

Substance	Magnetic?
Iron(III) oxide powder	
Sodium carbonate powder	
Match head (before heating)	
Charred remains (after heating)	

Discussion: Analysis

1. In this experiment, you reacted iron(III) oxide powder with carbon to try to extract the metal. Which chemical did the carbon come from?
2. How did you know that iron metal was the product formed?
3. Write a word equation for the reaction studied.
4. Explain why most metals are not found in their elemental state so need to be extracted from compounds.

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Figure 6.18 Molten iron spews out of a blast furnace where iron ores are reacted with carbon to form pure iron metal.



Figure 6.19 An open-cut gold mine in Fosterville, Central Victoria

Electrolysis

Some of the most reactive metals require a lot of energy to be converted back to their elemental form. To extract these metals, an electric current is passed through a molten (liquid) form of the impure metal, resulting in the extraction of the pure form of the metal, in a method called **electrolysis**. As this process is expensive, it is only used to extract reactive metals such as aluminium, sodium and potassium.

electrolysis
a process in which an electric current is used to decompose a chemical compound

green
(environmental) something that has a reduced impact on the environment

sustainable
a way of using natural resources responsibly so they are available for future generations

Quick check 6.6

1. **Define** 'native metal'.
2. **Name** an example of a metal from this chapter that can be extracted by:
   a) reacting with carbon
   b) electrolysis.

Principles of green chemistry

VIDEO
Green chemistry

From an environmental perspective, industrial synthesis of elemental metals can be considered highly energy consuming and unsustainable. For example, decomposing metal oxides in a blast furnace burning coal requires very high temperatures, consumes a lot of energy and produces carbon dioxide, a greenhouse gas. Furthermore, electrolysis of reactive metals requires a significant amount of energy in the form of electrical energy, which is often produced by unsustainable coal-fired power stations.

However, the increase in consumer and regulatory demand for more **green** and **sustainable** approaches to chemical synthesis has resulted in a significant shift towards green chemical synthesis. Chemical manufacturers have also considered the cost and benefits to their reputations of conducting chemical syntheses in sustainable ways.

In 1998, scientists Paul Anastas and John Warner published a book that detailed the 12 principles of green chemistry. These principles, some of which are detailed in Table 6.2, provide a framework for chemical manufacturers to produce products in a more sustainable way, including by optimising their chemical reactions.

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Green principle	Details
Prevent waste	Chemical syntheses should be designed to prevent waste, rather than having to clean up the waste produced.
Use renewable feedstocks	Reactants should be sourced from renewable resources rather than non-renewable resources.
Design for energy efficiency	High temperatures and pressures use large amounts of energy, which are often produced from unsustainable sources. Ambient temperatures and pressures should be used in chemical syntheses.
Less hazardous synthesis	Chemical reactions should be designed so that products are not hazardous or toxic to humans or the environment.
Design for degradation	Chemical reactions should be designed so that products are naturally degradable and are broken down in the environment.

Table 6.2 Principles of green chemistry

Chemical manufacturers produce a variety of products that we use every day, including common household objects. Many of these products have started to become more environmentally friendly or be produced by considering the 12 principles of green chemistry. For example, you might already use eco-friendly biodegradable toothbrushes, cutlery or cups. All chemical synthesis is heading towards a more sustainable future.



Figure 6.20 Bamboo toothbrushes are made from renewable feedstocks and are biodegradable.

Science as a human endeavour 6.1

Greener energy and ethical innovation



Today, lithium-ion batteries are used to power your laptop, your phone and even your car; however, the cathodes of the batteries traditionally contain cobalt. Cobalt is expensive, difficult to source, and environmentally destructive when mined. Cobalt mining is also deeply tied to exploitative labour practices, particularly in the Democratic Republic of Congo, where mining operations have been linked to human rights violations, child labour and the displacement of communities. Addressing these ethical concerns is as crucial as reducing environmental harm.

In January 2024, researchers at MIT in the USA published some very exciting work. With a shift toward more sustainable and ethical chemistry, the researchers designed a new lithium-ion battery with a cathode based on a carbon-based organic material widely available in nature. This new material could replace cobalt in the cathodes of batteries. This alternative offers the same performance without the ethical and environmental costs often associated with resource extraction.

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Making thinking visible 6.2

Reporter's notebook: Is everyone happy about the principles of green chemistry?

Imagine you are an online newspaper reporter who needs to differentiate the facts about the push for green chemistry from your personal thoughts and feelings about why it is important. This is an opportunity to step back from your own perspective and consider the views of others, such as the industries that need to change (the economic implications) and the people that will be affected (the social implications). You should also consider ethical implications. As a reporter, you will do the following.

- Name the facts and reasons behind the push for greener chemistry.
- Identify the thoughts and feelings of the different groups involved or affected by the push for greener chemistry.
- Make your best judgement about the situation, based on this information.

The *Reporter's notebook* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Explore! 6.1



Twelve principles of green chemistry

Some of the principles of green chemistry have been discussed in this chapter; however, there are more to explore. The American Chemical Society (ACS) has produced a pocket guide for quick reference.

Head to the ACS website and explore the details of each of the 12 principles of green chemistry.



Figure 6.21 The Green Chemistry Pocket Guide created by the American Chemical Society. Reprinted with permission from ACS Green Chemistry Institute®. Copyright 2023 American Chemical Society. Green Chemistry Pocket Guides: https://www.acs.org/green-chemistry-sustainability/principles/12-principles-of-green-chemistry.html

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Did you know? 6.2

Green chemistry education

Dr Amy Cannon is recognised as the first person to earn a PhD in green chemistry. As the cofounder and executive director of Beyond Benign, a US non-profit organisation that promotes sustainable science education and green chemistry principles, Cannon has made significant contributions to the advancement of safer chemicals and processes in both academic and industrial settings. She has also developed innovative educational programs that aim to educate future scientists on the importance of sustainability and green chemistry. Partially because of Dr Cannon's contributions, you can now study green chemistry in higher education in Australia.



Figure 6.22 Dr Amy Cannon has received many awards for her leadership in promoting environmentally responsible chemistry practices.

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Section 6.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 6.3 questions

Remembering

1. **Define** 'electrolysis'.
2. **List** three metals that can be found in the earth as native metals.

Understanding

3. **Describe** what is meant by the use of renewable feedstocks in green chemical synthesis.
4. **List** three household objects in your house that may have been synthesised according to green chemistry principles.

Applying

5. **Outline** what determines whether electrolysis, a blast furnace or open-cut mining is the right approach for producing an element.

Analysing

6. **Explain** why extraction of iron using a blast furnace is not an energy-efficient chemical synthesis.

Evaluating

7. **Evaluate** how the 12 principles of green chemistry can be used to promote the use of renewable sources of energy such as solar power and wind power for chemical synthesis.

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Chapter review

Chapter checklist

Success criteria		Linked question
6.1	I can recall the evidence of chemical change.	1
6.1	I can define 'chemical reaction'.	2
6.1	I can identify the reactants and products in a chemical equation.	2, 8
6.1	I can write a word equation.	5
6.2	I can define the 'Law of Conservation of Mass'.	4
6.2	I can explain the outcome of experiments based on the Law of Conservation of Mass.	10
6.2	I can identify a balanced equation for a chemical reaction.	6, 8
6.3	I can describe how some chemical reactions are used to extract metals and produce elements.	7,
6.3	I can explain how manufacturers can improve chemical syntheses by using green chemistry principles.	3, 9

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Remembering

1. **List** five indicators of chemical change.

Understanding

2. **Describe** what is happening in the following reaction. Use the following keywords: 'reactants', 'product', 'bonds', 'rearranged' and 'chemical reaction'. Make sure you also mention the reaction conditions.

$$\text{hydrogen} + \text{oxygen} \xrightarrow{\text{heat}} \text{water}$$

3. **Describe** the green chemistry principle 'design for degradation'.
4. **Explain** how a balanced chemical equation can provide evidence of the Law of Conservation of Mass.

Applying

5. **Write** word equations for the following chemical reactions.
   a) Nitrogen gas and hydrogen gas react to produce ammonia (NH_3).
   b) Calcium carbonate is a white solid with the formula $CaCO_3$. When heated, it breaks down to form solid calcium oxide (CaO) and carbon dioxide gas (CO_2).
   c) Water is formed when hydrogen gas and oxygen gas react.
   d) When calcium carbonate reacts with nitric acid (HNO_3), water, carbon dioxide and calcium nitrate ($Ca(NO_3)_2$) is formed.

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6. **Rewrite** each of the following chemical equations so that they obey the Law of Conservation of Mass.
   a) $Mg + O_2 \rightarrow MgO$
   b) $H_2\,(g) + Cl_2\,(g) \rightarrow HCl\,(g)$
   c) $H_2 + O_2 \rightarrow H_2O$

Analysing

7. **Compare** the conditions required for the reaction of a metal with carbon and an electrolysis reaction.
8. Analyse the following word equation (top) and formula equation (bottom).

   hydrochloric acid + magnesium → magnesium chloride + hydrogen

   $2HCl + Mg \rightarrow MgCl_2 + H_2$

   Identify:
   a) the reactants
   b) the products
   c) whether it observes the Law of Conservation of Mass
   d) the chemical formula of magnesium chloride.

Evaluating

9. The chemical synthesis of sodium chloride (NaCl), or table salt, requires that sodium metal (Na) and chlorine gas (Cl_2), both hazardous reactants, are heated at 800°C. This produces an explosive reaction. **Propose** three ways this chemical synthesis could be adjusted in line with the 12 principles of green chemistry.
10. Reactants weighing a total of 20 g were reacted together. Only 18 g of product was made. **Propose** what may have happened to the remaining 2 g of mass.

Data questions

A variety of fuel sources are shown in Table 6.3, with the relative number of carbon atoms per fuel molecule and the mass of CO_2 produced by burning 1 kilogram (kg) of each fuel. This information is also shown as a graph in Figure 6.23.

Fuel	Relative number of reactant carbon atoms per molecule	Mass of CO_2 produced (kg)
Natural gas	1	2.74
LPG	3	2.99
Butane	4	3.03
Petrol 91	8	3.08
Petrol 98	8	3.08
Diesel	10	3.09
Coal	–	3.66

Table 6.3 The relative number of carbon atoms per fuel molecule and the mass of CO_2 produced by burning 1 kg of the fuel

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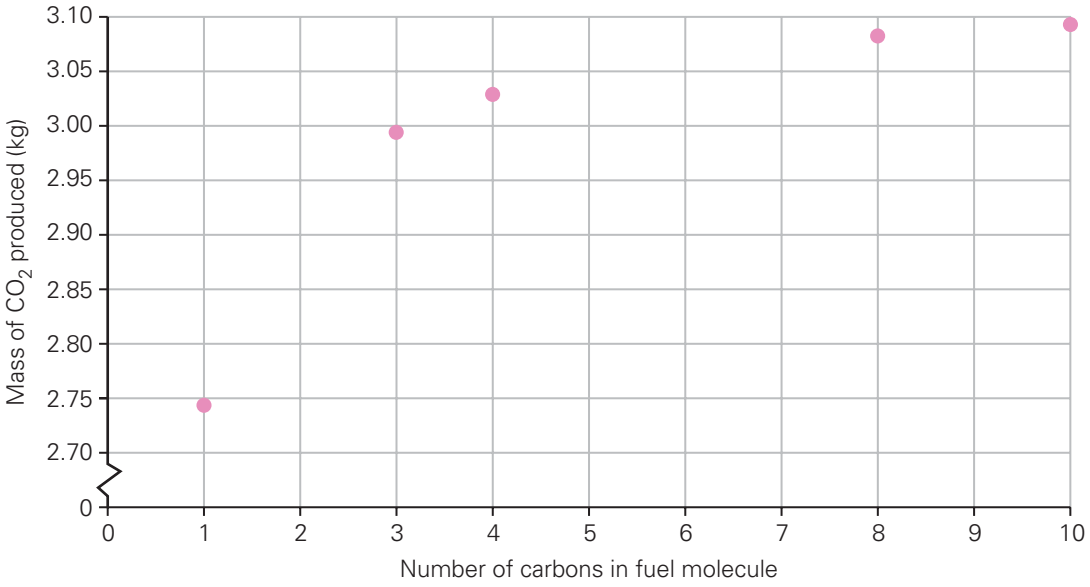


Figure 6.23 The relative number of carbon atoms per fuel molecule versus the mass of CO_2 produced by burning 1 kg of the fuel

Applying

1. **Identify** the fuel that produces the lowest mass of carbon dioxide per kilogram burned.
2. A premium unleaded (petrol 98) brand has stated that its fuel produces less carbon dioxide emissions than a petrol 91 brand. **Determine** whether this statement is correct.
3. A coal mining company has argued that burning 1 kg of their fuel produces less than 1 kg of additional carbon dioxide, compared with the mass of carbon dioxide produced from burning natural gas. **Determine** whether the evidence from Table 6.3 supports this claim.

Analysing

4. **Identify** the trend between the number of carbon atoms per reactant molecule and the mass of carbon dioxide produced.
5. Generally, at atmospheric temperature, fuel molecules with four carbons or less are gaseous fuels, and those with five or more carbons are liquid fuels. Coal is a solid fuel. **Classify** the fuels in Table 6.3 as gas, liquid or solid.

Evaluating

6. A fuel company is producing a new biofuel made primarily from ethanol, which is a molecule with two carbon atoms. **Predict** the mass of carbon dioxide that would be produced by burning 1 kg of this fuel.
7. For a given volume of coal and natural gas, **deduce** which one contains more carbon atoms.
8. **Extrapolate** the data to predict the mass of carbon dioxide that would be produced by burning a fuel with a relative number of carbon atoms per molecule of 11.

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STEM activity: Baristas and the curdling milk problem

Background information

Baristas in Australian coffee shops have felt the frustration of milk curdling. They want to be able to offer their customers a range of choices of milk (e.g. cow's, rice, almond, oat and soy), but all these products respond differently when heated and added to tea and coffee.

Curdling is the process of coagulation that occurs when the protein components in the milk clump together. Certain blends of coffee can be quite acidic (low pH), and acid causes the proteins in milk to unravel and clump together, similar to what happens when an egg is boiled and the yolk solidifies. Soy milk is particularly susceptible to curdling.

As with many chemical reactions, temperature can affect the rate at which the reaction occurs. If you add an acid such as lemon juice or vinegar to hot milk, the milk will curdle almost immediately. But if you add an acid to cold milk, the reaction will not occur for some time.

Chemical engineers apply the principles of chemistry, biology, physics and maths to implement best-practice strategies involving chemicals, drugs and food. In 2015, an Australian milk brand, MILKLAB, worked with baristas to create a range of soy milk that would not curdle in acidic coffee blends.

However, not all coffee shops can afford speciality products, so adding sodium bicarbonate (baking soda) to coffee to prevent soy milk curdling is a common cheap hack used by many baristas and coffee enthusiasts. Adding a small amount of sodium bicarbonate to the coffee before adding the soy milk can help neutralise the acidity and prevent curdling. However, it's important to note that although this trick is safe and effective, adding too much baking soda can alter the flavour of your coffee, so it's best to use it sparingly!



Figure 6.24 (a) An Australian flat white coffee and **(b)** lumpy curdled milk

DESIGN BRIEF

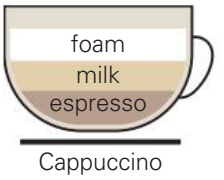
Create an infographic for baristas, based on your experimentation results, for a best-practice approach to heating milk. Use images from your experimentation process.

Activity instructions

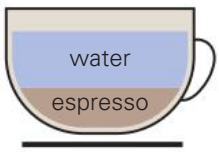
As the chemical engineer representing the Hipsters Coffee Union of Australia, you are responsible for ensuring that baristas know how to make a coffee in which the milk does not curdle, so no barista loses their job over split milk. You will propose the best pH, temperature and ratio of volume of coffee to milk for a range of milk types in order to prevent curdling.

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To do this, you will need to design several tests or trials. You will need to use fresh milk in your samples, use the same amount of milk for each test, determine a way of measuring the acidity of the milk and record the weight of any curdled milk produced. Be sure to record all your data, amounts and settings for your trials, so that you can create your infographic for the Union with confidence.



Cappuccino



Americano



Latte

Figure 6.25 An infographic showing the milk and froth ratios for three popular coffee drinks

Suggested materials

- white vinegar or fresh lemon juice (both have a pH of approximately 2)
- instant coffee
- a range of different milks, including cow's milk and soy milk
- water
- beakers
- measuring cylinder
- transfer bulb pipettes
- spoons or stirring rods
- clear plastic cups for cold coffee
- kettle
- paper towels
- several pieces of cheesecloth or cotton fabric
- thermometer
- data-logging pH meter or alternative method for measuring pH
- digital balance
- permanent marker
- gloves

Research and feasibility

1. Conduct some research on the process of how milk curdles and list all the factors.
2. Conduct some research on and list the ingredients that are used in barista-made coffee, and the ratios involved. Take note of any temperatures and pH values of the ingredients. Make sure you include research on all the suggested materials.

Design and sustainability

3. Design an experiment that demonstrates the conditions under which combining coffee and milk either curdles the milk or achieves a smooth texture. Think about how milk curdles and see if you can replicate this situation.

Be careful
Do not consume any of the food.
Take care when handling boiling water.

Create

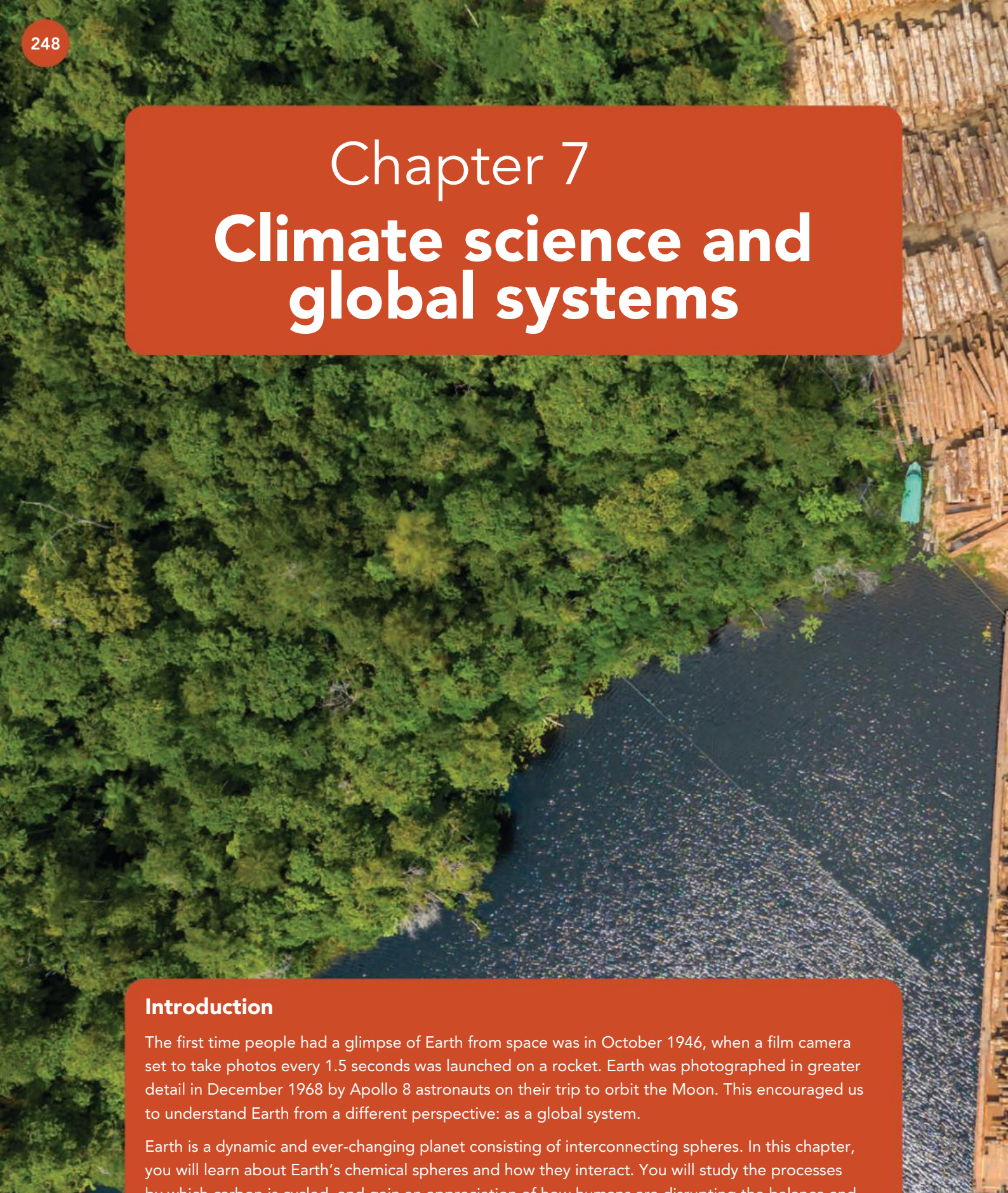
4. Perform your experiment, ensuring you take photos and notes of all observations of the experiment along the way.
5. Create an A5 'cheat sheet' of infographics for baristas so they can easily identify the ratios possible for normal milk and soy milk with the most acidic coffee blends. You may do this by hand, or search for free infographic design tools on the internet.

Evaluate and modify

6. Discuss your findings with your colleagues and present your infographic.
7. Propose the best ratio of coffee to milk for preventing the curdling of milk for acidic coffee blends with different milk products.
8. Identify possible sources of error in your testing procedure and suggest some ways to improve and modify your experiments in the future.
9. Predict how the temperature of the milk may have affected your findings.

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Chapter 7
Climate science and global systems



Introduction

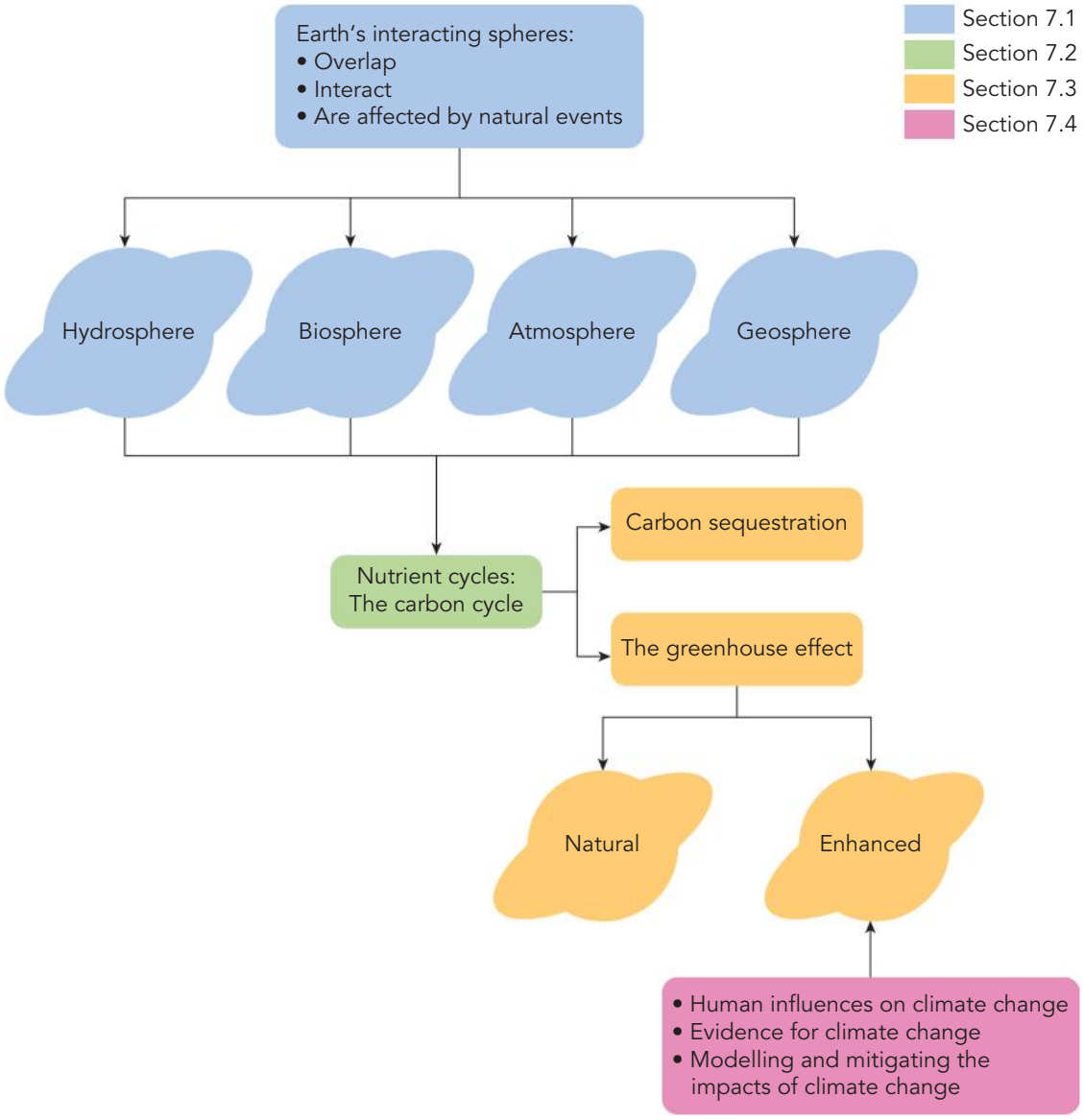
The first time people had a glimpse of Earth from space was in October 1946, when a film camera set to take photos every 1.5 seconds was launched on a rocket. Earth was photographed in greater detail in December 1968 by Apollo 8 astronauts on their trip to orbit the Moon. This encouraged us to understand Earth from a different perspective: as a global system.

Earth is a dynamic and ever-changing planet consisting of interconnecting spheres. In this chapter, you will learn about Earth's chemical spheres and how they interact. You will study the processes by which carbon is cycled, and gain an appreciation of how humans are disrupting the balance and impacting the composition of our planet. Scientists have new tools at their disposal to measure, model and predict how our climate continues to change. It is critical our generation finds ways to mitigate the effects of climate change and better prepare for the impacts in the future.

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Concept map



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Curriculum content

carbon is cycled on Earth through key processes including photosynthesis, respiration, fire, weathering, vulcanism and the combustion of fossil fuels; these processes change the composition of Earth's interrelated systems (atmosphere, biosphere, hydrosphere and lithosphere) over time (VC2S10U10)	
• identifying Earth as a system, differentiating between Earth's 4 systems and discussing interactions between these systems, such as pesticides applied to soils (lithosphere) leaching into waterways (hydrosphere) and affecting organisms (biosphere)	7.1
• examining the carbon cycle using diagrams, animations or simulations and explaining the role of photosynthesis and respiration in that cycle	7.2
• investigating the greenhouse effect and relating it to the role of carbon dioxide in maintaining temperatures that support life on Earth	7.3
• investigating how Aboriginal and/or Torres Strait Islander Peoples use fire-mediated chemical reactions to facilitate energy and nutrient transfer through the practice of cultural burning	7.2
• investigating how Aboriginal and/or Torres Strait Islander Peoples are reducing Australia's greenhouse gas emissions by reinstating cultural burning practices	7.3
• conducting a field investigation to evaluate carbon sequestration in an ecosystem, such as measuring tree biomass, deadwood, leaf litter and soil depth, and using formulas to calculate approximate carbon storage	7.3
• identifying how carbon dioxide is captured and stored naturally or using technologies	7.3
the dynamics of global climate change can be modelled and explained by examining the interactions between greenhouse gas emissions and energy exchanges within and between Earth's systems; mitigating human-induced climate change requires addressing various activities including power generation, deforestation, manufacturing, transportation, food production and resource consumption (VC2S10U11)	
• examining how interactions of radiation from the Sun with the atmosphere, ocean and land are the foundation for the global climate system	7.4
• investigating indicators of climate change such as changes in ocean and atmospheric temperatures, sea levels, biodiversity, species distribution, permafrost and sea ice	7.4
• identifying changes in global climate over time, exploring visualisations and using simulations to investigate why energy balances have changed	7.4
• examining the factors, including energy, that drive deep ocean currents, their role in regulating global climate and their effects on marine life	7.4
• predicting changes to the Earth system and identifying strategies designed to reduce climate change or mitigate its effects	7.4
• calculating an individual's carbon footprint, examining the impact of human activities on atmospheric carbon dioxide levels and suggesting strategies to reduce carbon dioxide emissions	7.3

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scientific knowledge is contestable and is validated and refined over time through expanding scientific methods, replication, publication, peer review and consensus (VC2S10H01)	
• examining the scientific consensus supporting global warming and examining why scientists use different climate change models when there is a climate change consensus among scientists	7.4
advances in technologies have enabled advances in science, while science has contributed to developments in technologies and engineering (VC2S10H02)	
• considering how computer modelling has improved knowledge and predictability of phenomena such as climate change and atmospheric pollution, and how quantum computers enhance modelling of complex weather and climate systems	7.4
• investigating how satellites generate global data including for ocean temperatures, sea levels, and forest and ice cover, and examining how that data is used to evaluate the effects of climate change	7.4
the use of scientific knowledge to address socio-scientific issues and shape a more sustainable future for humans and the environment may have diverse projected outcomes that affect the extent to which scientific knowledge and practices are adopted more broadly by society (VC2S10H03)	
• examining how government initiatives such as Landcare support adoption of effective land-restoration practices that improve soil quality and increase carbon sequestration in soils	7.3
• considering how the traditional ecological knowledges of Aboriginal and/or Torres Strait Islander Peoples are being recognised by Western science and how these practices are being used by Traditional Owners in carbon farming initiatives to increase carbon sequestration and reduce greenhouse gas emissions	7.2, 7.3

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Glossary terms

Anthropogenic	Climate	Interglacial period
Atmosphere	Decomposers	Keystone species
Bioaccumulate	Enhanced greenhouse effect	Lithosphere
Biodiversity	Geosphere	Stratosphere
Biomass	Glacial period	Sustainable ecosystem
Biosphere	Global warming	Troposphere
Carbon sequestration	Greenhouse effect	Weather
Carbon sink	Greenhouse gas	
Carbon source	Hydrosphere	

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7.1 Earth's interacting spheres

WORKSHEET
Earth's spheres

Learning goals

At the end of this section, I will be able to:

1. Distinguish between Earth's chemical spheres: atmosphere, biosphere, geosphere and hydrosphere.
2. List the five layers of the atmosphere.
3. Describe the effect of natural events such as earthquakes, volcanos and cyclones on the chemical spheres.

In your previous studies, you may have learned about two of Earth's cycles: the rock cycle and the water cycle. Matter on Earth is constantly moving, and Earth itself is a dynamic system. There are various interacting spheres, each playing a crucial role in maintaining the balance of the planet. Understanding how these spheres interact with each other, and how they are affected by natural and human-made events, allows scientists to identify and address the environmental challenges facing our planet today.

Chemical spheres

To make it easier to describe the movement of matter around Earth, scientists have split the planet into four major sub-systems called spheres. Despite their name, they are not spherical in shape. These spheres are the:

- atmosphere (the gases surrounding Earth)
- biosphere (the part of the planet that can support life)
- hydrosphere (all the water present on Earth)
- geosphere (all Earth's geological materials, such as the interior and surface of Earth).

Let's look at each of these spheres in more detail.

Atmosphere

atmosphere the mixture of gases above the surface of Earth

troposphere the layer of Earth's atmosphere that is closest to Earth's surface and where most of the weather occurs

stratosphere the layer of Earth's atmosphere above the troposphere; it contains the ozone layer

The **atmosphere** consists of all the gases above Earth's surface; without it there would be no life on Earth. Two main gases make up the atmosphere: nitrogen and oxygen. There are also smaller proportions of other gases (see Table 7.1).

In total, the atmosphere is about 500 kilometres (km) thick and consists of five layers: the **troposphere**, **stratosphere**, mesosphere, thermosphere and exosphere (see Figure 7.1).

Atmospheric gas	Percentage composition (%)
Nitrogen	78.084
Oxygen	20.947
Argon	0.934
Carbon dioxide	0.035
Trace gases (e.g. neon, helium)	Very low

Table 7.1 The percentages of gases in Earth's atmosphere

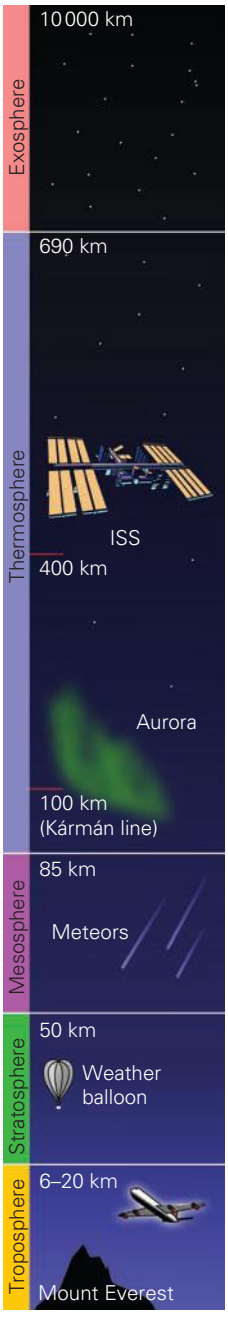


Figure 7.1 The five layers of Earth's atmosphere

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These layers allow us and other living things to breathe, protect us from the Sun's harmful ultraviolet (UV) radiation, protect us from meteorite bombardment and keep the surface temperature of Earth constant. The most important layers to us and other life on Earth are the troposphere and the stratosphere.



Figure 7.2 The view of the crescent moon through the top of Earth's atmosphere

Quick check 7.1

1. **List** Earth's four chemical spheres.
2. **Name** the gas that is found at 21% concentration in Earth's atmosphere.
3. **List** the five layers of Earth's atmosphere.

Troposphere

The troposphere is the lowest layer of Earth's atmosphere, extending from Earth's surface up to an altitude of approximately 6–20 km. It is where most weather occurs and it is the layer in which we live and breathe. The troposphere contains around 75% of the mass of the entire atmosphere, and is composed of mainly nitrogen and oxygen, along with trace amounts of other gases such as carbon dioxide, methane and water vapour. 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.



Figure 7.3 Most of Earth's weather occurs in the troposphere.

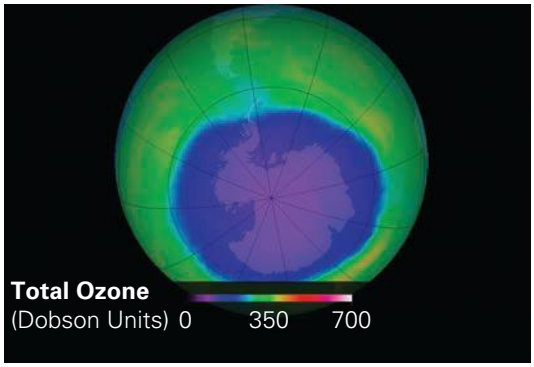


Figure 7.4 Human activities such as the release of chlorofluorocarbons (CFCs) have caused damage to the ozone layer, leading to the formation of the ozone hole, which poses a threat to human health and the environment.

Stratosphere

The stratosphere lies directly above the troposphere, extending from approximately 20–50 km in altitude. It is characterised by a relatively high concentration of ozone molecules (O_3), which absorb harmful ultraviolet radiation from the Sun and trap heat to create a warming effect on Earth. This stable ozone layer inhibits mixing with the troposphere below. In order to avoid turbulence, most jet aircraft fly in the lower part of the stratosphere, which is home to the jet stream, a high-altitude, fast-moving wind that influences weather patterns.

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Figure 7.5 Propeller-driven planes fly in the troposphere, while commercial jets may avoid turbulence by flying above the weather, in the lower stratosphere.

Explore! 7.1

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.

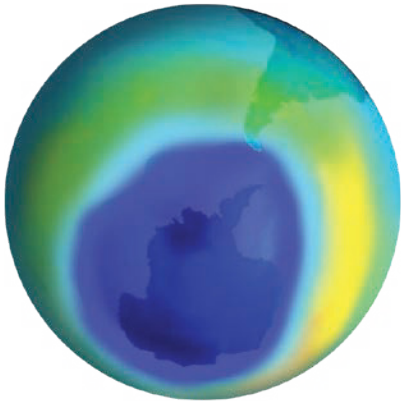


Figure 7.6 The hole in the ozone layer above Antarctica. The bluish-purple areas show the least amount of ozone.

Conduct some research and answer the following questions.

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. Identify 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 that said the ozone layer is on track for a full recovery. When do they predict this will happen by?

Science as a human endeavour 7.1

Felix Baumgartner: The fastest skydiver on Earth

On 14 October 2012, Austria's Felix Baumgartner rose nearly 39 km to the stratosphere in a helium-filled balloon. He then jumped into thin air, freefalling for 4 minutes and 22 seconds before opening his parachute. The entire journey back to the ground lasted just under 10 minutes. Baumgartner reached an estimated speed of 1342 km h^{-1}, which makes him the first man to break the speed of sound in freefall, and he broke the record for the world's highest ever freefall. The jump nearly did not happen because a fault in the heater of Baumgartner's visor was making it fog up when he breathed out. Early in the dive, there was concern that he could not get into the correct position for freefall (head down, arms swept back). Instead, he found himself tumbling over and over. However, due to his extensive freefalling experience, Baumgartner was able to correct his fall and get into a stable position.



Figure 7.7 Felix Baumgartner

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Quick check 7.2

1. **Recall** some of the roles of the stratosphere.
2. **State** the atmospheric layer in which weather occurs.
3. **Justify** which atmospheric layers are most important to humans.

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. oceans, lakes and rivers)

geosphere
all Earth's geological materials, including magma, lava, rocks and minerals

Hydrosphere

The **hydrosphere** refers to all the water on Earth, including the oceans, rivers, lakes, groundwater and even the water vapour in the atmosphere. It plays a critical role in supporting life on Earth, as all living organisms require water to survive. 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 7.8 These Antarctic emperor penguins, as living organisms, are part of the biosphere. The ice shelf they stand upon is part of the hydrosphere.

Quick check 7.3

1. **Describe** what the hydrosphere is composed of.
2. 'Fish are part of the hydrosphere.' **Propose** whether this statement is true or false. **Justify** your choice.

Geosphere

The **geosphere** encompasses all of Earth's geological materials, including the solid and fluid rock that constitutes the crust, mantle and outer and inner 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, that are essential to human societies.



Figure 7.9 The impressive rock structures of Karlu Karlu (Devils Marbles) in the Northern Territory form part of the geosphere.

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The geosphere undergoes a continuous cycle: matter is constantly in motion through the various processes of the rock cycle. Volcanic eruptions expel magma, which cools and solidifies into rocks. The rocks are gradually broken down into sediment through weathering and erosion, which accumulates over time and eventually sinks deeper into Earth's crust. The sediment is then transformed into new rocks through lithification and may resurface as lava through volcanic activity, completing the cycle.



Figure 7.10 The geosphere is constantly in motion because of the many processes involved in the rock cycle.

Lithosphere

lithosphere the geological parts of Earth's crust and upper mantle only

The **lithosphere** is often included in discussions of Earth's global systems; however, it is best conceptualised as part of the geosphere – specifically, the upper layers consisting of Earth's crust and the top rigid section of the upper mantle (see Figure 7.11). The lithosphere is divided into tectonic plates, which rest and move upon the underlying softer upper mantle, known as the asthenosphere. Many seismic and volcanic events occur along the boundaries between the tectonic plates.

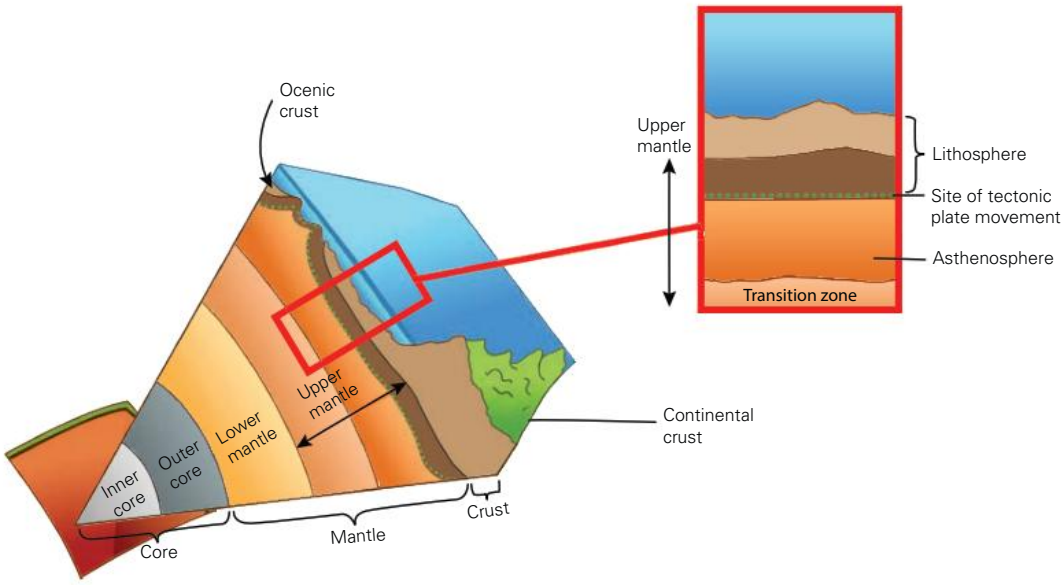


Figure 7.11 Earth's layers

Quick check 7.4

1. **Describe** where most volcanoes and earthquakes occur.
2. **State** what the lithosphere is composed of.
3. **Name** the cycle that results in constant movement of matter within the geosphere.

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Overlapping and interacting spheres

Sometimes it is not easy to exclusively classify substances into one sphere. Take soil as an example. Productive soil is primarily composed of minerals, so it could be considered part of the geosphere. However, it also contains organic matter and plenty of bacteria (from the biosphere), water from the hydrosphere, and air from the atmosphere.

Humans have been altering soil composition through their agricultural practices for thousands of years, and impacting multiple chemical spheres in the process. Pesticides that are sprayed on agricultural crops have the potential to leach into soil and waterways, disrupting the chemistry of the hydrosphere and negatively affecting other living organisms in the biosphere.



Figure 7.12 Plants are part of the biosphere, while productive soil has components of each of the chemical spheres.

Interactions between Earth's spheres are dynamic relationships. The atmosphere interacts with the other spheres by circulating heat, gases and energy throughout the planet. The hydrosphere interacts with the atmosphere by exchanging water vapour through the process of evaporation and precipitation. The biosphere interacts with the other spheres through the cycling of nutrients and the exchange of gases, such as carbon dioxide and oxygen. Carbon dioxide is absorbed by plants during photosynthesis, and the oxygen produced by plants is released into the atmosphere.

The geosphere interacts with the atmosphere and hydrosphere through processes such as erosion, volcanic activity and the movement of tectonic plates. Similarly, the chemical composition of rocks in the geosphere can affect the mineral content of the soil, which affects the growth of plants and the availability of nutrients in the biosphere.

Did you know? 7.1

Contaminated dolphins

Victoria's critically endangered Burrunan dolphins, found in Port Phillip Bay and the Gippsland Lakes, have been found to contain the highest concentrations of PFAS chemicals anywhere in the world. PFAS has been widely used as a non-stick coating for cookware, in packaging and notably in fire extinguishing foam that has contaminated multiple Victorian firefighter training facilities. It presents an environmental and biological problem as it is slow to biodegrade, and can **bioaccumulate** in organisms. The sources of PFAS in the marine environment include runoff from urban areas and wastewater treatment plant discharge.



Figure 7.13 Burrunan dolphins are exclusively found in Victoria. With fewer than 200 individuals in the wild, they were classified as critically endangered in 2021.

bioaccumulate when the concentration of a substance increases inside a living organism, as intake exceeds excretion

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Matter constantly moves between spheres in cycles. The energy driving the movement of matter comes from the Sun and from Earth's core. It is this flow of energy and the cycling of matter that produces the chemical and physical changes in Earth's materials that we will discuss in Section 7.2. Earth gains energy from radiation from the Sun (mostly infrared, visible and ultraviolet wavelengths) and radiates heat energy back into space. Similarly, Earth gains a tiny amount of mass via comets and meteorites, and loses mass through gases escaping into space.

Quick check 7.5

1. Earth can be described as a closed system, meaning that its total mass does not change. **Decide** whether this statement is true or false.
2. **List** one way that Earth can gain and lose mass, and one way it can gain and lose energy.
3. **Describe** an example of a transfer of matter from the biosphere to the atmosphere.
4. **Describe** the sphere interactions happening in Figure 7.14.



Figure 7.14 There are many sphere interactions occurring at Mackenzie Falls, near Halls Gap in Victoria.

Making thinking visible 7.1

Parts, people, interactions: Earth's interacting spheres

Earth is a system because it is composed of interconnected components that interact with each other to form a complex and dynamic whole.

- What are the parts of the system?
- How do people interact with the parts of the system?
- How does a change in one element of the system affect the other parts of the system?

The *Parts, people, interactions* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

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Practical 7.1

Demonstrating the interaction between chemical spheres

Aim

To demonstrate the interaction between two chemical spheres

Materials

- celery stalks with leafy tops
- food colouring
- 250 mL measuring cylinder
- paring knife
- cutting board

Method

1. Copy the results table below into your science book.
2. Using the measuring cylinder, measure 25 mL of water and then add several drops of food colouring.
3. Use the paring knife and cutting board, cut along the base of the celery stalk to expose a fresh section.
4. Place the stalk into the measuring cylinder, with the cut end in the liquid.
5. Leave it in bright sunlight.
6. Every 5 minutes for 30 minutes, record the height the water has travelled up the celery stalk.

Results

Copy and complete the following table.

Table showing height of water travelling up a celery stalk over time

Time (minutes)	Height of water (nearest cm)
5	
10	
15	
20	
25	
30	

Discussion: Analysis

1. Explain what happened to the height of the water over the duration of the experiment.
2. Identify the sphere interactions that were demonstrated during this experiment.
3. Plants also interact with the atmosphere. Using your knowledge of the needs of living things, explain how plants do this.

Discussion: Evaluation

1. Identify a limitation in the experimental method that could be improved upon repeat testing.

Conclusion

1. Make a claim about the interactions between chemical spheres based on your observations in this experiment.
2. Support your claim by referring to your experimental data and include potential sources of error.
3. Explain how your data supports your claim.

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Natural events affecting spheres

Natural events such as earthquakes, volcanoes and cyclones influence the interactions between the spheres. Table 7.2 summarises how natural events cause sphere interactions.

Effect on	Natural event		
	Earthquake	Volcano	Cyclone
Geosphere (specifically, the lithosphere)	• Fault lines move apart or together • Land rises or subducts (sinks) • Landslides • Mudslides 	• Volcanic lava can create islands • Eruptions can destroy mountains and islands 	• Intense rainfall causes erosion of the land 
Biosphere	• Destroys ecosystems 	• Lava burns plants and animals • New islands become new habitats 	• Uproots trees and plants, destroying ecosystems 
Atmosphere	• Toxic gases are emitted from the ground 	• Large ash clouds release many gases, including greenhouse gases and toxic gases 	• High wind speeds 
Hydrosphere	• Tsunamis • Changes the course of rivers • Destroys dams 	• Toxic gases dissolve in water and fall as acid rain 	• Produces heavy rain, causing floods • Storm surges 

Table 7.2 How natural events influence the interaction between spheres

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Section 7.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 7.1 questions

Remembering

1. **Identify** the sphere that each of the following belongs to.
   a) Iceberg
   b) Pebble
   c) Wombat
   d) Air
2. **Recall** the layer of the atmosphere where jet streams are found.
3. **Recall** the most abundant gas in Earth's atmosphere.
4. **Recall** the two sources of energy that drive the movement of matter on Earth.

Understanding

5. **Explain** the effect of earthquakes on the lithosphere.
6. **Describe** why Earth's spheres can be described as overlapping.

Applying

7. **Identify** the spheres present in Figure 7.15.
8. **Identify** the sphere interactions taking place in Figure 7.16.



Figure 7.15 An alpine ecosystem



Figure 7.16 A freshwater lake ecosystem

Analysing

9. **Classify** the components of a healthy river (river water, algae and other organisms; dissolved nitrogen, oxygen and carbon dioxide; and minerals and rock fragments) into the chemical spheres to which they belong.
10. **Discuss** how a chosen natural disaster affects the chemical spheres. Try to include all spheres in your answer.

Evaluating

11. **Discuss** how the biosphere interacts with all other spheres.
12. **Discuss** how the atmosphere protects life on Earth.

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7.2 Nutrient cycles

Learning goals

At the end of this section, I will be able to:

1. Recall the seven processes of the carbon cycle.
2. Identify the impact of combustion reactions as a result of human activity on the carbon cycle.
3. Describe the role of cultural burning practices in facilitating energy and nutrient transfers.

sustainable ecosystem a biological environment that can support itself without outside assistance

The cycling and recycling of nutrients such as carbon, nitrogen and water in the spheres is important for sustaining life and ecosystems. A **sustainable ecosystem** is a biological environment that can support itself without outside assistance.

The carbon cycle



WORKSHEET Understanding the carbon cycle



VIDEO The carbon cycle

The carbon cycle describes the movement of carbon through all four spheres. Organisms require carbon as a key component of organic molecules such as carbohydrates, lipids, proteins and DNA that make up living organisms. Carbon is essential for the formation of the backbone of these molecules, and it is involved in energy transfer and storage within cells.

The carbon cycle occurs in many stages, but it is important to note that carbon can stay at one stage for thousands of years before moving on to the next stage.

Table 7.3 summarises the forms of carbon in each of the spheres.

Sphere	Carbon content
Atmosphere	Carbon dioxide (CO_2) and methane (CH_4)
Biosphere	Carbohydrates (such as glucose ($C_6H_{12}O_6$)), fats, proteins, vitamins and DNA of all living things
Hydrosphere	CO_2 dissolved in rivers, lakes and the ocean, forming carbonic acid (H_2CO_3)
Geosphere (lithosphere)	Decomposed organic matter in soils Fossil fuels (coal, oil and gas) Limestone (calcium carbonate ($CaCO_3$))

Table 7.3 A summary of the carbon content in each sphere

The carbon cycle can be summarised in seven processes (see Figure 7.17), which either increase or decrease carbon dioxide in the atmosphere:

1. photosynthesis
2. transfer of carbon through the food chain
3. respiration
4. excretion, egestion, death and decomposition
5. formation of fossil fuels
6. combustion
7. formation of limestone.



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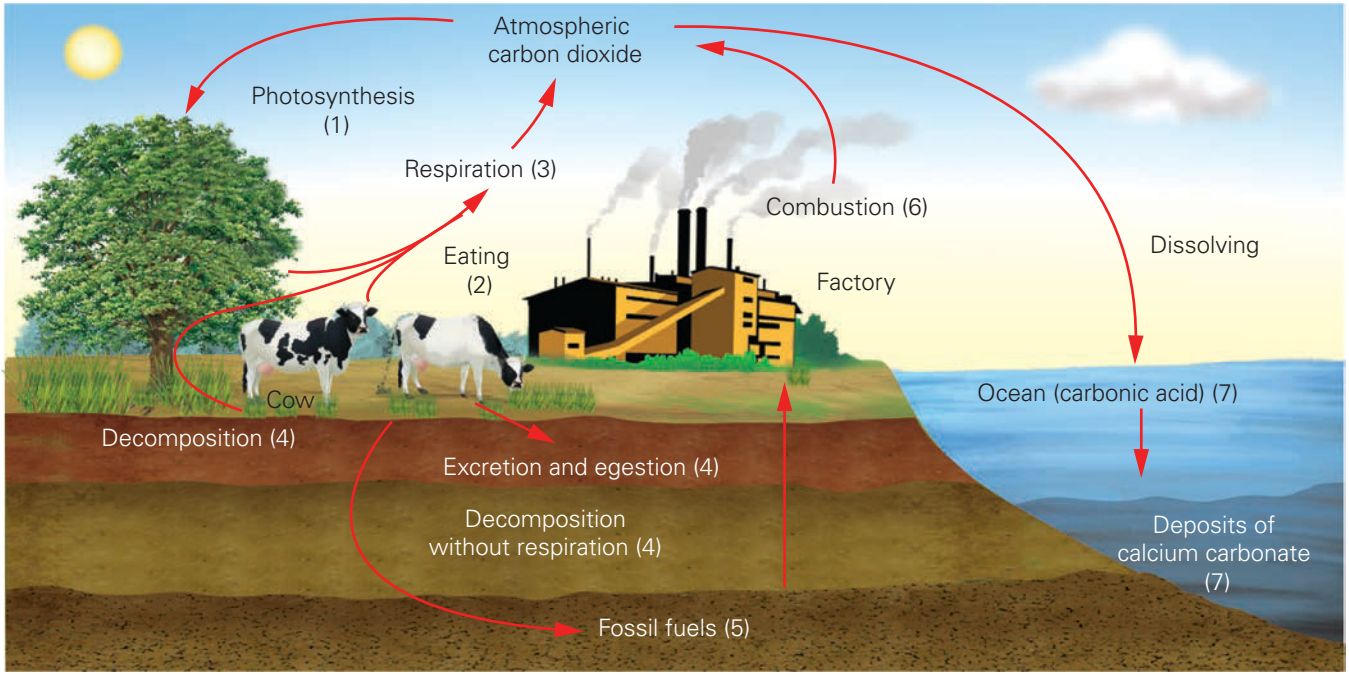


Figure 7.17 The main stages and processes in the carbon cycle

1. Photosynthesis

Carbon dioxide in Earth's atmosphere is absorbed by plants during photosynthesis. The carbon dioxide reacts with water taken in from the soil to make glucose, a carbon-containing compound.

The following equations summarise the process of photosynthesis for plants.

$$\text{carbon dioxide} + \text{water} \longrightarrow \text{glucose} + \text{oxygen}$$

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

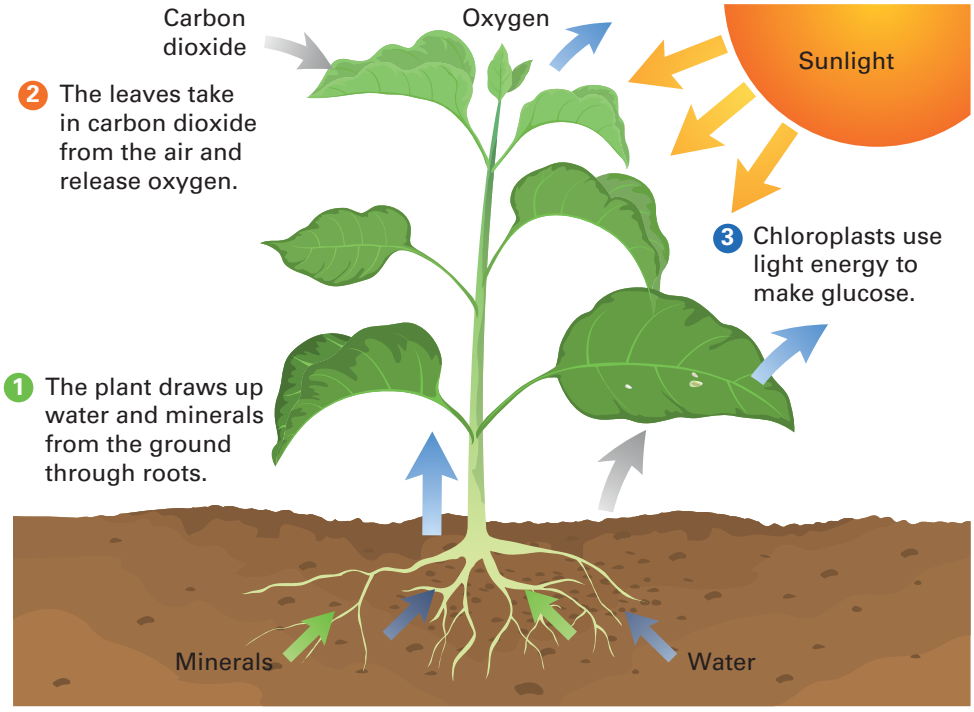


Figure 7.18 Plants remove carbon dioxide from the atmosphere during photosynthesis.

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Quick check 7.6

1. **Define** a sustainable ecosystem.
2. **Explain** why the cycling of carbon is important.
3. **State** the name of the form carbon takes in the hydrosphere.
4. **State** what form carbon dioxide is converted into during photosynthesis.

2. Transfer of carbon through the food chain

Animals obtain their carbon by eating plants and other animals. When animals and plants are eaten, their carbon content is transferred through the food chain.



Figure 7.19 The carbon content of the toad is being transferred to the kookaburra.

3. Respiration

Inside the cells of both plants and animals, oxygen is used to break down glucose in a process known as cellular respiration. Energy in the form of adenosine triphosphate (ATP) is released, and the waste products are water and carbon dioxide. The carbon dioxide is released back into the bloodstream, and as the organism breathes out, this is added to the atmosphere.

The following equation summarises respiration.

$$\text{glucose} + \text{oxygen} \xrightarrow{\text{ATP (energy released)}} \text{carbon dioxide} + \text{water}$$

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{ATP (energy released)}} 6CO_2 + 6H_2O$$



Figure 7.20 A horse exhales heavily after exertion, releasing the carbon dioxide that was produced as a waste product of respiration.

4. Excretion, egestion, death and decomposition

Some of the carbon content of animals and plants enters the soil as waste such as urine (excretion) and faeces (egestion).

Dead animals and plants (organic matter) also contribute to the carbon content of the soil. Waste material and dead organic matter is broken down by **decomposers**, which respire, releasing carbon dioxide back into the atmosphere.

decomposers living organisms, such as bacteria and fungi, that break down dead organic matter



Figure 7.21 Egestion of faeces, such as these cube-shaped wombat faeces, increases the carbon content of the soil.

Try this 7.1

Modelling decomposition

Search online for an Interactive Model of Leaf Decomposition. This will allow you to compare how different mathematical models, climates, litter types and ecosystems affect decomposition rate.

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Quick check 7.7

1. **State** how animals obtain carbon in the carbon cycle.
2. **Name** the two waste products produced in the breakdown of glucose during cellular respiration.
3. **State** one way animals can increase the carbon content of soil.

5. Formation of fossil fuels

Fossil fuels such as coal, oil and gas are composed of the carbon from plants and animals that died millions of years ago. Carbon is stored as fossil fuels for millions of years before re-entering the carbon cycle.



Figure 7.22 Coal is a fossil fuel formed from the carbon content of dead plants that have been buried and compressed for millions of years. Sometimes, fossilised plants can be found in coal.

6. Combustion

Combustion reactions that involve the burning of fuels (such as the bushfire shown in Figure 7.23) have a significant impact on the carbon cycle because they release carbon dioxide into the atmosphere, contributing to the increase in atmospheric carbon dioxide concentrations.

Often, the fuels being burned are fossil fuels such as coal, oil and natural gas. The following equation shows the combustion of octane, a component of oil.

$$\text{octane} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water}$$

$$2C_8H_{18} + 25O_2 \longrightarrow 16CO_2 + 18H_2O$$

The release of carbon dioxide from combustion reactions disrupts the natural balance of the carbon cycle. Normally, carbon moves between the atmosphere, ocean and land through processes such as photosynthesis, respiration and decomposition. However, burning fossil fuels releases carbon that has been stored underground for millions of years, disrupting the natural flow of carbon, and leading to an excess of carbon in the atmosphere.



Figure 7.23 Bushfires release carbon dioxide into the atmosphere.

Fire knowledge and cultural burning practices

Fire has been used as a vital land management tool by Aboriginal and Torres Strait Islander Peoples for tens of thousands of years. Cultural burning is a deeply embedded practice of caring for Country, ensuring the health of landscapes, ecosystems and communities.

Through careful and controlled use of fire, a mosaic of vegetation is maintained, supporting biodiversity and strengthening ecosystems. These fires are deliberately timed and placed, guided by a deep knowledge of Country, seasonal changes and ecological relationships.

Cultural burning enhances soil health, cycling nutrients back into the land and supporting the growth of plants that sustain animals and people. It also helps manage invasive species and reduce the intensity of destructive wildfires. In some cases, burning has been used as a hunting strategy, guiding animals towards particular areas.

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Explore! 7.2

Traditional fire management

New research has found that the cultural burning practices of Aboriginal Peoples can help protect koalas. The research was conducted over two years in collaboration with the Quandamooka people on North Stradbroke Island in Queensland.



Figure 7.24 A koala rescued from a bushfire

The study found that cultural burns are cooler, lower and slower than 'hot fires'. The study also found that cultural burns can protect koalas by encouraging regeneration of native plants and controlling species such as banksias and wattle, reducing the risk of fire reaching the koalas' canopy. The researchers used drones fitted with thermal cameras and hormone metabolite analysis to monitor koala stress during the cultural burns. The study found no negative impacts on koala population densities or their stress levels.

In small groups, investigate how Aboriginal and Torres Strait Islander Peoples' fire management practices are informing and being adopted in contemporary fire management, including in Victoria. You may want to consider how controlled burning can stimulate the growth of fire-tolerant trees and plants that can store carbon in their biomass and in the soil, or how it reduces the fuel load of an ecosystem.

7. Formation of limestone

Carbon dioxide gas in the atmosphere can dissolve in the oceans, forming carbonic acid. Carbon dioxide also provides the carbon that combines with calcium ion mineral deposits to make calcium carbonate ($CaCO_3$), which is the major component of shells. Shells from dead animals sink to the bottom of the ocean. Over millions of years, these shells are compacted and form limestone.

Limestone is a sedimentary rock and an important building material in the construction industry. The carbon stored in limestone can remain there for millions of years, but under certain conditions, such as weathering and erosion, carbon dioxide can be released from limestone back into the atmosphere. For example, when limestone is exposed to acidic water or soil, it can react with the acid to release carbon dioxide.



Figure 7.25 Fossils of an extinct group of calcareous (containing calcium carbonate) sponges in limestone

Table 7.4 summarises the gains and losses of atmospheric carbon in the carbon cycle.

Atmospheric carbon gains	Atmospheric carbon losses
Respiration	Photosynthesis
Combustion	Formation of fossil fuels
Excretion, death and decomposition	Dissolving in the oceans and forming limestone

Table 7.4 A summary of the gains and losses of atmospheric carbon within the carbon cycle

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Practical 7.2

The oceans and carbon dioxide

Be careful

Wear appropriate personal protective equipment.
Wear safety glasses.
Use the correct method for blowing into the test tube.

Aim
To determine what happens when carbon dioxide dissolves in water

Materials
- bottle of universal indicator and pH scale
- water
- test tube
- test-tube rack
- drinking straw

Method
1. Copy the results table below into your science book.
2. Fill the test tube with water to a depth of about 5 cm.
3. Add 3 drops of universal indicator and note the colour and pH in the results table.
4. Place the straw into the test tube and blow gently into it for 10 seconds. Be careful to only blow into the straw; you might want to practise first.
5. Note the colour and pH of the solution after you have blown into it.

Results
Copy and complete the following table.

Table showing the pH of water before and after adding carbon dioxide

	Colour	pH
Before blowing		
After blowing		

Discussion: Analysis
1. Identify what is indicated by the colour and pH of the water before blowing.
2. Identify what is indicated by the colour and pH of the water after blowing.
3. Give the name and formula of the solution formed after blowing.
4. Which stage of the carbon cycle does this experiment represent? Justify your choice.
5. Discuss what happens to carbon dioxide in water after it has dissolved.
6. Determine the ability of carbon dioxide to dissolve in water, based on this experiment.
7. Discuss the global issues behind carbon dioxide dissolving in water.

Discussion: Evaluation
1. Is this experiment an appropriate model for showing how carbon dioxide dissolves in oceans? Discuss the limitations of the methodology.

Conclusion
1. Make a claim about the ability of carbon dioxide to dissolve in water based on this experiment.
2. Support your statement by using the data you gathered, and include potential sources of error.
3. Explain how the data supports your claim.

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Practical 7.3

Limestone and carbon dioxide

Be careful
Wear appropriate personal protective equipment.
Wear safety glasses.

VIDEO Practical 7.3 Limestone and carbon dioxide

Aim
To determine whether limestone is a store of carbon dioxide

Materials
- calcium carbonate chips (approximately 0.5 to 1 cm pieces)
- hydrochloric acid (1 mol L^{-1})
- limewater
- 10 mL measuring cylinders × 2
- test tubes × 2
- test-tube rack
- delivery tube

Method
1. Using a 10 mL measuring cylinder, measure 5 mL of hydrochloric acid and pour it into one of the test tubes.
2. Using another 10 mL measuring cylinder, measure 5 mL of limewater and pour it into the other test tube.
3. Add three calcium carbonate chips to the hydrochloric acid, then quickly attach the bung of the delivery tube to this test tube, with the other end in the limewater solution.
4. Observe what happens to the limewater.

Results
Record your observations from the experiment in your science book.

Discussion: Analysis
1. Describe what happened to the limewater solution.
2. In this reaction, calcium carbonate was reacted with hydrochloric acid. Three products were formed. Two of those products were calcium chloride and water. Write a word equation for the reaction that includes the third product.

Discussion: Evaluation
1. Identify which part of the carbon cycle is modelled in this experiment.
2. Is it an appropriate model? Discuss the limitations of the methodology.

Conclusion
1. Make a claim about whether limestone is a store of carbon.
2. Support your statement by referring to your experimental observations and include potential sources of error.
3. Explain how your observations support your claim.

Quick check 7.8

1. **Name** one example of a fossil fuel.
2. **Name** the process in which fossil fuels are burned, releasing carbon dioxide back into the atmosphere.
3. **State** the scientific name and chemical formula for limestone.

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What else is cycled on Earth?

In previous years, you would have studied both the water and rock cycle, which explain how water molecules and rock particles are cycled through various states over time. Other minerals such as nitrogen, phosphorus and sulfur, and gases such as oxygen, have their own cycles through which they flow on Earth.

The nitrogen cycle

VIDEO
The nitrogen cycle

Nitrogen is critical for all living things as it is an important component of nucleic acids and amino acids, the building blocks of proteins. It is the fourth most abundant element in living things after oxygen, carbon and hydrogen. Our atmosphere is composed of around 78% nitrogen gas (N_2), and it can be found as nitrates (NO_3^-) in the lithosphere, formed from the decomposition of organic matter and nitrification by bacteria in the soil. The nitrogen cycle is divided into six stages:

1. nitrogen fixation
2. transfer through the food chain
3. ammonification
4. nitrification
5. uptake by plants
6. denitrification.

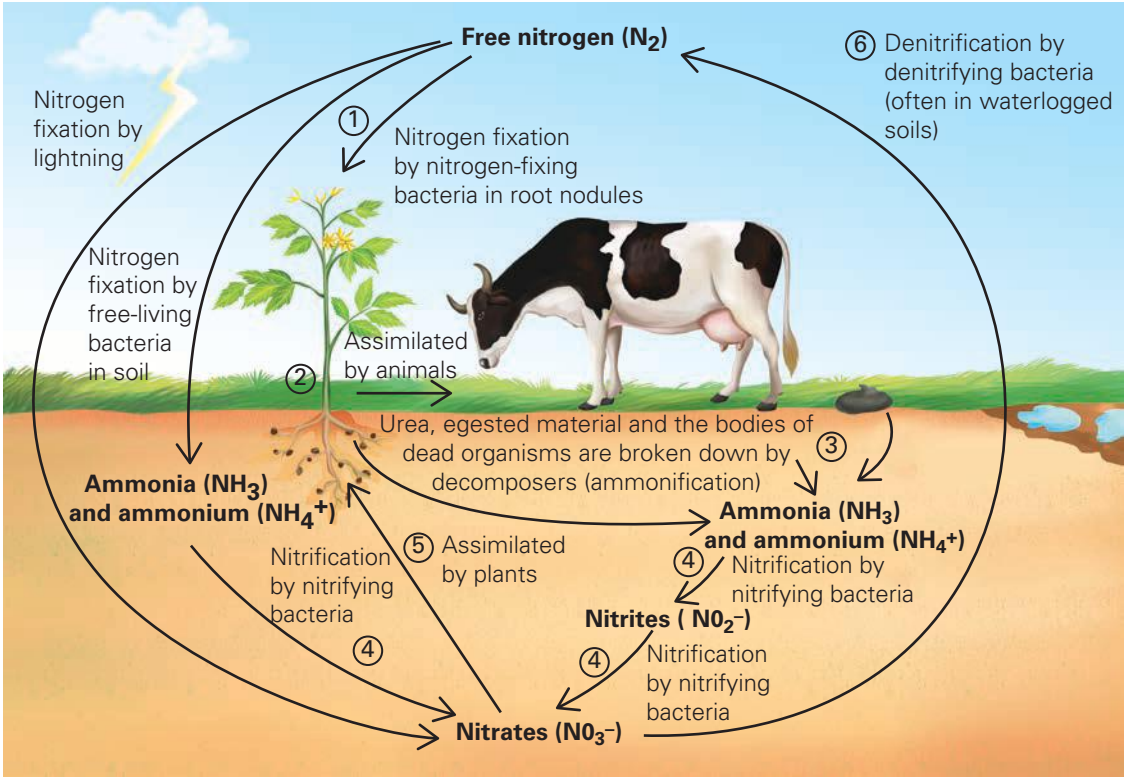


Figure 7.26 The nitrogen cycle on land has six main stages.

Explore! 7.3

The nitrogen cycle

Research the nitrogen cycle, and construct a table briefly outlining what happens during each of the six stages of the cycle.

Consider where each process occurs and whether it contributes to an overall gain or loss in soil nitrates.

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The water cycle

The water cycle is responsible for the recycling of water around the chemical spheres (see Figure 7.27). Precipitation falls from clouds in the atmosphere. This water either joins the oceans or rivers in the hydrosphere or reaches the soil in the lithosphere. Plants take in water from the soil and then lose this water through transpiration. Thermal energy from the Sun returns water to the atmosphere as water vapour through the process of evaporation.

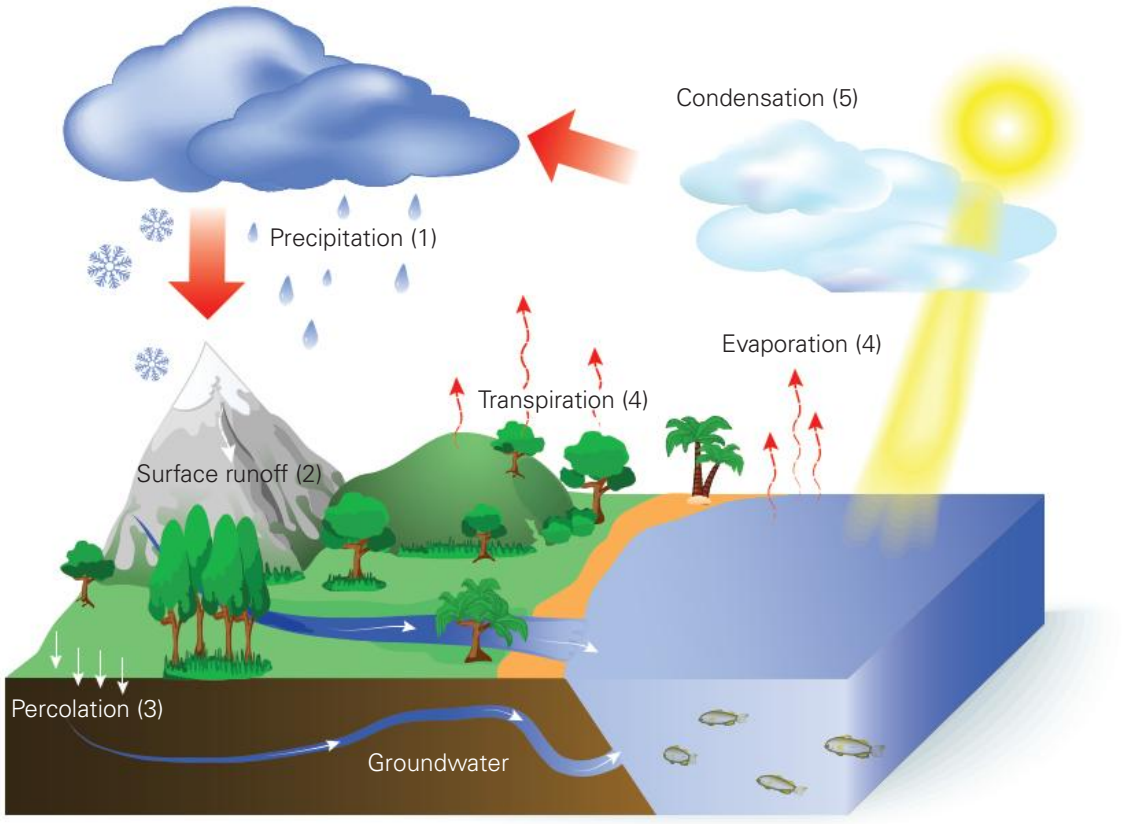


Figure 7.27 The main stages in the water cycle

Go online to access the interactive section review and more!

Section 7.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 7.2 questions

Remembering

1. **Identify** the cycle (carbon, nitrogen or water) that includes the following processes.
   a) Denitrification
   b) Respiration
   c) Decomposition
   d) Transpiration
   e) Combustion
2. **State** the name and formula of a compound in which carbon is found in the atmosphere.
3. **Recall** why plants and animals require carbon.

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Understanding

4. **Select**, from the below choices, the best definition for a sustainable ecosystem and **justify** your choice.
   a) An environment that requires intervention to continue
   b) A biological environment that is self-sustaining
   c) A system that consists of both biotic (living) and abiotic (non-living) factors
5. **Summarise** the role of decomposers in the carbon cycle.

Applying

6. **Annotate** a worded chemical equation to show why respiration is part of the carbon cycle.
7. **Explain** why the water cycle involves all four chemical spheres.
8. **Explain** where the carbon in coal, oil and gas originated.

Analysing

9. **Infer** what would happen to the carbon cycle if all human activities that emit carbon were suddenly stopped.
10. **Categorise** the following as either atmospheric carbon *gains* or atmospheric carbon *losses*.
    a) Formation of fossil fuels
    b) Respiration
    c) Excretion
    d) Photosynthesis
    e) The formation of limestone
    f) Combustion

Evaluating

11. Hamish suggests that deforestation is affecting the carbon cycle in a negative way; however, his classmate Bodhi disagrees, saying the death of trees is a natural part of the cycle. State who you think is correct. **Justify** your answer.
12. **Discuss** how cultural burning practices stimulate plant growth and facilitate the transfer of energy through a food chain.



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7.3 The greenhouse effect

WORKSHEET
The enhanced greenhouse effect

Learning goals

At the end of this section, I will be able to:

1. Recall four different greenhouse gases.
2. Compare the natural greenhouse effect and the enhanced greenhouse effect.
3. Describe how Aboriginal and Torres Strait Islander Peoples are reducing Australia's greenhouse gas emissions through the reinstatement of traditional fire management regimes.
4. Identify how carbon dioxide is captured and stored naturally or through the use of technologies.

The natural greenhouse effect

greenhouse gas
a gas that contributes to the greenhouse effect

Earth naturally retains heat through a process similar to a human-made greenhouse (see Figure 7.28), but on a much larger scale. Most of the Sun's radiation enters Earth's atmosphere and warms the ground and oceans. Some of the radiation is reflected back into space by ice, clouds and water. However, the ground and oceans continue to emit radiant energy back towards the atmosphere in the form of infrared radiation. This infrared radiation is absorbed and reflected back towards Earth's surface by a layer of gases known as **greenhouse gases**. Water vapour (H_2O) is the most abundant greenhouse gas, making up 95% of the total. Methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) are three of the other most common greenhouse gases.

Did you know? 7.2

How greenhouses work

Greenhouses can be used to cultivate temperature-sensitive or out-of-season plants in colder climates. Greenhouses provide a protective shield against harsh weather conditions, and act to concentrate the heat from the Sun to meet the needs of specific plants. They are typically constructed from glass or plastic, which allows the solar radiation to pass through the walls and roof and heat the ground and air inside. The heated ground emits infrared radiation, which is reflected back into the greenhouse by the glass or plastic. The hot air rises, but cannot escape the greenhouse, increasing the temperature inside and promoting plant growth.

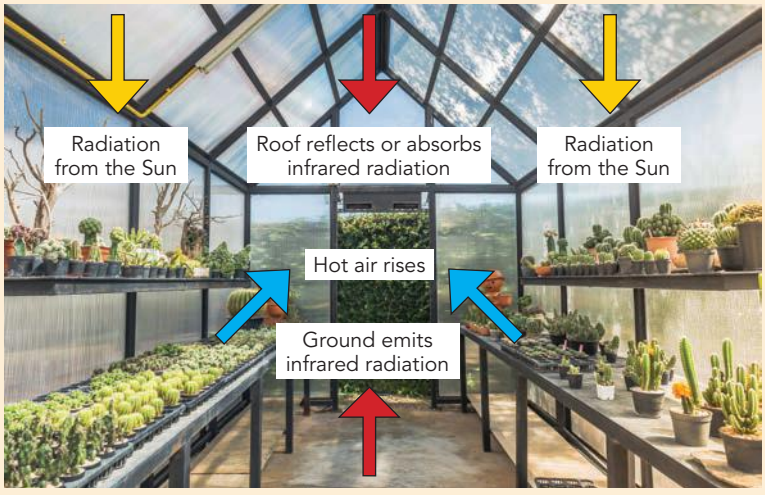


Figure 7.28 Greenhouses protect plants from cold and adverse weather conditions by keeping in thermal energy.

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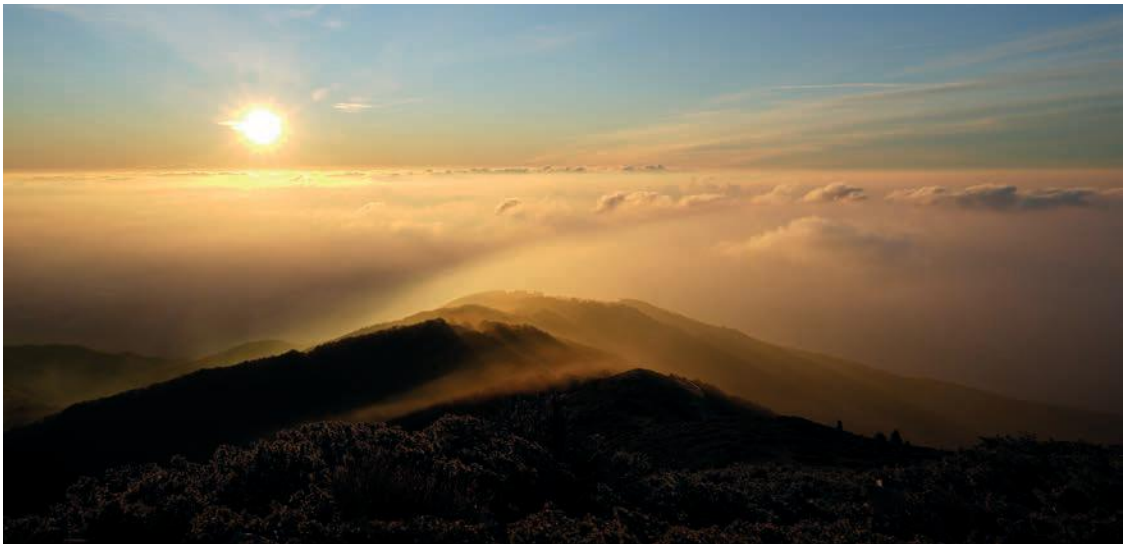


Figure 7.29 The Sun emits radiation, which passes through the atmosphere.

Table 7.5 compares the effectiveness in retaining heat of the three most common greenhouse gases after water vapour. Methane is more effective than carbon dioxide at trapping heat because it has a higher global warming potential, meaning it can absorb more heat per unit of mass than CO_2. However, CO_2 is much more abundant in the atmosphere and has a longer lifespan, so overall it has a greater impact on global climate.

Feature	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)
Proportion of greenhouse gas once water vapour is excluded (%)	84	9	5
Persistence in the atmosphere	100 years	10 years	100 years
Effectiveness at trapping heat compared to carbon dioxide		30 times more effective	300 times more effective

Table 7.5 A summary of the three most common greenhouse gases, excluding water vapour

The process by which the Sun's solar energy is trapped in Earth's atmosphere is known as the **greenhouse effect**. The Sun's radiation, primarily in the visible light wavelength, can directly pass through the atmosphere because it is short wave. However, long-wave radiation emitted from the ground and oceans in the form of infrared radiation is absorbed by greenhouse gases, keeping Earth warm. Without this conversion of solar radiation to infrared radiation, Earth would lose its thermal energy back into space, making the planet less habitable. The greenhouse effect maintains a consistent average temperature that is crucial for the survival of organisms on Earth. Earth's average temperature is 14°C. Without the natural greenhouse effect, this temperature would decrease to −18°C.

greenhouse effect the trapping of the Sun's warmth by a layer of gases in the lower atmosphere

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Greenhouse gases can absorb a certain amount of infrared radiation; the rest is radiated back into space. The more greenhouse gases there are in the atmosphere, the more infrared radiation is trapped and reflected back to Earth, and the hotter Earth becomes.

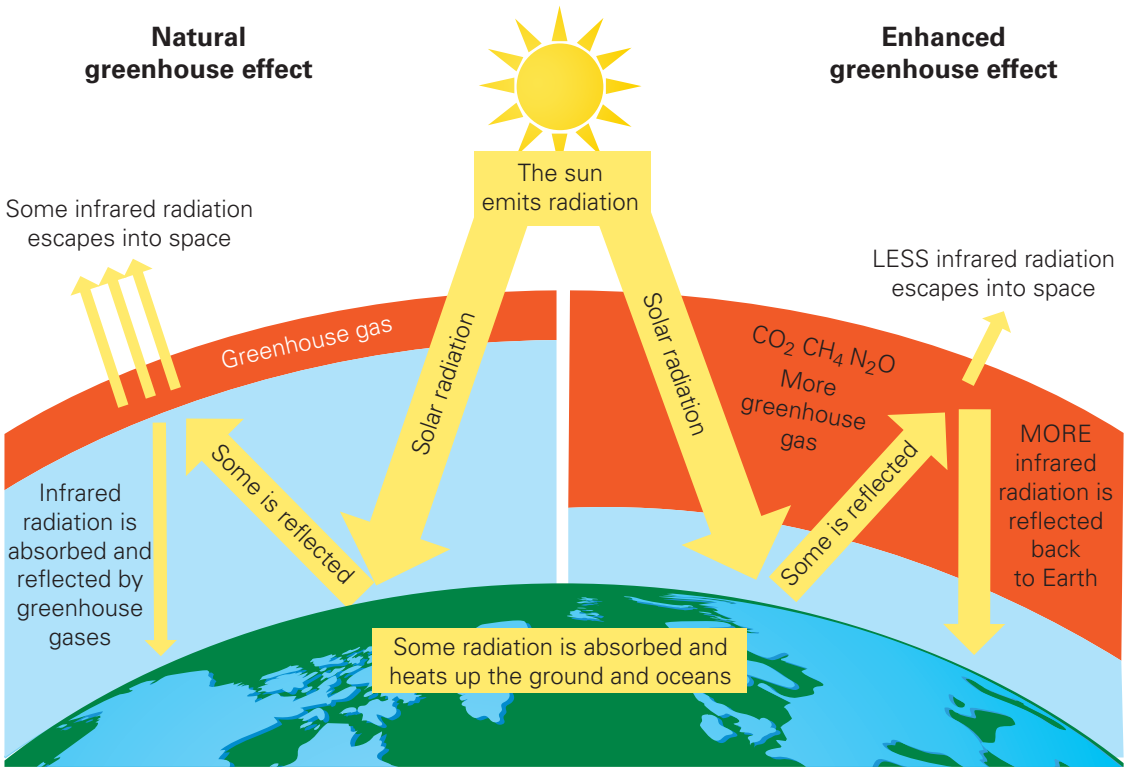


Figure 7.30 A summary of the natural (left) and enhanced (right) greenhouse effects

Quick check 7.9

1. **State** the name and formula of one common greenhouse gas.
2. Most of the radiation emitted from the Sun heats the ground and the oceans. **Explain** what happens to the rest of this radiation.
3. **Name** a source of short-wave radiation.
4. **Name** the radiation that is absorbed by greenhouse gases in the atmosphere.

Table 7.6 summarises the features of solar and infrared radiation.

Feature	Solar radiation	Infrared radiation
Source	Sun	Sun, ground and oceans
Wavelength	Short	Long
Trapped or not	Not trapped by atmosphere	Trapped by greenhouse gases in atmosphere

Table 7.6 Features of solar and infrared radiation

enhanced greenhouse effect the intensifying of the natural greenhouse effect due to human activity

global warming the long-term rise in the average temperature on Earth, primarily caused by the increase of greenhouse gases in the atmosphere

The enhanced greenhouse effect

The **enhanced greenhouse effect** (right-hand side of Figure 7.30) is a phenomenon in which human activities, such as burning fossil fuels and deforestation, release large amounts of greenhouse gases, such as carbon dioxide, into the atmosphere. These gases trap more heat from the Sun, which increases the temperature of Earth's atmosphere and surface, leading to **global warming**.

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Causes

The major cause of the enhanced greenhouse effect is increased concentrations of greenhouse gases (carbon dioxide, methane, nitrous oxide and water vapour) in the atmosphere. Table 7.7 summarises how humans have contributed to the increased levels of these greenhouse gases.

Greenhouse gas	How humans have increased its concentration in the atmosphere	
Carbon dioxide	Burning fossil fuels such as coal, oil and gas. Currently, 46% of Australia's electricity is produced by burning coal.	
Methane	Farming cattle (which produce methane when they digest grass) and growing rice in paddies. Increased temperatures lead to the melting of permafrost. Permafrost is frozen soil that contains trapped methane produced from the decomposition of plants and animals.	
Nitrous oxide	Using fertilisers that increase the amount of nitrogen in the nitrogen cycle, which increases the production of nitrous oxide.	
Water vapour	Although water vapour is naturally the most abundant greenhouse gas, as the concentrations of carbon dioxide, methane and nitrous oxide increase due to human activity, more heat is trapped, which contributes to increasing water vapour concentrations (increased humidity). This has a positive feedback effect on increasing temperatures, enhancing the greenhouse effect.	

Table 7.7 How humans have increased the concentration of greenhouse gases in the atmosphere

Explore! 7.4

Global Greenhouse Gas Monitoring Infrastructure

In 2023, the United Nations announced that it had created a new Global Greenhouse Gas Monitoring Infrastructure. The infrastructure will integrate space and Earth surface-based observation systems, and aims to provide real-time tracking of greenhouse gases to help inform policy choices. The platform will address uncertainties about the emission of greenhouse gases and provide faster and more accurate data on the state of the planet's atmosphere. What are the advantages to this new infrastructure?

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Did you know? 7.3

The carbon impact of emails

A book published in 2010 popularised the idea that reducing the number of emails sent could have a significant impact on greenhouse gas emissions. The book stated that an average person's yearly email use generates 3–40 kg of carbon dioxide and other greenhouse gases, which is comparable to driving 16–206 km.

While deleting 1000 emails would save about 5 grams (g) of CO_2, manually deleting them on a laptop for 30 minutes emits 28 g of CO_2. This means that manually deleting emails can have a greater carbon impact than just storing them, because deleting them consumes more energy from using the computer.

In reality, the carbon footprint of sending emails is difficult to quantify and the numbers constantly change due to improving data transmission and storage efficiency. The carbon values for emails seem small, and reducing the number of emails sent or deleting them may not significantly reduce energy consumption as digital data storage and transmission systems operate continuously (see Figure 7.31). Instead, reducing the carbon footprint of email use can be achieved by using electronic devices that consume less electricity and retaining them for as long as possible.



Figure 7.31 Digital data storage and transmission centres, like this Google-owned one in Iowa, United States, operate continuously. They use a constant amount of energy, regardless of whether an email is sent or not.

Quick check 7.10

1. **State** one way humans have increased the concentration of carbon dioxide in the atmosphere.
2. **State** one way humans have increased the concentration of nitrous oxides in the atmosphere.
3. **State** one outcome that the enhanced greenhouse effect is leading to.

Investigation 7.1

Comparing the natural and enhanced greenhouse effects

Aim

To compare the impacts of the natural and enhanced greenhouse effects

Hypothesis

Read the experimental method and then construct an appropriate hypothesis regarding the contents of the beakers and the expected temperature change, using the 'If ... then ...' framework.

Be careful

Take care when handling the lamp because it can become hot with prolonged use. Wear heat-resistant gloves.

continued ...

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Materials

- baking soda
- vinegar
- 2 L plastic bottles × 2
- 100 mL measuring cylinder
- funnel
- rubber stoppers × 2
- weighing boat
- electronic balance
- marker pen
- stirring rod
- stopwatch
- thermometers × 2
- high-intensity lamp
- heat-resistant gloves



VIDEO Investigation 7.1 Comparing the natural and enhanced greenhouse effects

Method

Part 1: Prepare the results table

1. Read the rest of the steps in the method and make a prediction about what will happen.
2. Create an appropriate results table for this experiment.

Part 2: Collect the data

1. With the marker pen, label one of the 2 L bottles 'Control'.
2. With the marker pen, label the second bottle 'CO_2'.
3. Using the 100 mL measuring cylinder, measure 65 mL of vinegar and pour it into the control bottle. Place the stopper in the top of the bottle.
4. Using the same 100 mL measuring cylinder, measure 65 mL of vinegar and pour it into the CO_2 beaker.
5. Using the balance, weigh 35 g of baking soda into the weighing boat and pour it into the CO_2 bottle using the funnel. If it gets stuck in the funnel, you can use a stirring rod to push it through.
6. Swirl the contents until the fizzing stops, then place the rubber stopper in the top of the bottle.
7. Place both bottles underneath the lamp.
8. Record the starting temperature of each 'atmosphere' before the lamp is turned on.
9. Turn on the lamp and start the stopwatch.
10. Measure the temperature in each bottle every 2 minutes for 8 minutes. Record the temperatures in your results table.
11. At 8 minutes, measure the temperature and then turn off the light.
12. Record the final temperature 2 minutes later.

Discussion: Analysis

1. Calculate the increase in temperature in each container by subtracting the initial temperature from your measurement after 8 minutes. State which container showed the greatest increase in temperature.

Discussion: Evaluation

1. Did the results of your experiment align with your knowledge of the enhanced greenhouse effect?
2. Is this experiment an appropriate model for the enhanced greenhouse effect? Discuss the limitations of the methodology.

Conclusion

1. Make a claim about the enhanced greenhouse effect based on this experiment.
2. Support your statement by using the data you gathered, and include potential sources of error.
3. Explain how the data supports your claim, and justify whether your hypothesis was supported or not supported.

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Practical 7.4

Does land or water warm faster?

Aim

To determine whether land or water heats up faster

Hypothesis

Construct an appropriate hypothesis for this experiment using the 'If … then …' framework.

Materials

- thermometers × 2
- plastic containers × 2 (same size and shape)
- sand
- water
- lamp

Method

1. Copy the results table below into your science book.
2. Pour sand into one container to a depth of 5 cm, and water into the other container to a depth of 5 cm. These containers will represent 'land' and 'water'.
3. Using a designated thermometer for each material, record the initial temperature and record it in the table at time = 0.
4. Place the two containers 10 cm either side of the lamp and switch it on.
5. Start the stopwatch and record the temperature of each container every 2 minutes for 10 minutes. Then turn off the lamp.
6. Record the temperature of each container every 2 minutes for a *further* 10 minutes.

Results

Copy and complete the following table.

Table showing the temperatures of each container over time, with heating and after heating

Time (minutes)	Temperature (°C)	
	Sand (land)	Water
0		
2		
4		
6		
8		
10 (turn off lamp)		
12		
14		
16		
18		
20		

Discussion: Analysis

1. Plot a line graph of the data, with time in minutes on the horizontal axis and temperature of the materials on the vertical axis. You will need one line for 'land' and one line for 'water'.
2. Which substance heated up faster?
3. Which substance retained heat better?

continued …

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Discussion: Evaluation

1. With reference to your experimental data, explain how your results support your understanding of the greenhouse effect.
2. Is this experiment an appropriate model for the greenhouse effect? Discuss the limitations of the methodology.

Conclusion

1. Make a claim about whether land or water heats up faster based on this experiment.
2. Support your statement by using the data you gathered, and include potential sources of error.
3. Explain how the data supports your claim, and justify whether your hypothesis was supported or not supported.

Explore! 7.5

Your carbon footprint

A carbon footprint is the volume of greenhouse gases (including carbon dioxide) emitted into the atmosphere as a result of the actions of a specific individual, event, organisation or product.

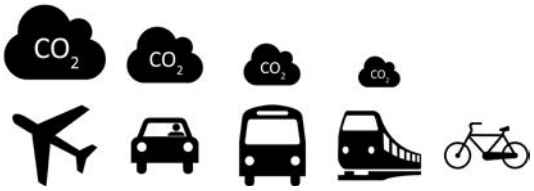


Figure 7.32 Some methods of transport have a bigger environmental impact than others.

- Search online for a reliable carbon footprint calculator. Suggested websites include the United States Environmental Protection Agency or the Global Footprint Network.
- Gather information on your daily habits such as transportation, energy usage, diet and waste management.
- Use the carbon footprint calculator to input your daily habits and activities. The calculator will provide you with an estimate of your carbon footprint in metric tonnes.
- Analyse your carbon footprint results and identify areas where you could reduce your carbon emissions. For example, you could consider walking or riding a bicycle instead of travelling to school in the car, reducing energy consumption at home, or reducing waste.

Try this 7.2

Reducing carbon footprints

Plan a social media campaign to encourage young people to reduce their carbon footprint.

- Consider the most appropriate social media platform for your audience, and the format of the campaign. For example, would a video/reel be more engaging than a post? Should the campaign be targeted from the perspective of an expert scientist or a well-known celebrity or influencer? Are you going to encourage young people to reduce their footprint in a certain area, such as transport or technology use at home?
- Ensure you access high-quality sources for your information and present it in a visually effective way. Draft a proposal for the campaign. This could include your slogan, hashtags, a mock-up of images and the scientific facts you will include.

The carbon cycle out of balance

Carbon dioxide emissions from human activity are the most significant contributor to the enhanced greenhouse effect. Since the Industrial Revolution in the 1800s, we have been burning large amounts of fossil fuels for energy. This means we have been moving stored carbon from the lithosphere into the atmosphere, directly affecting the balance of the carbon cycle.

As part of the carbon cycle, Earth has **carbon sources**, which are processes or areas that release carbon (such as the atmosphere), and **carbon sinks**, which are areas where carbon is stored (such as the oceans, forests or fossil fuels).

VIDEO
The greenhouse effect

carbon source
a process or an area that releases carbon

carbon sink
an area where carbon is stored (e.g. oceans, forests or fossil fuels)

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Burning fossils fuels and releasing their stored carbon is a problem because the carbon cycle does not have enough carbon sinks to remove the excess carbon from the atmosphere. Fossil fuels take millions of years to form, and Earth's carbon sinks cannot remove enough carbon dioxide to prevent it from building up in the atmosphere. The accumulation of carbon dioxide in the atmosphere is increasing Earth's greenhouse effect.

Bushfires and greenhouse gases

Bushfires are a significant contributor to greenhouse gas emissions, because the amount of fuel consumed in the blaze is directly proportional to the amount of carbon dioxide released into the atmosphere. Satellites such as NASA's Earth Observing System (EOS) carry equipment that detects thermal anomalies and fires, and the data collected allows scientists to track how the frequency and intensity of wildfires is changing over time. Other satellites detect atmospheric carbon dioxide concentration, and other greenhouse gases.

In Australia, the highly destructive and intensely hot fires tend to occur during the summer months when the accumulated fuel load is highest. As previously discussed, the cultural burns used by Aboriginal and Torres Strait Islander Peoples are traditionally undertaken during the cooler months. This produces less intense fires, as the night-time dew partially extinguishes the flames. The patchwork of carefully burnt areas provides natural fire breaks and reduces the fuel load, preventing the spread of future catastrophic wildfires. Frequent fires also result in plant regrowth (which sequesters [stores] carbon from the atmosphere), balancing the emissions from the fire itself.

Many state governments are now working with Traditional Owners to support the continuation of cultural fire practices that have been used to care for Country for tens of thousands of years. Aboriginal ranger groups and local land councils apply deep knowledge of landscapes, seasons and ecological relationships to fire management. Technology such as satellite vegetation and fire mapping can complement these practices, helping to monitor and document their effectiveness. Through the Emissions Reduction Fund, these efforts are being recognised for their role in reducing carbon emissions, strengthening cultural governance and self-determination in land management.

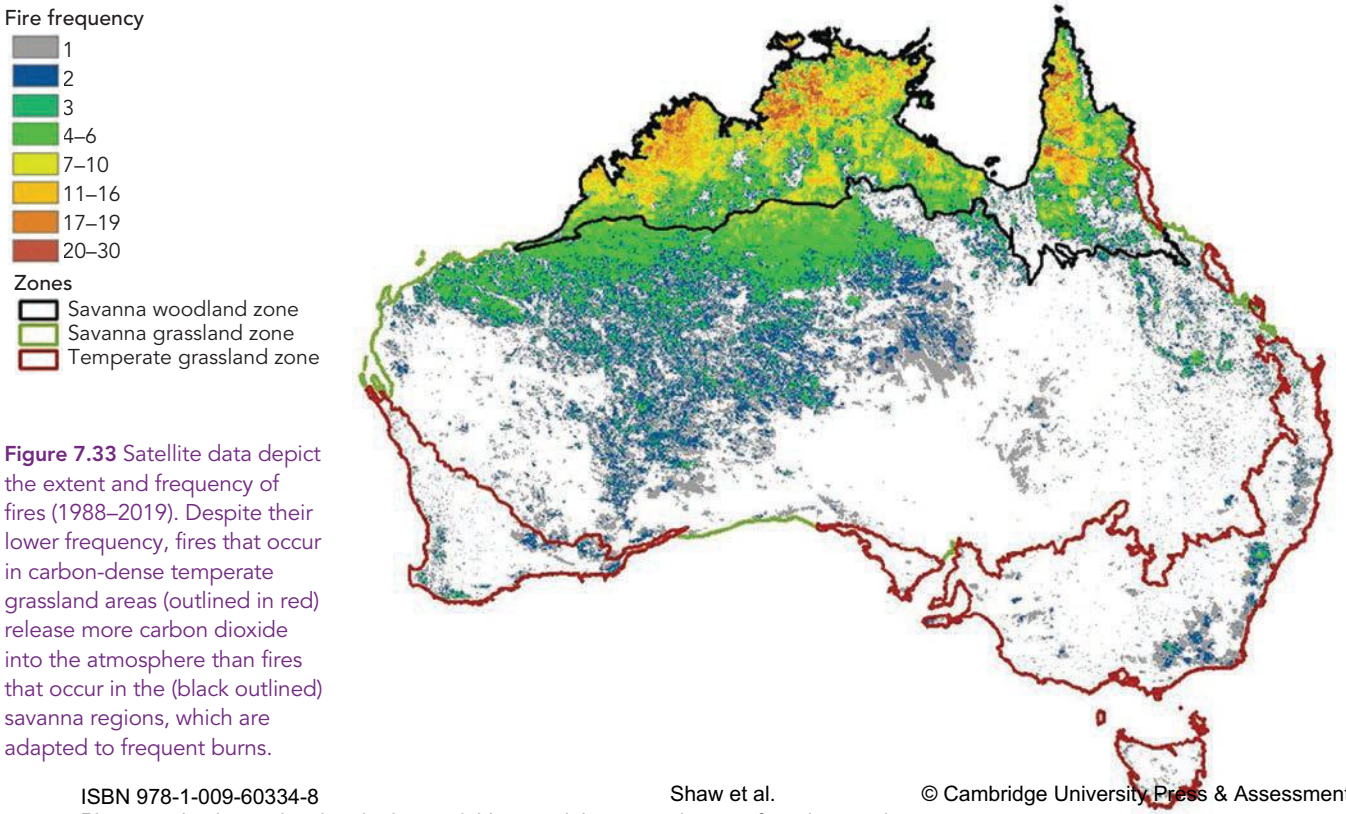


Figure 7.33 Satellite data depict the extent and frequency of fires (1988–2019). Despite their lower frequency, fires that occur in carbon-dense temperate grassland areas (outlined in red) release more carbon dioxide into the atmosphere than fires that occur in the (black outlined) savanna regions, which are adapted to frequent burns.

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Figure 7.34 Prescribed/cultural burns can help reduce the risk of catastrophic wildfires while also promoting forest growth and carbon sequestration.

Quick check 7.11

1. **Contrast** a carbon source and carbon sink, giving two examples of each.
2. **State** the primary greenhouse gas emitted during bushfires.
3. **Explain** how traditional Aboriginal fire management practices can reduce greenhouse gas emissions.

Carbon sequestration



Carbon sequestration refers to the process of capturing carbon dioxide from the atmosphere and storing it in long-term carbon sinks. This occurs naturally in forests and oceans, or can be accelerated through the use of technology.

carbon sequestration the process of storing carbon in a carbon sink

biomass the material produced by the growth of plants, animals and microorganisms

Capturing and storing carbon naturally

Forests are one of the most significant carbon sinks on Earth. As plants grow, carbon dioxide is absorbed from the atmosphere and used to build new plant cells (a form of **biomass**) via photosynthesis. Trees store carbon in their trunks, branches, leaves and roots, where it remains for many years. Tropical rainforests are known for their high carbon-storage capacity due to their dense vegetation and high rates of photosynthesis.

Biomass surveys can be undertaken in the field; however, new technologies are emerging that allow scientists to estimate the carbon storage of different vegetation types (above-ground biomass versus below-ground biomass). Satellite imagery and LiDAR (light detection and ranging) data provide measurements of canopy height, and drone-based aerial photography can be used to estimate percentage vegetation cover. Algorithms allow for this data to be translated into an estimate of above-ground biomass. Below-ground biomass is typically estimated at around 50% of the above-ground estimate.

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Investigation 7.2

Carbon sequestration in an ecosystem

Trees can sequester carbon. Scientists estimate that the average tree can sequester 25 kg of CO_2 per year, to an average of 250 kg over its lifetime. However, the rate of carbon sequestration depends on factors such as species, growth characteristics, wood density, location and stage of growth. By measuring the diameter and height of a tree, you can estimate the amount of carbon stored in its biomass. You can also determine carbon sequestration by measuring deadwood, leaf litter and soil depth.

Aim

To evaluate carbon sequestration in an ecosystem, using tree biomass

Materials

- tape measure

Method

1. Select the study site. Choose a suitable ecosystem for the investigation, such as a forest or grassland. Ensure that the area has not undergone any major disturbances, such as logging or fires, that could affect the accuracy of the results.
2. Divide the study area into manageable sections and select sampling points within each section. These points should be evenly distributed and representative of the entire area.
3. Copy and complete the following table.

Table showing the features of trees that can be used to estimate biomass

		Tree 1	Tree 2	Tree 3	Mean
a	Circumference (cm)				
b	Age $\left(\frac{\text{circumference}}{\text{growth rate}}\right)$				
c	Dry rate (kg) (see conversion table)				
d	Carbon stored (kg)				

a) Use a tape measure to measure the circumference of a tree at a height of 1.3 m (approximately chest height) from the ground.

b) Trees grow at different rates, but on average the circumference increases by approximately 2.5 cm per year. Divide the circumference by 2.5 to calculate the tree's age.

c) Use the following conversion table to convert the circumference of the tree into the dry weight.

Circumference (cm)	Dry weight (kg)	Circumference (cm)	Dry weight (kg)
1.5	0.009	50	106
2.5	0.040	75	310
5.0	0.230	100	668
10.0	1.400	125	1208
20.0	9.000	150	1964
30.0	27.000	175	3253
40.0	82.000	200	4221

d) Half of a tree's dry weight is carbon, so divide the dry weight by 2 to determine how much carbon is stored in the tree.

Example: A tree has a circumference of 100 cm. Its dry weight is approximately 668 kg. Dividing this value by 2 tells us that the tree is storing approximately 334 kg of carbon.

continued …

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Extension

A team of local scientists have approached you to provide some estimates regarding the above-ground biomass in a local temperate forest ecosystem.

1. Consider what would be an appropriate sample size for this extended investigation.
2. How might digital tools enable more efficient data collection for this extended investigation?

Try this 7.3

Carbon storage in biomass

Figure 7.35 shows the distribution of terrestrial carbon by ecosystem type in above-ground (top) soil, subsoil, and above- and below-ground plant biomass.

1. Identify the forest type that stores the most carbon in its soil.
2. Determine the ecosystem that has approximately half of the soil organic carbon of the cool temperate moist ecosystem.
3. Determine the approximate organic carbon found in the plant biomass of a tropical moist ecosystem.
4. Identify any general relationship in the data.
5. Sequence the following ecosystems in order of total carbon, from most to least: boreal moist, polar dry, tropical dry, warm temperature moist, and cool temperate dry.
6. Can the data in Figure 7.35 be used to justify the following statement? 'Tropical ecosystems sequester more carbon than other types of ecosystems.'

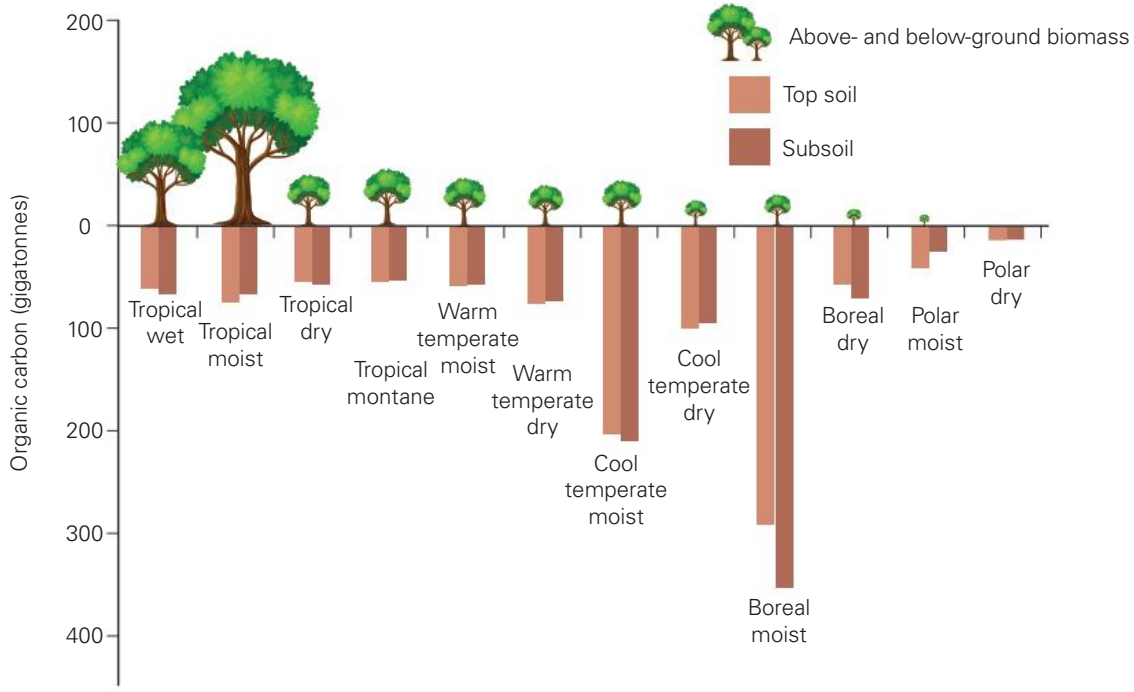


Figure 7.35 The total mass of organic carbon stored in different types of ecosystems, distributed between plant biomass, topsoil and subsoil.

Oceans are another natural carbon sink. When carbon dioxide dissolves in seawater, it forms carbonic acid (H_2CO_3) and bicarbonate ions (HCO_3^-), which then react with other ions in the water to form carbonate ions (CO_3^{2-}). The carbonate ions can then combine with calcium ions (Ca^{2+}) to form calcium carbonate ($CaCO_3$), which is the main component of the shells of marine organisms. When marine organisms die, their bodies sink to the ocean floor, taking the stored carbon with them.

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The ocean can also directly absorb carbon dioxide from the atmosphere, and scientists estimate that it can absorb and store about 25% of the carbon dioxide released into the atmosphere by human activities. However, the ocean's ability to act as a carbon sink is not unlimited. Colder water is more effective at dissolving and absorbing carbon dioxide than warmer water. The ocean's coldest waters contain a large amount of dissolved carbon dioxide, which can be stored for long periods when the cold water sinks to the deep sea. However, as the oceans warm up, they are becoming less efficient at absorbing carbon dioxide and may even release it back into the atmosphere more quickly. Another issue is that, as more carbon dioxide is taken up by the ocean, the water can become acidic, which is harmful to the marine organisms that rely on calcium carbonate to build their shells.

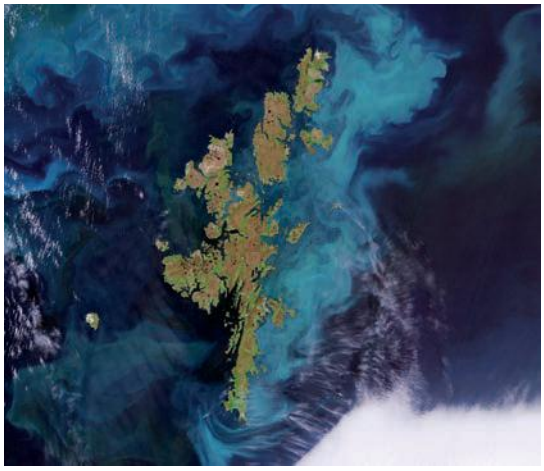


Figure 7.36 The image shows the Shetland Islands, a group of about 100 islands and islets north of Scotland. The turquoise-coloured bloom visible to the east is a coccolithophore bloom, a type of microscopic marine algae that multiplies rapidly near the surface and sheds calcium-rich coccoliths, turning the water a bright, milky-turquoise colour. These shells sink to deeper ocean depths after they die, storing carbon in the process.

Carbon sequestration can also occur in soil. When a plant dies, its stored biomass is deposited into the soil where it can be stored. Peatlands (see Figure 7.37) are a particularly important ecosystem for carbon sequestration, as they accumulate organic matter in the form of partially decomposed plant material called peat. This occurs under waterlogged conditions where oxygen is limited, resulting in a slow rate of decomposition and long-term carbon storage. If peatlands are disturbed through agriculture or development, the peat is exposed to oxygen and will decompose, releasing carbon dioxide into the atmosphere.



Figure 7.37 Peatlands are estimated to store twice as much carbon as all the world's forests.

Quick check 7.12

1. **Explain** how plants remove carbon dioxide from the atmosphere.
2. **State** which is more effective at storing carbon dioxide: cold water or warm water.
3. **Outline** how the conditions in peatlands maximise carbon storage.

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Explore! 7.6

Landcare

Landcare is a community organisation that aims to improve the health of the land and waterways in Australia by promoting sustainable land use and management practices. Established in the late 1980s, Landcare brings together farmers, landowners, natural resource managers and community members to collaborate on local projects that address issues such as soil erosion, water quality, biodiversity loss and carbon sequestration. Landcare is supported by the Australian Government, which provides funding and other resources. Landcare has become a widely recognised and respected initiative that has made significant contributions to environmental sustainability in Australia.

Examine how government initiatives such as Landcare have supported the adoption of effective land restoration practices that improve soil quality and increase carbon sequestration in soils.



Figure 7.38 A Landcare-funded project between CSIRO and local farmers is investigating the benefits of introducing dung beetles to Far North Queensland. Researchers are studying the behaviour of dung beetles in the region (e.g. their preferred habitats and the types of dung they prefer) and examining the economic benefits of dung beetle introduction (e.g. increased farm productivity and reduced fertiliser costs).

Capturing carbon using technology

As carbon dioxide emissions continue to rise, a variety of technologies are being developed for carbon capture. Once captured, the carbon dioxide can be compressed and transported to a storage or utilisation site where it can be used across a wide range of industries. In the oil industry, it can be injected into oil reservoirs to enhance oil recovery. In the chemical industry, it can be used as a raw material to produce chemicals and plastics. In the food industry, it can be used to carbonate beverages.

Carbon capture technologies, such as those shown in Figure 7.39, have the potential to significantly reduce carbon emissions and help slow the pace of climate change. However, there are still significant challenges that must be overcome to make large-scale carbon capture readily available.

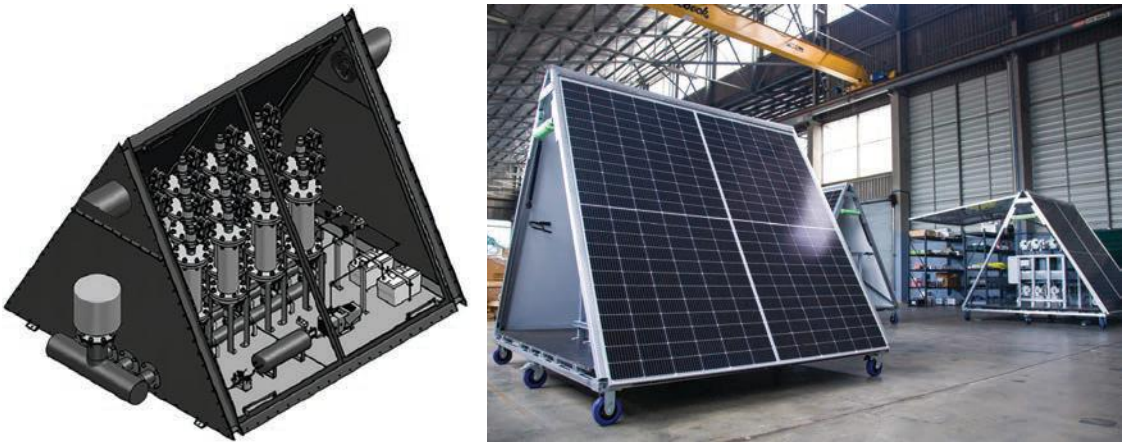


Figure 7.39 An example of direct air capture (DAC) technology, designed by Southern Green Gas, a newly formed Australian company that focuses on renewable energy projects. These DAC machines are solar powered, meaning they can capture CO_2 from the atmosphere without releasing further emissions.

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Technology	Explanation
Post-combustion capture	CO_2 from flue gases is captured after fossil fuels are burned in power plants or industrial facilities.
Pre-combustion capture	Fossil fuels are converted into a gas. The gas is then treated to remove CO_2 before being burned.
Oxyfuel combustion	Fossil fuels are burned in pure oxygen instead of air. The resulting gas is almost pure CO_2, which can be readily captured.
Carbon mineralisation	CO_2 is reacted with certain types of minerals to produce stable carbonates. The carbonates can then be stored underground or used in building materials.
Direct air capture	Machines directly capture CO_2.

Table 7.8 Some carbon capture technologies

Storing carbon using technology

Once captured, carbon dioxide can be stored in a variety of ways.

- Geological storage: CO_2 is injected into underground rock formations, such as depleted oil and gas reservoirs. In enhanced oil recovery, CO_2 is injected into oil reservoirs to recover more oil. The CO_2 is stored in the reservoir.
- Ocean storage: CO_2 is injected into the ocean, where it can dissolve and be stored in the deep ocean.
- Mineral storage: CO_2 is reacted with certain types of minerals to produce stable carbonates, which can then be stored underground.

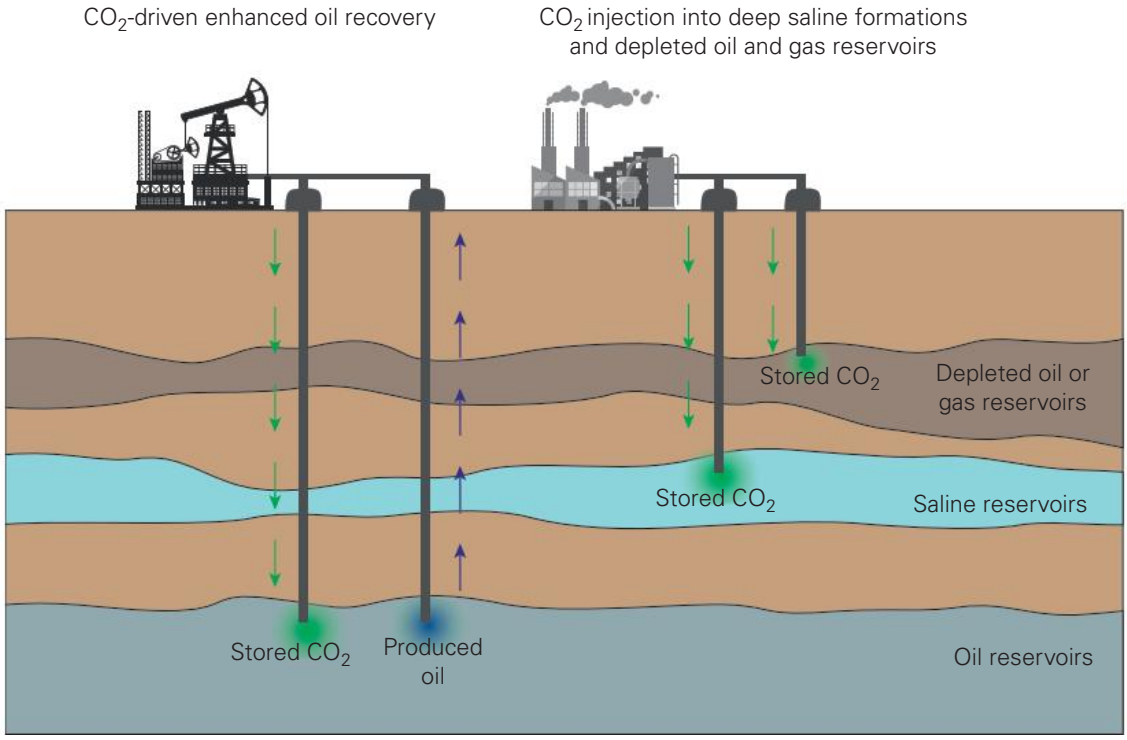


Figure 7.40 Injecting CO_2 underground can help increase oil recovery (left) or allow it to be stored underground in depleted oil and gas reservoirs (right).

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Quick check 7.13

1. **Describe** some of the ways carbon dioxide can be stored once it has been captured.
2. **State** which carbon capture technology recovers more carbon dioxide by burning fuels in pure oxygen.

Section 7.3 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Go online to access the interactive section review and more!

Section 7.3 questions

Remembering

1. **Name** three gases in the atmosphere that are responsible for the greenhouse effect.
2. **Define** 'enhanced greenhouse effect'.
3. **State** the types of radiation important in the greenhouse effect emitted from the:
   a) Sun
   b) ground and oceans.
4. **Recall** the sources of methane in the atmosphere.
5. **Define** 'carbon sequestration'.
6. **State** the main chemical component of marine organism shells.

Understanding

7. **Explain** the differences between the natural and enhanced greenhouse effects.
8. **Explain** why the following statement is incorrect: 'The greenhouse effect is caused by humans.'
9. **Explain** how a greenhouse mimics the greenhouse effect.

Applying

10. The sun emits visible light, ultraviolet radiation and infrared radiation. **Explain** which energy type is responsible for causing sunburn and which energy type is reflected to create the greenhouse effect.
11. **Illustrate** a diagram to show how the greenhouse effect keeps Earth warm.
12. **Compare** solar radiation and the radiation emitted by Earth.
13. **Describe** the consequences of ocean warming on ocean carbon sequestration.

Analysing

14. **Contrast** pre-combustion and post-combustion carbon capture.
15. **Contrast** carbon sinks and carbon sources, giving examples.

Evaluating

16. **Predict** what the conditions on Earth would be like without greenhouse gases and the greenhouse effect.
17. **Decide** why our focus related to the enhanced greenhouse effect is on carbon dioxide and not on the other greenhouse gases.
18. **Propose** reasons why, even though we have known about the damaging effects of carbon emissions for a long time, Australia still produces 46% of its electricity from coal.
19. **Discuss** the reasons why the carbon cycle is altered by the release of carbon emissions from burning fossil fuels.
20. **Discuss** how forests could be managed to maximise carbon sequestration.

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7.4 Our role in the changing climate

WORKSHEET
Increasing global temperatures

VIDEO
Climate change

Learning goals

At the end of this section, I will be able to:

1. Recall the difference between weather and climate.
2. Identify the changes in global climate over time, and provide evidence of these changes.
3. Explain the role that deep ocean currents have on global climate.
4. Outline the human influences on climate change.
5. Describe how we can collect data and predict changes to the Earth system.
6. Identify strategies used to reduce climate change or mitigate its impacts.

Climate versus weather

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 a long period

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 Victoria is very different from the climate in Queensland.

Different areas of the world have differing climates due to the:

- uneven distribution of the Sun's rays because of the curvature of 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
- type of soil or plant life
- 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.

Did you know? 7.4

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 7.41 Lightning over Melbourne, Victoria

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The role of deep ocean currents

Most of 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, but also distributes it around the globe. Figure 7.42 shows that water temperatures are highest around the equator and cool as you move towards the polar regions.

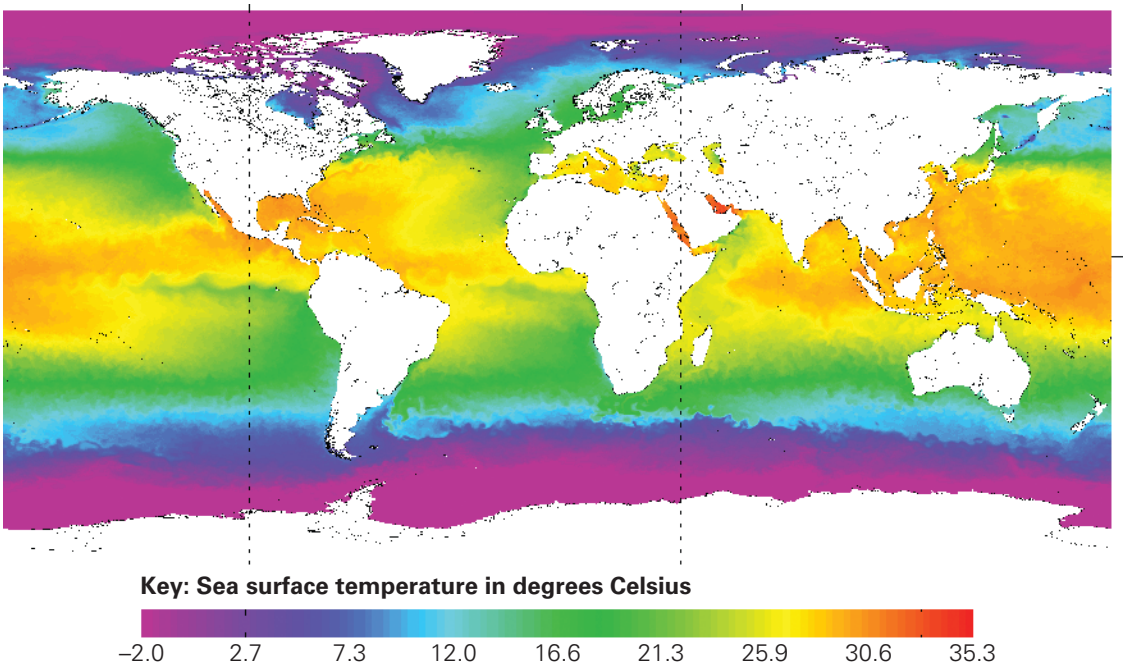


Figure 7.42 Global sea-surface temperatures taken from the US National Oceanic and Atmospheric Administration (NOAA) Office of Satellite and Product Operations. The colourmap ranges from −2.0°C (purple) to 34.6°C (red).

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 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.

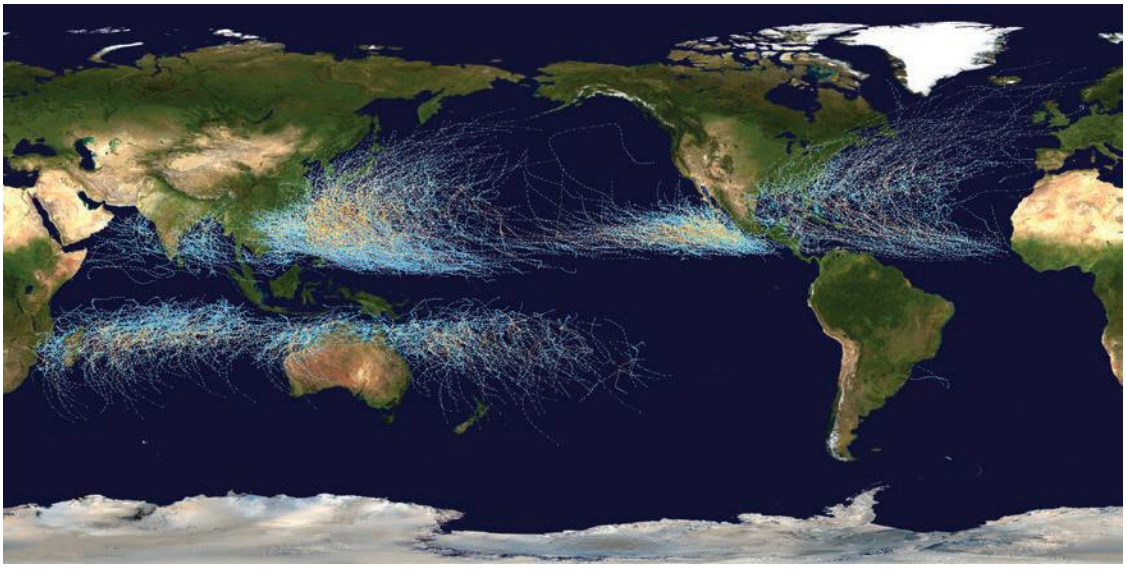


Figure 7.43 A map of tropical cyclone tracks. The higher evaporation rates in the tropics contribute to the higher rainfall and more active weather patterns in that region.

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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. If the 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 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, as well as play a major role in the global climate system. Deep ocean currents also move water and nutrients from the ocean's surface to its depths, helping to improve the overall health and productivity of oceanic ecosystems.

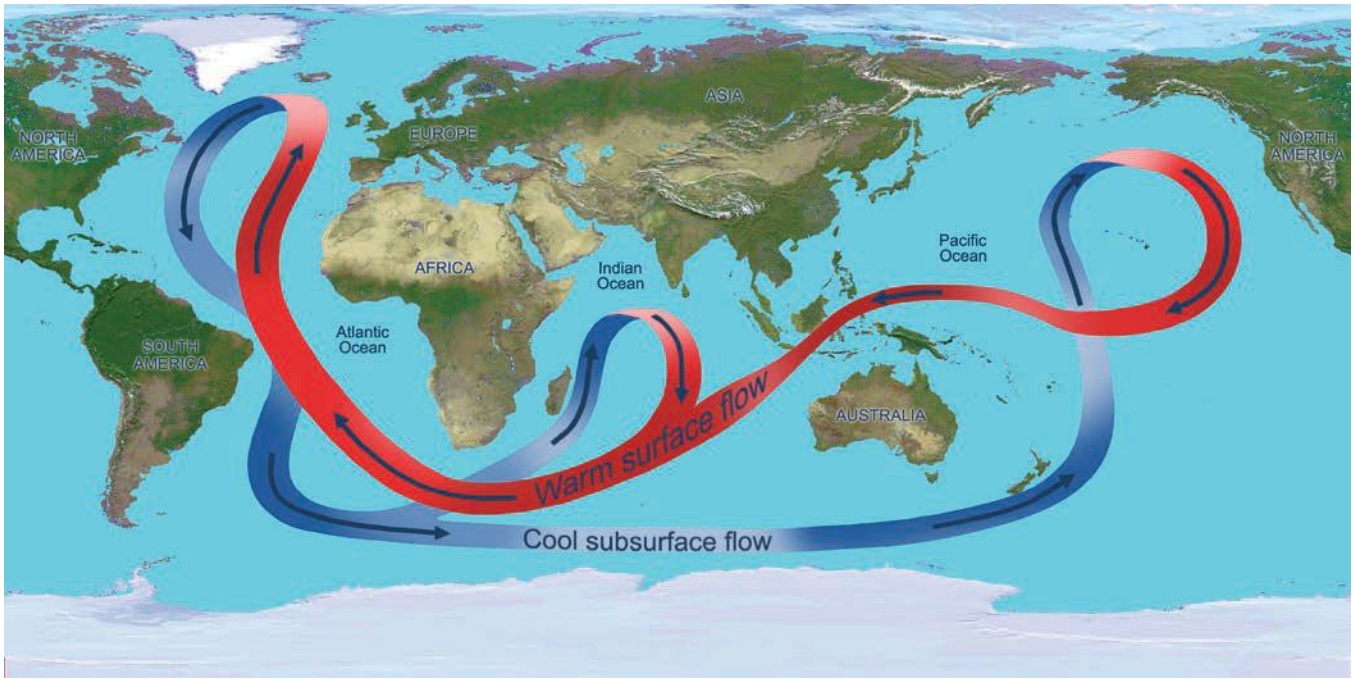


Figure 7.44 The most well-known deep ocean current is the thermohaline circulation, also known as the 'global conveyor belt'. This current carries warm water from the tropical regions to the colder regions in the North Atlantic, releasing heat into the atmosphere, and then returns as cold, dense water 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.

Quick check 7.14

1. **Define** 'weather'.
2. **State** one reason why climates on Earth differ.
3. **Describe** how deep ocean currents regulate global temperatures.

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 can occur due to natural causes, such as changes in the Sun's intensity, volcanic eruptions and variations in ocean currents.

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Earth's climate is dynamic and has undergone significant changes throughout history. In the past, Earth has experienced many ice ages, when 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 (see Figure 7.45). However, as sea levels rose, the land bridge was submerged, creating the Bass Strait.

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.

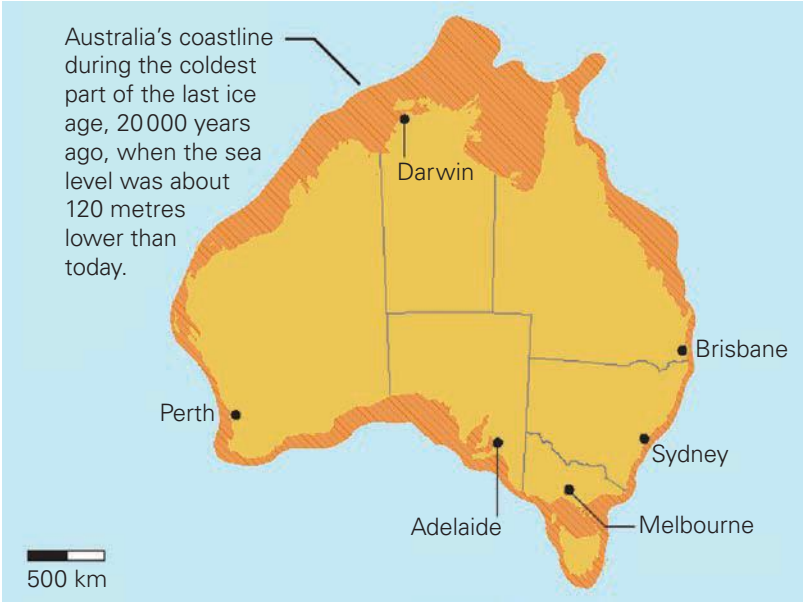


Figure 7.45 In the last ice age, ice sheets locked up much of Earth's water, making the coastline of every continent far lower than it is today.

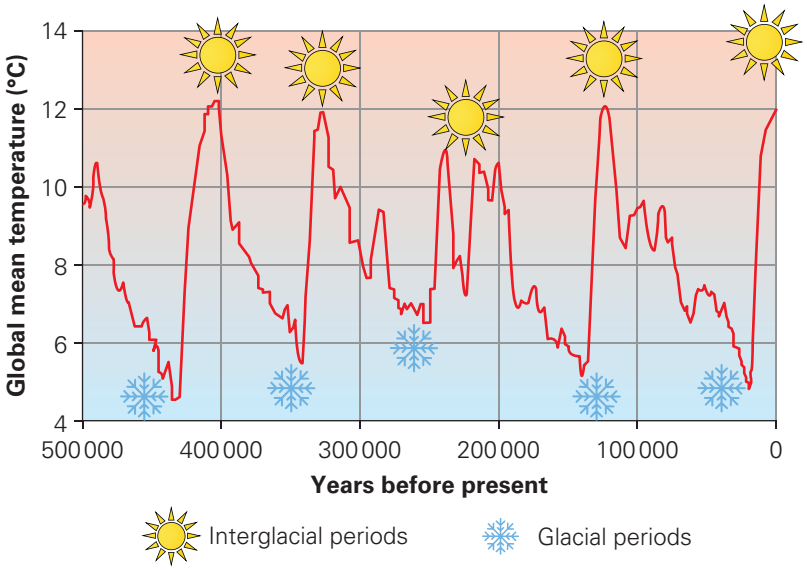


Figure 7.46 Earth has undergone natural cycles of warming and cooling.

Human influences on climate change

Scientific consensus about global warming

There is overwhelming evidence that human activities are the primary cause of climate change. This evidence comes from multiple sources, including observations of rising temperatures, melting ice caps and changes in weather patterns. Scientists have also developed sophisticated computer models that simulate Earth's climate and have used these models to project future climate scenarios. These projections consistently show that if greenhouse gas emissions do not stop increasing, Earth's temperature will continue to rise.

The scientific community has reached a consensus on these issues through a rigorous process of peer-reviewed research and analysis. This is based on thousands of studies conducted by scientists from around the world and is supported by professional scientific organisations such as the Intergovernmental Panel on Climate Change (IPCC).

glacial period
a period in Earth's history when a reduction in global temperatures is sustained for a long period

interglacial period
a period in Earth's history when an increase in global temperatures is sustained for a long period

anthropogenic
caused or influenced by people

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Media headlines regarding the concentration of carbon dioxide in the atmosphere or temperature fluctuations over time can be misleading. As critical consumers, we need to evaluate the validity of the information by considering the credibility of the authors and the methodology of their research.

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; 2023 was the hottest year and 2016 and 2020 tied as the second hottest since records began. The years since 2014 have been the warmest years on record.

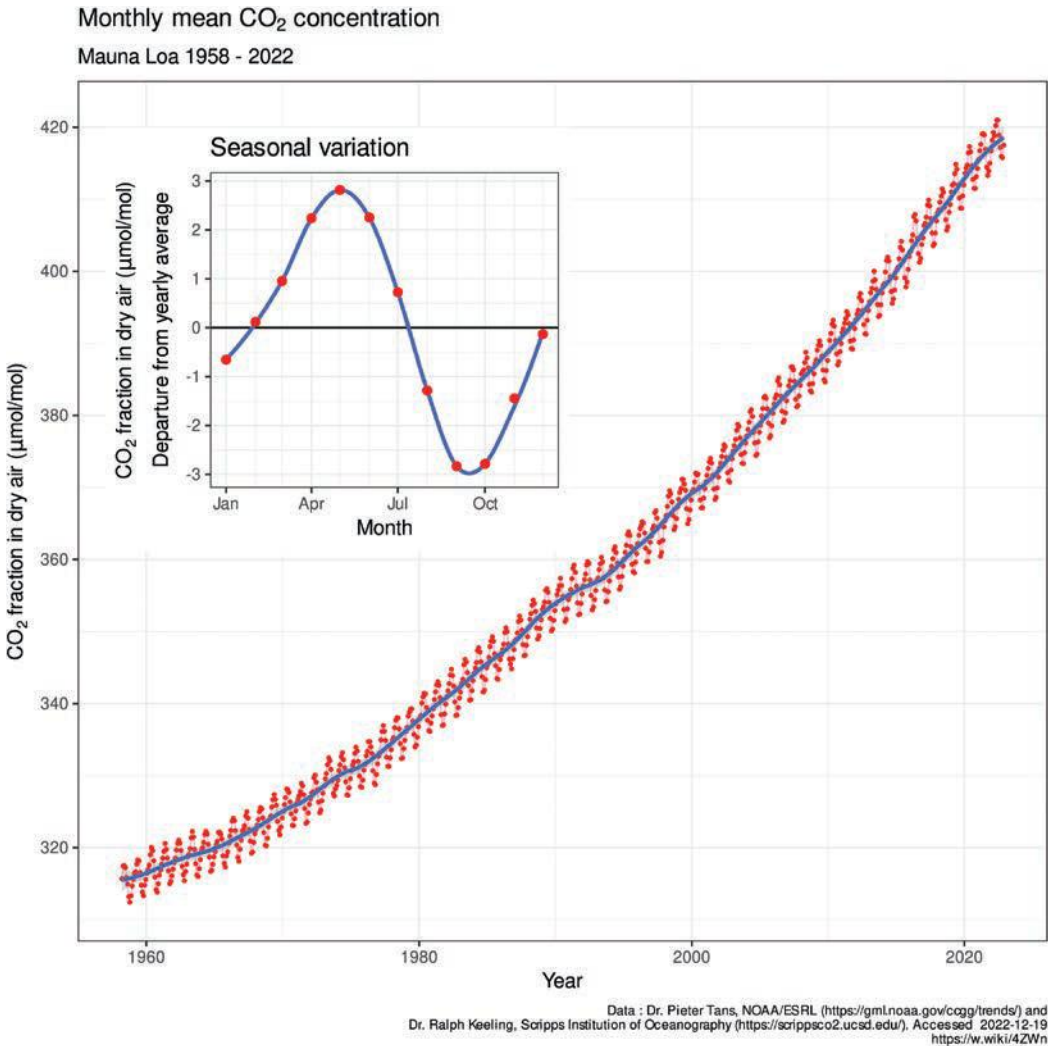


Figure 7.47 The changes in energy balances, such as the burning of more fossil fuels, have contributed significantly to global climate change. The Keeling curve shows the concentration of carbon dioxide in parts per million (ppm) from 1958 to 2022 using measurements taken from an observatory in Hawaii. The concentration of carbon dioxide in the atmosphere has increased from 280 ppm before 1800 to well over 420 ppm in 2022.

Quick check 7.15

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 7.9 summarises the influences that humans are having on the climate and how climate change is affecting global systems.

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. 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. 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. Nitrogen oxides 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 7.9 A summary of some human influences on climate change

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Making thinking visible 7.2

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 of the page and less important ones towards the outside.
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.

The *Generate, sort, connect, elaborate* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Did you know? 7.5

Cows and climate change

The farming of beef and dairy cattle contributes to climate change through the following processes.

- Methane emissions: Cows produce methane through their digestive process, known as rumination.
- Land use: Beef and dairy farming often involves land clearing and the conversion of forests and grasslands into arable land (agricultural land using 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 for feeding cattle often involves the use of fertilisers that contain nitrates, which in turn produce nitrous oxide.
- Transportation emissions: Livestock and beef and dairy products are often transported over long distances between farms, saleyards, abattoirs and manufacturing facilities.



Figure 7.48 Australia produces some of the best beef in the world, but it comes at a cost to the environment.

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Evidence for climate change

VIDEO
Indicators of climate change

Scientists draw on various data sources to study how the climate is changing and the impact humans are having, and to track progress in mitigating the effects. Historical records provide a source of secondary data, and fieldwork allows the collection of primary data. A variety of indicators provide a picture of the state of the global 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 system, including ocean circulation 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 also 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, with the data providing evidence for climate change and the ongoing impact of human activities.

Polar ice, permafrost and rising sea levels

WORKSHEET
Analysing Antarctic ice core data

Scientists can track the climatic changes in temperature and carbon dioxide levels by taking cores (vertical samples) deep down into the polar ice. These cores show the layers of snow that fell and were compacted thousands of years ago, and their chemical composition gives clues about conditions at the time.



Figure 7.49 An ice core sample collected in Antarctica

Permafrost – a permanently frozen layer of soil, gravel and sand bound together by ice – can also provide information about past climatic conditions as it melts. When permafrost melts, it releases trapped greenhouse gases, such as carbon dioxide and methane. The presence, thickness and temperature of permafrost provide scientists with valuable information about the rate of climate change.



Figure 7.50 Thawing permafrost

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Glaciers advance during periods of cooling and retreat during periods of warming. However, the increasing trend in global oceanic and atmospheric temperatures has seen melting of the polar ice caps (themselves giant glaciers) and a subsequent rise in sea levels. Low-lying areas of land, such as some of the Pacific Islands, are most at risk. Ice acts as a barrier to prevent sunlight from reaching the ocean's surface, so with less ice cover there is a greater rise in oceanic temperatures, creating a vicious cycle. Ocean water in equatorial regions expands as it warms, further contributing to sea level rises. Rising sea levels leads to coastal flooding and erosion and affects coastal ecosystems and communities. Scientists must monitor sea levels, using equipment such as satellite altimeters and tide gauges.



Figure 7.51 The Franz Josef glacier on the South Island of New Zealand



Figure 7.52 Coastal infrastructure will be destroyed by sea level rises and an increase in extreme weather events.

Did you know? 7.6

Rocks tell a story

The location of sedimentary rocks and fossil distribution paint a picture of the world's changing coastlines. Fossilised sea creatures have even been found in the centre of Australia, which was once a tropical inland sea! This sea drained as a result of tectonic plate movement rather than rising temperatures.



Figure 7.53 Fossilised remains of sea creatures

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Did you know? 7.7

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.

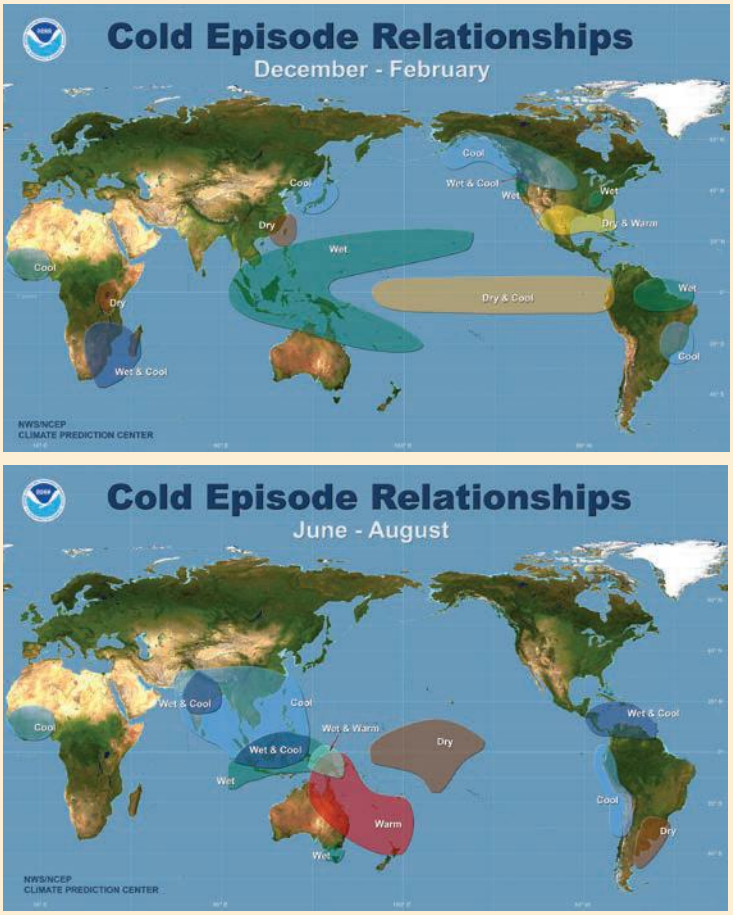


Figure 7.54 Global weather impacts of La Niña

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 7.55 An aerial view of Bulleen, Melbourne (2022). The park shown is in a floodplain of the Yarra river.

VIDEO
El Niño southern oscillation

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Practical 7.5

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
- 100 mL beakers × 5
- pipettes × 5
- food colouring (blue, green, yellow and red)
- salt
- water
- weighing boats
- balance

Method

1. Copy the results table into your science book.
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. Referring to the table above, add the required drops of food colouring 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 it to the 10 mL measuring cylinder.
7. Using a pipette, draw up 2 mL of solution 4. Position the pipette against the inside of the measuring cylinder, with the tip of the pipette close to the solution added previously. Slowly add solution 4 drop by drop, allowing the drops of solution to roll down the side of the measuring cylinder. Be careful not to knock the cylinder or let the pipette disturb the solution in the cylinder!
8. Repeat step 7 for solutions 3, 2 and 1, slowly adding each in turn to the 10 mL measuring cylinder.
9. Note the distribution of coloured solutions, taking a photo if possible.

continued …

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Results

1. Sketch a coloured diagram of the appearance of the solutions in the measuring cylinder.
2. Complete the results table.

Table showing the densities of the different solutions

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	

3. Plot a graph of mass of salt on the *x*-axis and density on the *y*-axis.

Discussion: 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.

Discussion: Evaluation

1. Discuss any limitations in your methodology.

Conclusion

1. Make a claim about the effect of climate change on ocean currents.
2. Support your statement by using the data you gathered, and include potential sources of error.
3. Explain how the data supports your claim.

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 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.



Figure 7.56 Melting sea ice

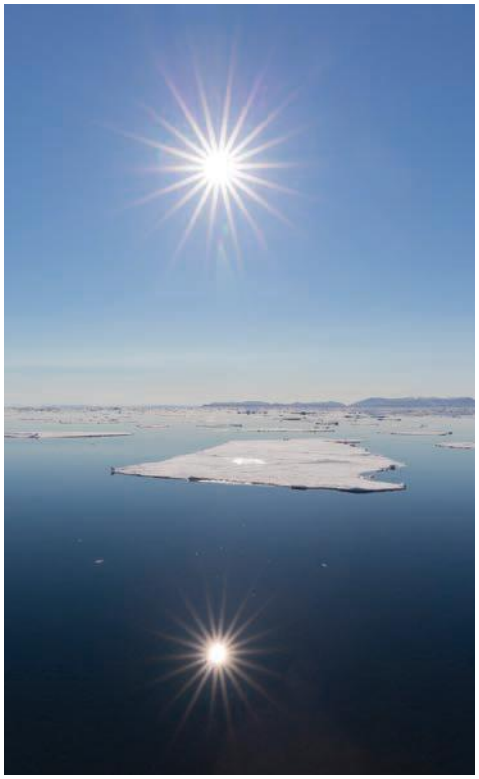


Figure 7.57 Ice reflecting the midnight sun in the Arctic Ocean

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Did you know? 7.8

Antarctic emergency?

In July 2023, the Antarctic sea ice winter levels were recorded to be at their lowest since the continuous satellite record began in 1978. The sea ice follows a seasonal trend each year, shrinking during summer and then expanding again in winter. Since 2014, there has been a downwards trend in winter sea ice levels, culminating in 2023's record low area.

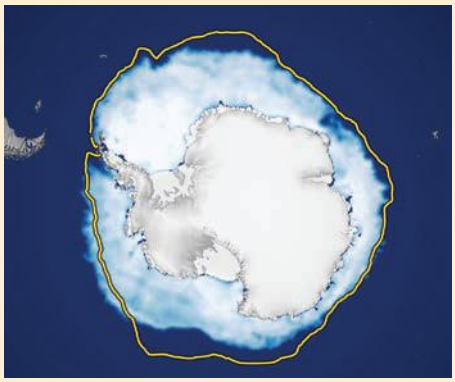


Figure 7.58 An image showing the Antarctic sea ice levels in August 2023 compared to the winter average (yellow line).

Quick check 7.16

1. **State** one indicator that scientists can use to monitor climate conditions.
2. **Identify** the main problem caused by melting polar ice caps.
3. **Identify** the problem caused by decreased ocean density as a result of reduced freezing of ice in winter.

keystone species a species that has a significantly large role/impact on a particular ecosystem relative to its population

Explore! 7.7

Changing reefs

Climate change has a significant impact on coral reefs, which are some of the most biodiverse ecosystems on the planet. Coral is considered a **keystone species**, because many other species rely on it for food and shelter.



Figure 7.59 Corals and fish in the Great Barrier Reef



Figure 7.60 Bleached branching coral

The main effects of climate change on coral reefs include the following.

- Ocean acidification: Increases in atmospheric carbon dioxide cause the oceans to become more acidic. This makes it difficult for corals to build and maintain their calcium carbonate skeletons, leading to the degradation of reefs.
- 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 increase their exposure to other stressors such as pollutants and disease, threatening their survival.

The degradation and loss of coral reefs will also have consequences for the millions of people who rely on them for food, income and coastal protection.

Research some of the reasons why coral bleaching is so disastrous for the environment.

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Biodiversity and species distribution

Climate change is one of the biggest threats to global **biodiversity**. The more biodiverse an environment, the more resistant that environment is to change. (It is more stable.) Climate change 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.

biodiversity the variety of species, ecosystems and genes that exist in a particular area

Did you know? 7.9

Dating pollen

By dating the rock that fossilised pollen is found in, scientists can deduce the number and species of plants living in that location during that time period. This in turn provides information about the climate at that time.



Figure 7.61 A bee pollinating a flower

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 7.62 The blue dragon (*Glaucus atlanticus*) is a small venomous sea slug 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, including decreased biodiversity.

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Explore! 7.8

Citizen science

In citizen science, the general public participates in collecting scientific 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 to obtain.

Research the citizen science project Redmap to see how everyday Australians have documented the movement of species around Australia's coasts over the past decade and how this is contributing to our knowledge about climate change.



Figure 7.63 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, more than 17 000 taggers contributed over 198 600 days (or 544 years) of effort to reach the milestone.

Try this 7.4

Make an infographic

Create a digital infographic to highlight the multiple lines of evidence (e.g. from polar ice caps, ocean temperatures and extreme weather) that explain how climate change is impacting Earth.

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.

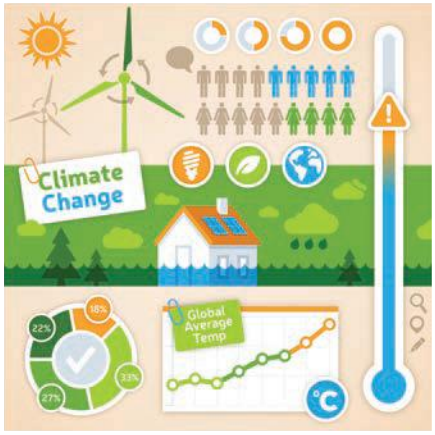


Figure 7.64 Infographic inspiration

DOC
WORKSHEET
Evaluating impacts on climate change

Modelling and mitigating the impacts of climate change

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 how they 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.

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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.

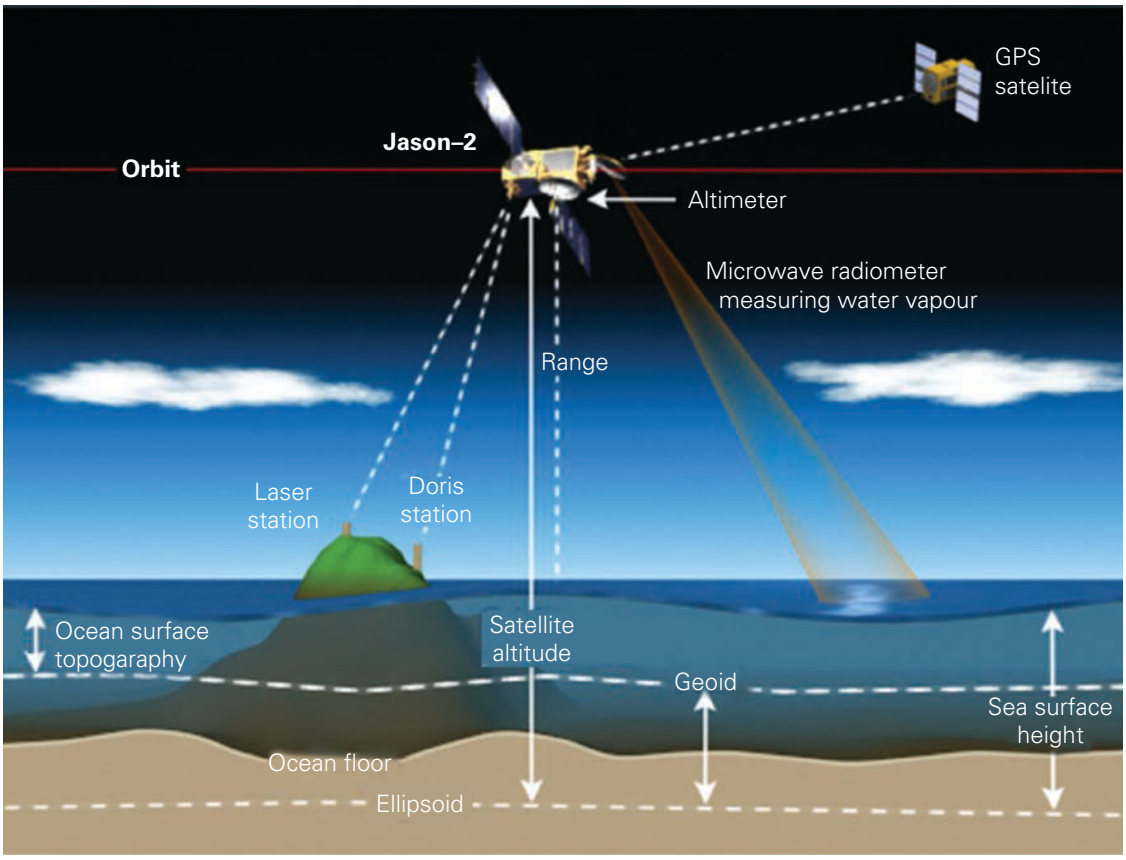


Figure 7.65 Satellite radar altimeters measure sea levels by measuring the time it takes a radar pulse to travel from the satellite to the sea surface and back.

Satellites also use optical and microwave sensors to monitor changes in forest and ice cover. These instruments can detect changes in 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.

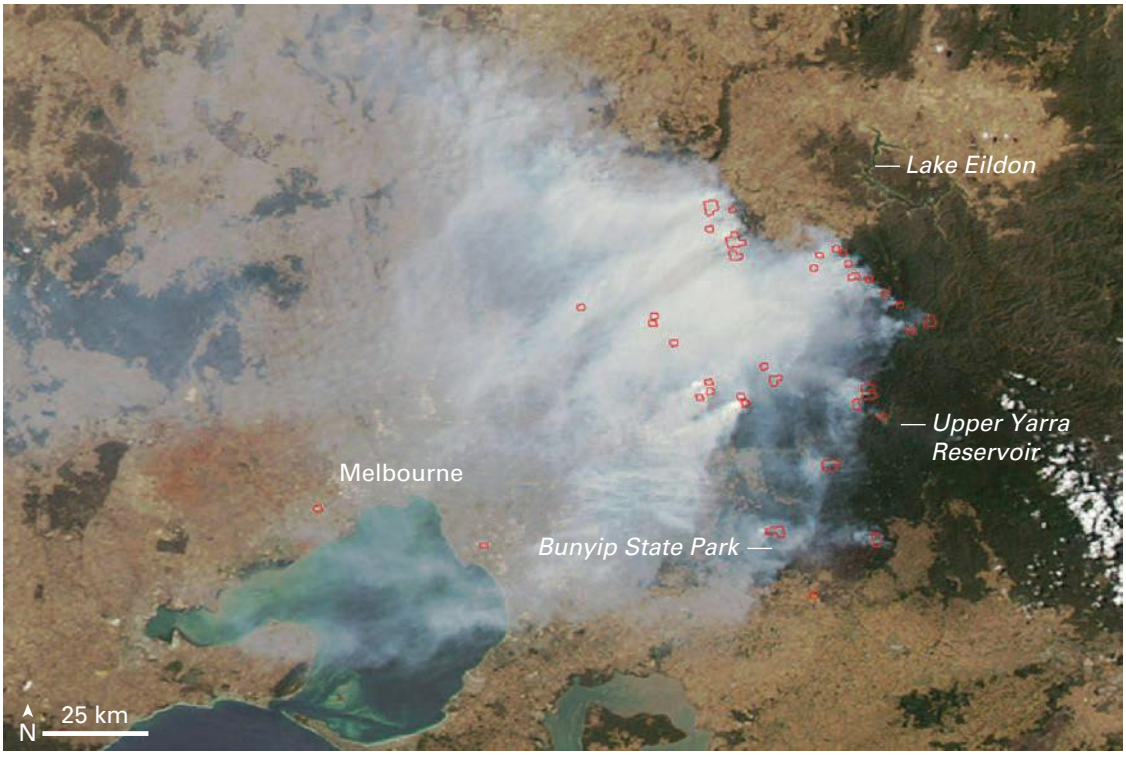


Figure 7.66 Aerial imagery showing MODIS data from NASA's Aqua satellite, during the catastrophic 2009 bushfires in Victoria. Actively burning areas are outlined in red.

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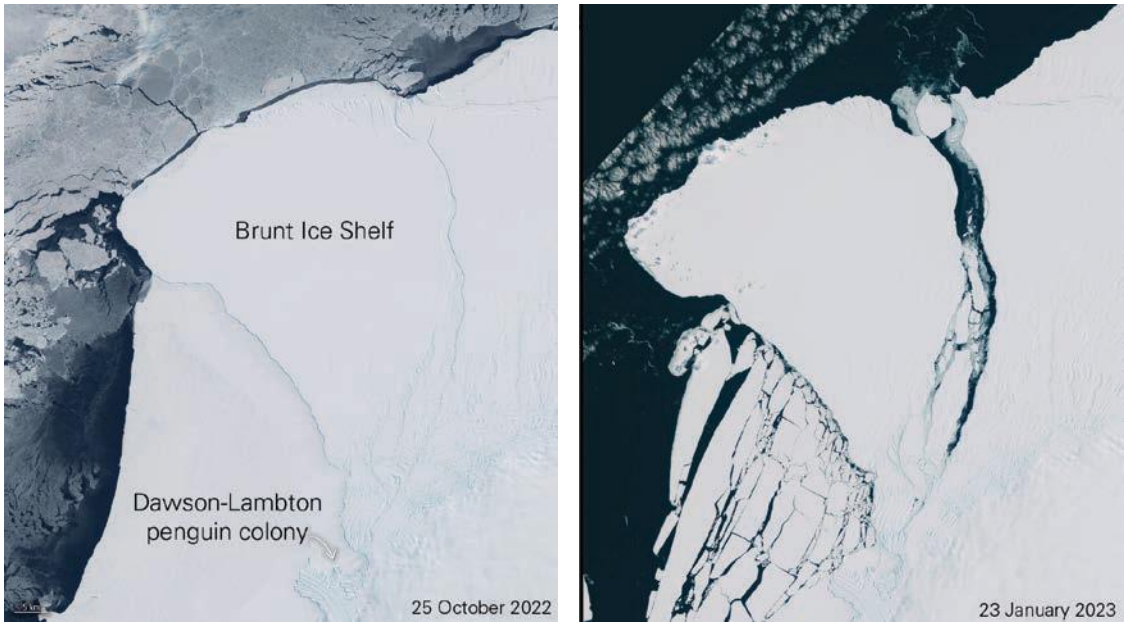


Figure 7.67 The two-satellite mission Copernicus Sentinel-2 has produced before and after photos of the ice slab that broke away from the Brunt Ice Shelf, Antarctica. The image on the left shows cracks on the ice shelf on 25 October 2022 and the image on the right shows the ice breaking away on 24 January 2023.

The data generated by satellites is used to monitor the effects of climate change by providing a record of changes over time.

VIDEO
Computer modelling

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 7.68 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.

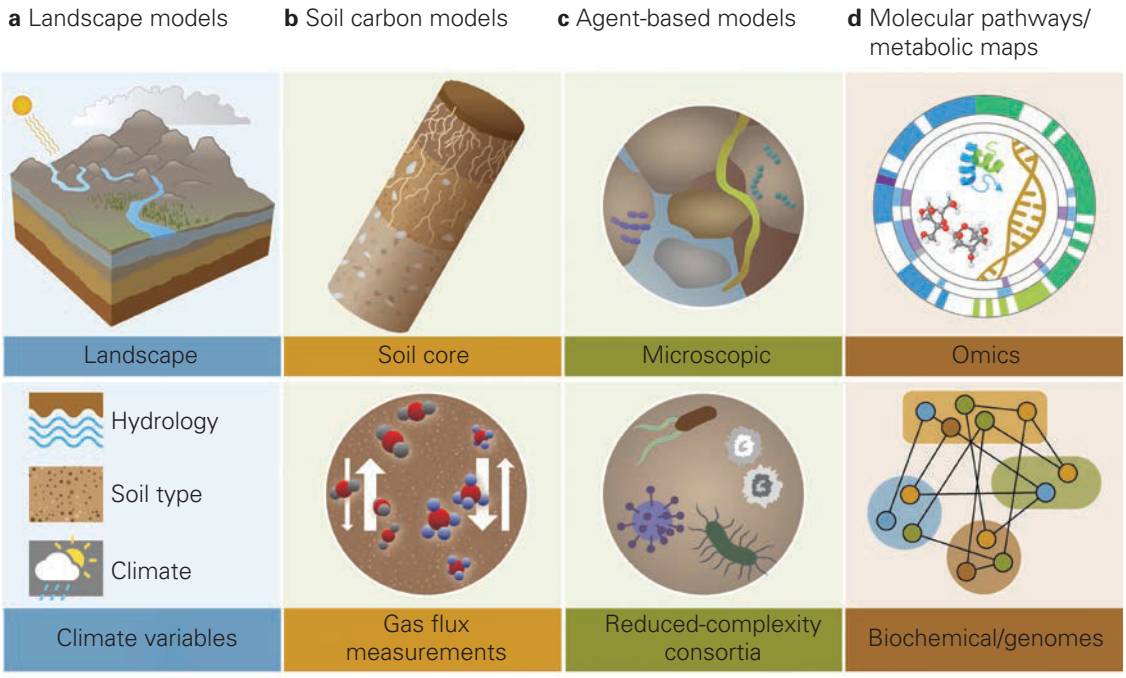
Table 7.10 lists some of the applications of computer modelling.

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 7.10 Some of the applications of computer modelling

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) that exist in multiple states simultaneously. This allows quantum algorithms to perform certain tasks such as simulations much faster than classical algorithms.

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Naylor D, et al. 2020. *Annu. Rev. Environ. Resour.* 45:29–59

Figure 7.69 Climate change models can predict changes at a range of different levels: from effects on entire landscapes to effects on individual species' genomes.

Quantum computers will be able to process large amounts of data faster and more efficiently, enabling more detailed simulations. It may even be possible to process enormous amounts of data from multiple sources in real time! 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.

Quick check 7.17

1. **Explain** why scientists use computer modelling to predict phenomena.
2. **State** one application of computer modelling.
3. **Suggest** how quantum computers enhance climate modelling.

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. To address this uncertainty, scientists use multiple models, each using different assumptions, with the aim of achieving a more comprehensive understanding of the potential impacts of climate change.

All models, including climate models, are limited by the amount and quality of their input data, and by the fact that real-world processes are subject to complex and random events that lead to unpredictable variations. Therefore, different models and approaches are used to predict the impacts of climate change based on different scenarios, resulting in different projections of how the climate will change in the future. Further, as more data is collected and our understanding of climate change improves, new models are continually being developed and refined.

Taken together, the data generated by these models can be used to better understand the likely future impacts of climate change, which helps guide governmental decision-making about how to mitigate its effects.

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Making thinking visible 7.3

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. Some individuals deliberately spread false information to discredit the models and cause people to doubt the science of climate change, and science more broadly.

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 and businesspeople).
2. Select one of the viewpoints to consider, using the following statements:
    - I am considering climate change from 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 7.70 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.

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Quick check 7.18

1. **Suggest** one reason why computer models are not perfect.
2. **Suggest** two reasons why people contest climate change models.

Reducing our impact on climate change

It can be argued that given our contribution towards climate change, humans have a responsibility to reduce our future impact and attempt to mitigate ongoing risks to the planet. Production of greenhouse gases is ultimately linked to consumption: of food, of fuel and of natural resources. Human activities such as power generation, transport, food production and manufacturing are all significant contributors to climate change. Earlier in the chapter you had the chance to calculate your carbon footprint (see Explore! 7.5) and perhaps this enabled you to identify some personal changes you could make. However, there are larger-scale issues that corporations and government must address if we are going to alter the increasing trend in global temperatures. New technologies will require government and financial support to implement on a meaningful scale.

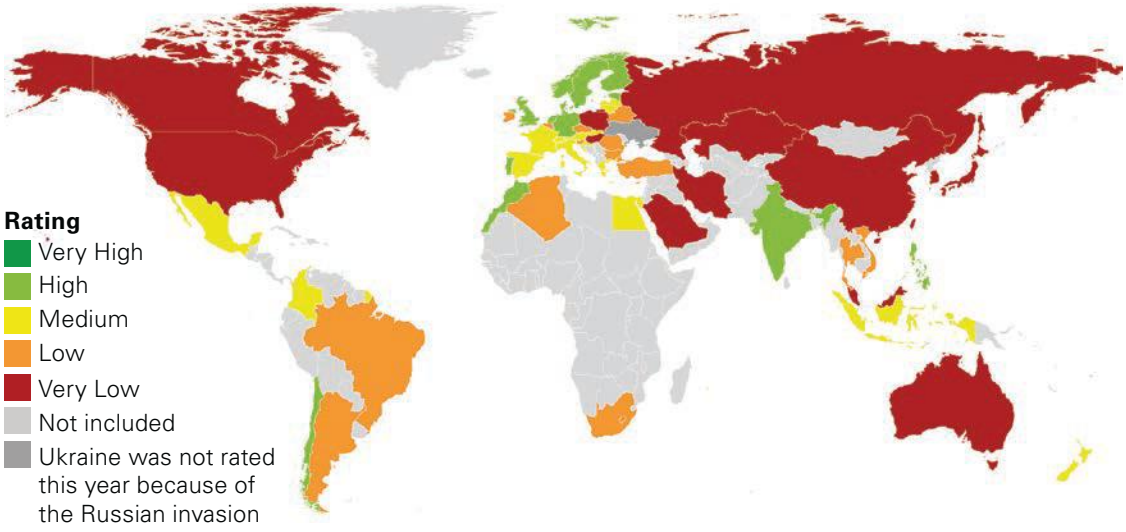


Figure 7.71 Australia's environmental protection efforts continue to be among the lowest in the world. Australia ranks 55th out of 63 possible places in the Climate Change Performance Index 2023.

Earlier in the chapter, Table 7.9 summarised various human influences on climate change. Below, we will expand on these categories of influence to consider some ways the effects can be addressed or mitigated.

Human influence	Strategies to reduce the impact in the future
Deforestation	• Sustainable logging • Carbon credits and planting initiatives
Agriculture	• Regenerative farming to minimise water and fertiliser use, and reverse soil degradation • Methane capture technology and feed additives for cattle to reduce the amount of methane they produce
Burning fossil fuels	• Move towards green energy production instead of relying on burning fossil fuels

Table 7.11 A summary of how human influences on climate change might be reduced

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Figure 7.72 The Waubra wind farm, near Ballarat, has been operational since 2009. It will soon be joined by the nearby Golden Plains wind farm, which will be the largest in the country and capable of providing 9% of Victoria's energy demand – enough to power every regional home in the state.

Developments in agricultural science

Global food demand is projected to increase by 70% to 2050. While this presents opportunities for innovation in the agricultural sector, the industry is also facing the economic challenge of climate change because it depends on natural resources. In many areas across the country, but particularly in the southern states, data from the Department of Agriculture, Fisheries and Forestry indicates that profits have decreased as a direct result of changes in seasonal conditions. To counteract this, the average farm size is increasing in an attempt to drive up productivity, and there has been a move towards more sustainable practices, such as regenerative farming techniques and the installation of green technology (e.g. wind turbines) on agricultural land.

Regenerative farming aims to improve soil health and address climate change by:

- moving away from monoculture cropping (growing one type of crop in a certain area) and towards intercropping (planting two or more species of plants together), which leads to more efficient use of resources such as water, and lower prevalence of pests
- planting cover crops to prevent erosion of arable soil, using native plants where possible
- reducing the use of chemical pesticides and herbicides
- using nitrogen-fixing crops, such as lentils, beans and lupin, to reduce the amount of nitrogen fertiliser needed
- using technology such as soil sensors for more precise application of nitrogen fertilisers.

It is thought that if regenerative agriculture practices were applied at scale, they could have a significant effect on climate change by turning farms into carbon sinks.

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Explore! 7.9

Cow burps

In 2022, a design group called ZELP (Zero Emissions Livestock Project) won a competition for creating a cow mask that traps the methane emitted in cow burps and converts it into carbon dioxide and water. They are planning widespread trials of the device in 2025.



Figure 7.73 This multi-purpose device captures methane emissions.

Research the technology and answer the following:

1. Restate the claim made by the company in terms of the percentage methane reduction.
2. Outline some of the additional monitoring benefits of this wearable technology.
3. Carbon dioxide is still a greenhouse gas. Propose a reason why releasing carbon dioxide is favourable compared to methane.

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. One aim of carbon farming is to sequester carbon in soil and vegetation to reduce atmospheric carbon dioxide. To this end, Australian farmers have been encouraged to return some of their arable land into forests and wetlands. In return, they would receive carbon credits. Embracing this mixed-use of land also has other benefits, such as providing shade and windbreaks for livestock, improving soil quality and making water use more efficient.

Traditional Owners are also implementing carbon-farming practices that support the management and restoration of natural ecosystems, in addition to mitigating the effects of climate change. Communities are using their Traditional knowledge of the land to implement reforestation projects that will naturally sequester carbon. They are also using their traditional land management practices, such as controlled burning, to reduce greenhouse gas emissions and improve ecosystem health. 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 reducing greenhouse gas emissions while also generating economic benefits for Indigenous communities.



Figure 7.74 Planting native trees on agricultural land provides many benefits for the environment, livestock and landowners (Macedon Ranges, Victoria).

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Green energy

Using renewable resources rather than continuing to burn fossils fuels for energy production is a key approach to tackling greenhouse gas emissions. Broadly speaking, a resource is considered renewable if it can be replaced within a human lifetime – approximately 80 years. Solar panels, wind turbines, and geothermal and hydroelectric power stations all present opportunities to generate electricity from the renewable resources of sunlight, wind, heat and the energy in flowing water. Nuclear power plants have also been proposed; however, they have proved politically problematic due to the potential health risks and environmental impacts of storing the wastes produced. While not a renewable resource, the radioactive uranium used as fuel in nuclear reactors is plentiful in Australia and does not generate greenhouse gases.

Electric vehicles (EVs), praised as a means of 'decarbonising' personal transport, offer lower greenhouse gas emissions than petrol, diesel and gas-powered vehicles. However, at present, charging them via the Australian electricity grid relies largely on fossil-fuelled power, and the production of the EV itself is not without greenhouse gas emissions.

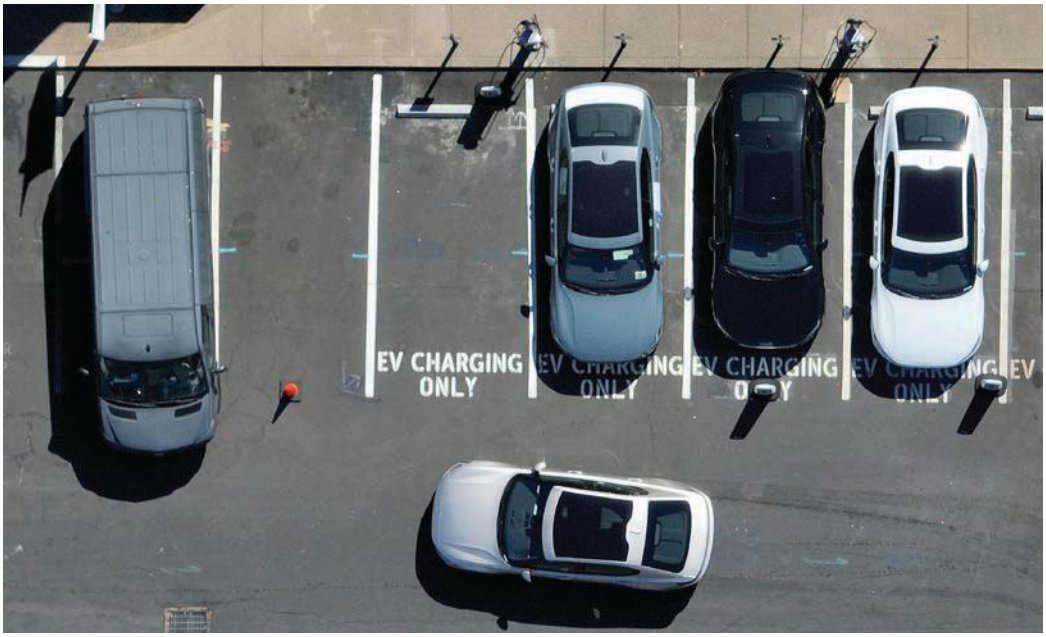


Figure 7.75 Current EV sales figures indicate that we will have difficulty meeting global emissions reduction targets unless their sale is incentivised, or conventional cars are phased out of production.

Explore! 7.10

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
- reforestation and forest preservation
- energy conservation
- public and active transportation
- carbon pricing.



Figure 7.76 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.

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Go online to access the interactive section review and more!

Section 6.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 7.4 questions

Remembering

1. **Identify** the correct word to complete the sentence: Earth is currently experiencing *an interglacial / a glacial* period.
2. **State** two human activities that have influenced the climate on Earth.
3. **Recall** how satellites measure sea levels.

Understanding

4. **Explain** the difference between climate and weather.
5. **Describe** two effects of climate change on coral reefs.
6. **Describe** atmospheric dispersion modelling.
7. **List** three actions a farmer could take to reduce greenhouse gas emissions on their property.

Applying

8. **Summarise** the impact that deep ocean currents have on the global climate.
9. **Name** three different global indicators of climate change and **state** what trends they have shown.
10. **Classify** the following energy sources as renewable or non-renewable: fossil fuels, hydroelectric, wind, nuclear, solar and geothermal.

Analysing

11. **Critique** the following statement: Models of climate change allow us to know with certainty what the climatic conditions will be like in the future.
12. **Classify** the following as either an effect or a cause of climate change.
    a) Melting polar ice
    b) Reduced ocean currents
    c) Increased use of fertilisers
    d) Reduced biodiversity

Evaluating

13. **Discuss** the impact of global warming on sea levels.
14. **Discuss** some reasons why people might not believe that climate change is occurring.



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Chapter review

Chapter checklist

Success criteria		Linked question
7.1	I can distinguish between Earth's chemical spheres: atmosphere, biosphere, geosphere and hydrosphere.	2, 20
7.1	I can list the five layers of the atmosphere.	1
7.1	I can describe the effect of natural events such as earthquakes, volcanos and cyclones on the chemical spheres.	9
7.2	I can recall the seven processes of the carbon cycle.	17
7.2	I can identify the impact of combustion reactions as a result of human activity on the carbon cycle.	24
7.2	I can describe the role of cultural burning practices in facilitating energy and nutrient transfers.	10
7.3	I can recall four different greenhouse gases.	3, 6, 15, 19, 25
7.3	I can compare the natural greenhouse effect and the enhanced greenhouse effect.	4, 11, 12, 14
7.3	I can describe how Aboriginal and Torres Strait Islander Peoples are reducing Australia's greenhouse gas emissions through the reinstatement of traditional fire management regimes.	21
7.3	I can identify how carbon dioxide is captured and stored naturally or through the use of technologies.	18, 27
7.4	I can recall the difference between weather and climate.	5
7.4	I can identify the changes in global climate over time, and provide evidence of these changes.	13, 22
7.4	I can explain the role that deep ocean currents have on global climate.	7
7.4	I can outline the human influences on climate change.	16, 23, 26
7.4	I can describe how we can collect data and predict changes to the Earth system.	8
7.4	I can identify strategies used to reduce climate change or mitigate its impacts.	25, 28

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Remembering

1. **List** the five layers of the atmosphere.
2. **Recall** the four spheres that make up the Earth system.
3. **Recall** the name and formula of the form of elemental nitrogen in the atmosphere.

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4. 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.
5. **State** one reason why different areas on Earth have different climates, **defining** weather and climate in your answer.
6. **Identify** the most abundant greenhouse gas.
7. **Recall** how deep oceans currents affect ocean temperatures globally.
8. **State** three applications of computer modelling for detecting and responding to Earth's changing climate.

Understanding

9. **Describe** the effects of cyclones on each of Earth's chemical spheres.
10. **Describe** how cultural burning practices facilitate energy and nutrient transfer in ecosystems.
11. **Outline** the journey of UV solar radiation emitted from the Sun.
12. **Describe** how greenhouse gases contribute to the natural and enhanced greenhouse effects.
13. **Describe** the effects that melting sea ice (because of climate change) is having on the planet.

Applying

14. **Contrast** the ozone layer and greenhouse gases by copying and completing the following table.

	Ozone layer	Greenhouse gases
Composition		
Most important effect		
Location		

15. **Construct** a worded equation to show how the process of respiration leads to an increase in atmospheric carbon dioxide.
16. **Construct** a graph to show how carbon dioxide concentrations in the atmosphere have changed over the last two decades.
17. **Illustrate** a diagram of the carbon cycle.
18. **Outline** three ways carbon dioxide can be stored using technology.

Analysing

19. **Compare** the effectiveness of methane and carbon dioxide at trapping heat.
20. **Analyse** the sphere interactions taking place in Figure 7.77.
21. **Outline** the beneficial impact of reintroducing traditional cultural burning regimes.
22. **Examine** the reasons why low-lying areas are at most risk from climate change.



Figure 7.77 Possible sphere interactions at the Twelve Apostles

Evaluating

23. **Discuss** the human effects on the enhanced greenhouse effect and climate change.
24. **Contrast** the advantages and disadvantages of using fossil fuels as a fuel source.
25. Using the summary table of greenhouse gases (see Table 7.5), **justify** why humans should focus on reducing nitrous oxide emissions as well as those from carbon dioxide.

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26. There is debate regarding 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.
27. **Evaluate** the role of forests in carbon sequestration.
28. **Discuss** which climate-mitigation strategy (listed in Explore! 7.10) would be the most successful in your home town. Give reasons for your answer.

Data questions

The Keeling curve in Figure 7.78 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'.

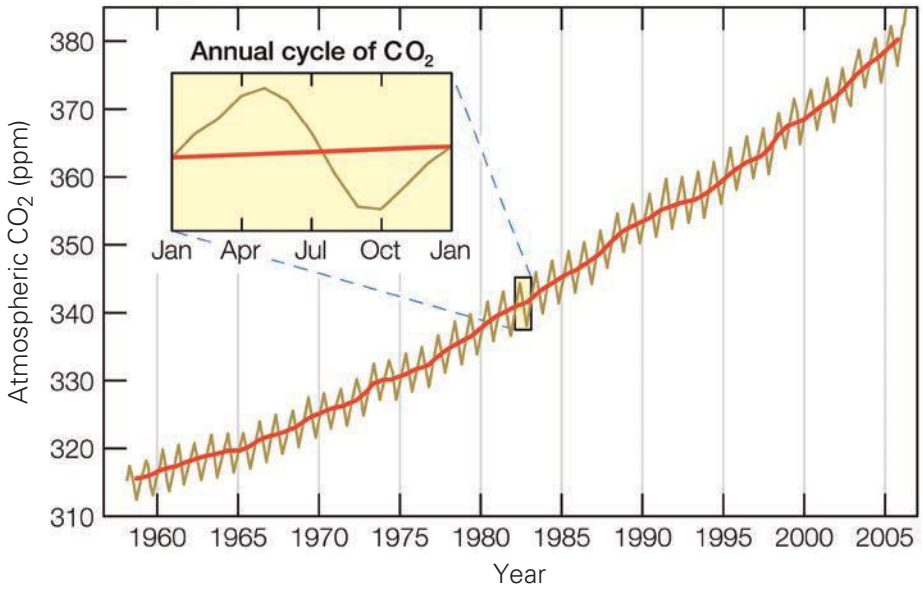


Figure 7.78 Keeling curve showing the atmospheric carbon dioxide concentration over time

Applying

1. **Identify** the year that 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.

Analysing

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.

Evaluating

7. **Deduce** whether the data in Figure 7.78 can be used to **justify** the statement, 'There is increasing atmospheric carbon dioxide'.
8. **Deduce** whether the data in Figure 7.78 can 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. Soon, aerial imagery was being used to gather information for military use and to monitor territories. Early military aerial photographers fixed small cameras to the chests of mail pigeons and flew them over enemy positions. These days, we use high-resolution satellite imagery and highly sophisticated drones.

Aerial imagery can be used to monitor the rate of deforestation, estimate the carbon storage capacity of ecosystems, survey habitats of vulnerable flora and fauna, assess natural disasters and plan for the development of sustainable cities.



Figure 7.79 Aerial photographs showing **(a)** farmland and **(b)** suburban houses.

DESIGN BRIEF

Use aerial imagery to track environmental change, and make environmental-impact predictions for a proposed development in your chosen area.

Activity instructions

You are an environmental researcher working for your local council along with a team of other professionals, including engineers, policymakers and designers. A proposal has been put to council to demolish several buildings in the area; however, these lie close to existing waterways. The Land Management Team has asked you to give a presentation outlining how the local landscape has changed over time, and how you think the proposed development will impact on local ecosystems. You will use existing aerial photographs (satellite imagery) and present them as a time-lapse video, to which you will add some visual predictions of the development's impacts.

Suggested materials

- Google Earth Pro (free to download for a desktop computer/laptop)
- Video-editing software, such as GIFMaker.org (recommended), iMovie or Movie Maker

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Research

1. **a)** 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.
   b) After viewing some satellite imagery of your chosen area, list the advantages and disadvantages of using satellite imagery to assess environmental change. Consider both the expertise (skills) needed to gather and decode these images, and the potential benefits to planning authorities in using them.
2. Identify some professionals you could engage with to gather knowledge for constructing your impact predictions. Discuss and reflect on the knowledge needed to make predictions about the possible environmental impact of a development.

Design and sustainability

3. Thinking about your chosen area, research and list all the environmental issues:
   a) currently being faced at the site
   b) predicted in the future.
4. As a group, discuss a future development that could be completed in the chosen area. Sketch and annotate the future development on an image of the site. List any environmental impacts the development might have.
5. Decide which technology and timescale you will use to create the time-lapse video. It should be long enough to show meaningful change, but short enough to be relevant to viewers.

Create

6. Locate at least 10 aerial photographs from Google Earth Pro to use in your time-lapse video. To do this:
   a) Download and install Google Earth Pro.
   b) Look for the 'Search' field, and enter the area you would like to focus on (e.g. San Remo, Victoria).
   c) Select View, then Historical Imagery. A time slider will appear at the top left of the map.
   d) Drag the time slider to the first image available (the oldest image). Select File > Save > Save Image. Edit the legend information using the 'Map Options' function.
   e) To save your first image, select Save Image > Save As.
   f) Repeat steps 4 and 5 to collect additional images. You want the newest available image (to contrast against the oldest image) and 8–10 more images to fill in the time lapse.
7. Export the images to your chosen video-editing software.
8. Edit your time-lapse video, ensuring your images are in the right order and the speed of transitions between slides is suitable. Include your future development diagram in the presentation to show the likely environmental impact of the development.
9. List five changes you have observed in the landscape of your chosen area. Outline the advantages and disadvantages of these changes for the local community.
10. Present the time-lapse video and your observations to the Land Management Team (the class).

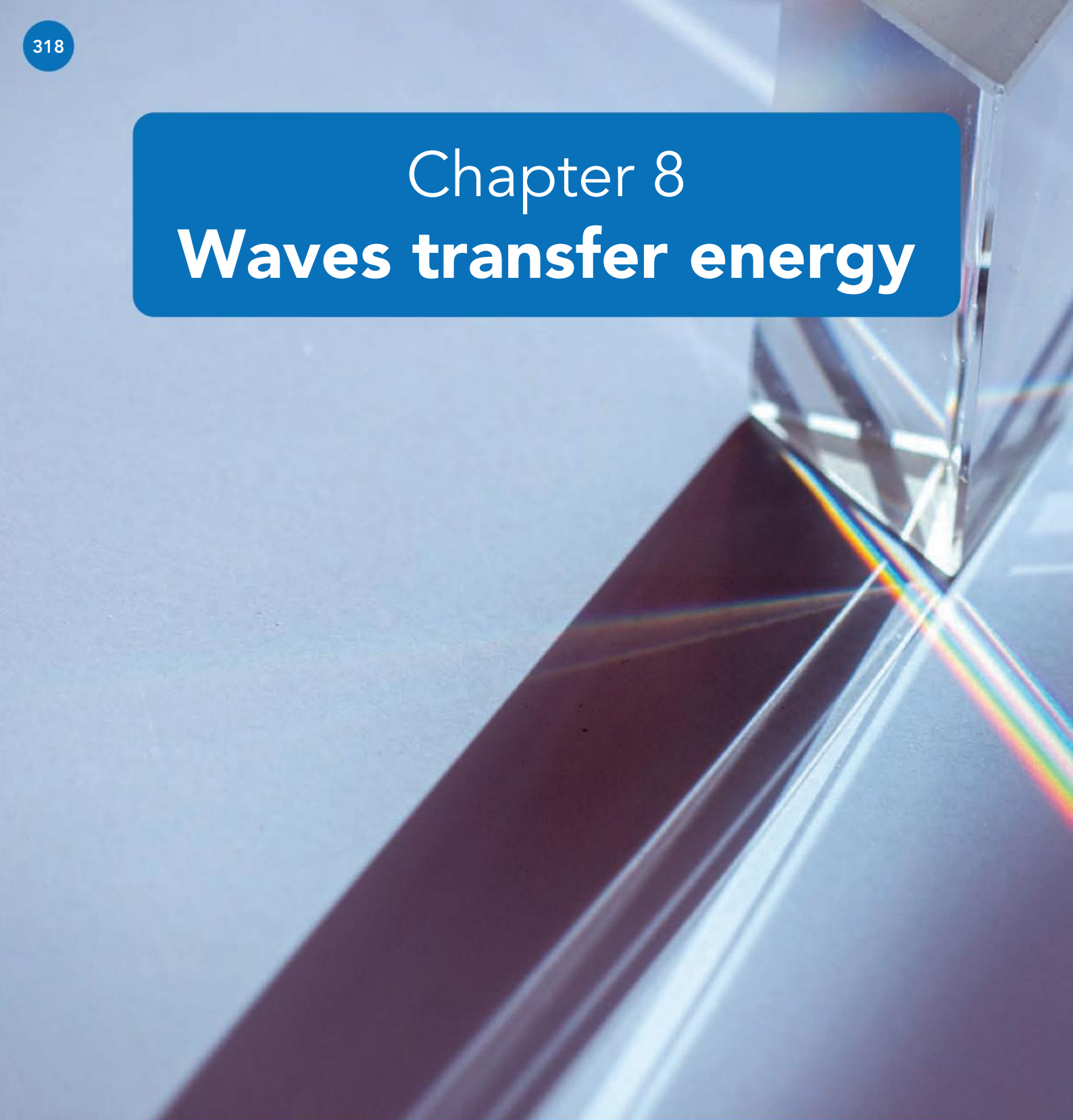
Evaluate and modify

11. Reflect on the challenges associated with anonymous aerial image gathering. What are the privacy implications of this technology? How can you address this?
12. Consider how aerial photography might be used to enhance environmental conservation in your local area.

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Chapter 8
Waves transfer energy

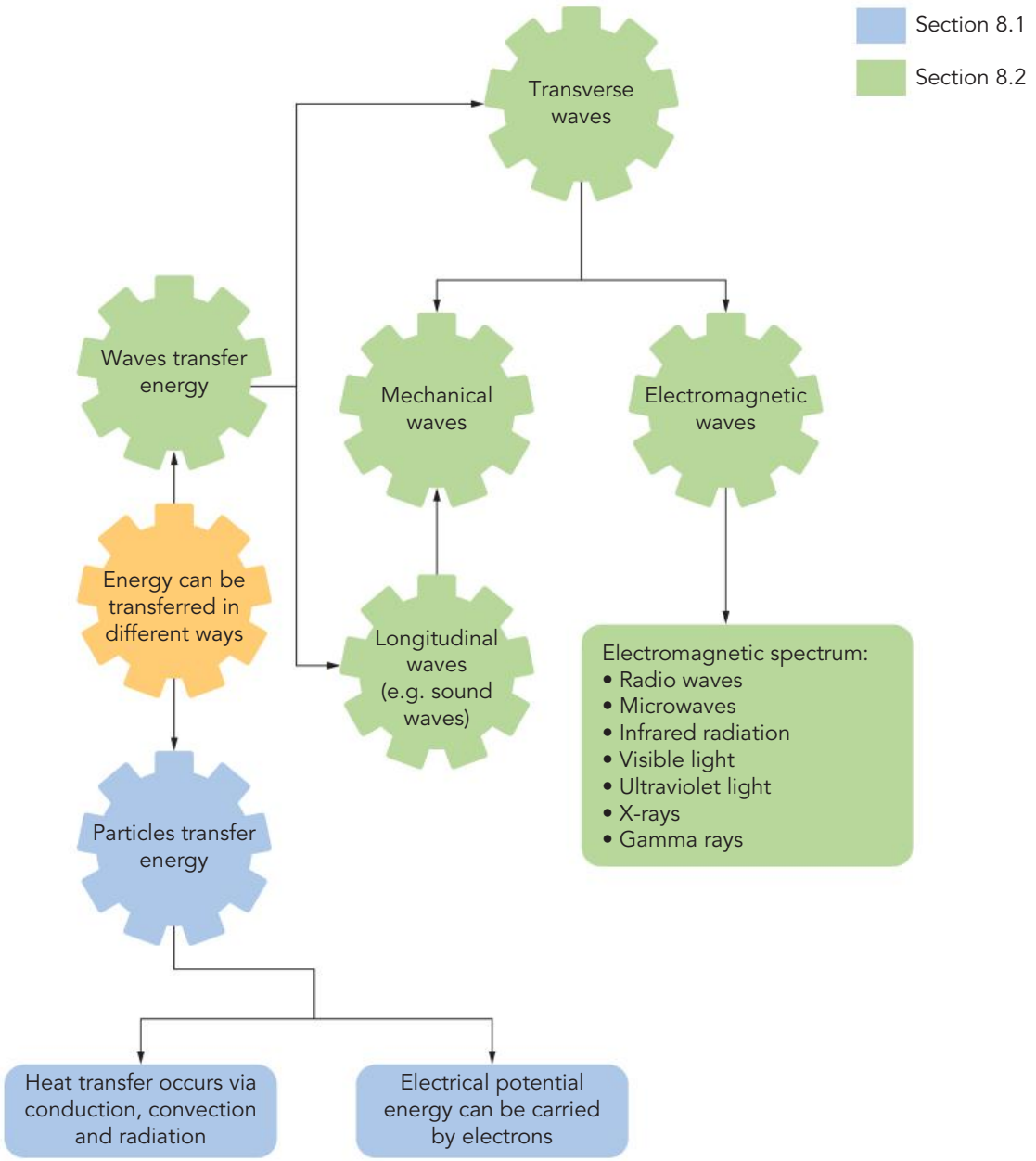


Chapter introduction

Energy can be transferred in useful ways in the form of light, sound, heat and electricity. The many everyday applications of these forms of energy include for work and leisure activities. Light is a wave. It is part of the electromagnetic spectrum, which extends from radio waves to gamma waves. Light can also sometimes behave like a particle, called a photon. Sound energy also travels in waves but requires a particle medium, while electrical energy is carried in the movement of electrons. In this chapter, you will bring together knowledge of wave and particle theories and apply them to the movement of light, sound, heat and electrical energy.

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Concept map



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Curriculum content

wave and particle models can be used to describe energy transfer (conduction, convection and radiation) through different media; waves (electromagnetic and mechanical) have different properties, features (including amplitude, wavelength, frequency and speed) and applications (VC2S10U14)	
• describing the processes underlying convection and conduction of heat in terms of the particle model	8.1
• modelling the transfer of sound energy as waves using slinky springs and relating to the medium through which the sound is transferred	8.1, 8.2
• investigating the relationship between the volume of a sound wave and the amplitude of the wave, or the relationship between the pitch or tone of a sound wave and its frequency	8.2
• examining how the particle model of electricity explains static electricity and electrical current and relating this to voltage, conductors and insulators	8.1
• making prisms of different shapes using gelatine (half concentration) poured into moulds and shining a torch through them to investigate how light is bent and dispersed	8.2
• discussing the wave and particle models of energy transfer, including the concept of photons, and how these models are useful for understanding aspects of light and other forms of electromagnetic radiation	8.2
• examining how properties of electromagnetic radiation relate to the uses of this radiation, such as in radar, medicine, sanitation, mobile phone communications, remote sensing and microwave cooking	8.2
• investigating the impact of material selection on the transfer of sound energy in Aboriginal and/or Torres Strait Islander Peoples' traditional musical, hunting and communication instruments	8.2

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Glossary terms

Amplitude	Gamma ray	Radio wave
Cochlea	Heat	Rarefaction
Compression	Hertz	Seismic wave
Conduction	Infrared radiation	Self-propagating
Conductor	Insulator	Temperature
Convection	Ionising radiation	Thermal energy
Crest	Kinetic energy	Transverse wave
Current	Longitudinal wave	Trough
Cycle	Mechanical wave	Ultraviolet light
Displacement	Medium	Vacuum
Electricity	Microwave	Visible light
Electromagnetic radiation	Oscillating	Voltage
Electromagnetic wave	Periodic motion	Wave
Electrostatic charge	Photon	Wavelength
Free electron	Pitch	X-ray
Frequency	Radiation	

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8.1 Particles transfer energy

Learning goals

At the end of this section, I will be able to:

1. Describe the difference between thermal energy and temperature.
2. Explain heat transfer by conduction, convection and radiation.
3. Explain how sound and electrical energy are transferred.
4. Distinguish between forms of energy transfer that require a medium to travel through and those that do not.



Particle model

The particle model of matter can explain the properties of solids, liquids and gases. According to the particle model:

- all matter is made up of particles
- particles are attracted to each other
- particles are always vibrating in place or moving around
- as temperature increases, particles move or vibrate faster.

Recall from Year 8 that the energy of moving particles of matter is called **kinetic energy**, and therefore all particles of matter have kinetic energy because they are always in constant motion. Objects at a higher temperature generally have faster-moving particles, and therefore a higher average kinetic energy.

kinetic energy the energy an object or particle has due to its motion

thermal energy the total kinetic energy of all particles in a system

heat thermal energy transferred from hotter objects or regions to colder objects or regions

temperature a measure of the average random kinetic energy of the particles in an object

The **thermal energy** of an object or a system relates to the *total* kinetic energy of its particles. The term **heat** is used in science to describe the specific thermal energy that is transferred between two objects. In contrast, thermal energy is something an object possesses whether or not there is a transfer of energy (see Figure 8.1).

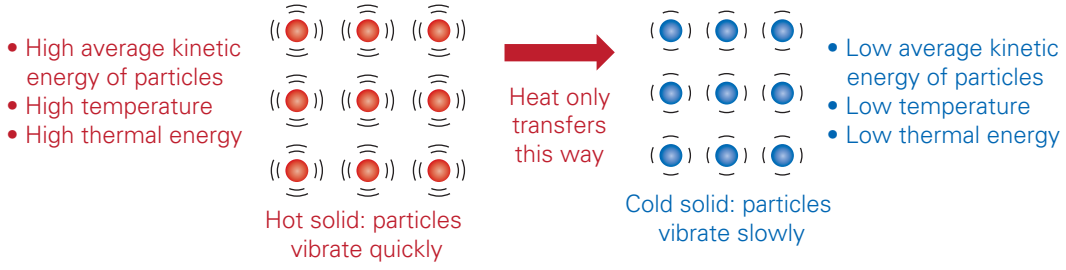


Figure 8.1 The particles in hot and cold solid objects of the same mass. The relationship between average kinetic energy of particles, thermal energy, heat and temperature is shown. This diagram also applies to liquids and gases; however, in those cases, the particles are not vibrating but rather moving around.

The **temperature** of an object is a measure of the *average* random kinetic energy of all its particles. It tells us what the level of thermal energy is, but not how much thermal energy or heat is present. You can imagine it like the level of water in a dam: that tells us how high it is, but it doesn't tell us how much water there is in total. Heat generally transfers from hotter objects to colder ones, so temperature can indicate whether heat transfer will take place, and in which direction.

Using the particle model, the thermal energy of an object can be explained as the total energy of all its particles due to their movement or vibration. Note that it is the kinetic energy of an object's particles, not the motion of the object itself, that relates to thermal energy.

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Quick check 8.1

1. **Explain** the relationship between the thermal energy and the kinetic energy of an object.
2. **Explain** what heat is in science.
3. **State** what temperature measures, in terms of particle theory.
4. **Determine** whether the particles in a cup of water at 30°C would, on average, move faster or slower than the particles in a cup of water at 45°C.



Figure 8.2 (a) A bath of warm water contains more thermal energy than **(b)** a cup of hot chocolate, even if the bath is at a lower temperature.

Thermal energy

To change an object's temperature, thermal energy needs to be added (to raise the temperature by heating) or removed (to lower it by cooling). The amount of thermal energy in an object depends on three factors:

- temperature – objects at higher temperatures have more thermal energy than identical objects at lower temperatures
- mass – heavier objects have more thermal energy than lighter ones of the same material and temperature
- material – some materials are better at storing thermal energy than others.

The total thermal energy depends on all three factors. For example, a warm bath at 35°C contains a lot more energy than a cup of hot chocolate at 75°C. The particles in the hot chocolate have greater average kinetic energy than the particles of water in the bath, and the higher temperature of the hot chocolate is a measure of that average kinetic energy. However, the mass of the bath water is much greater than the mass of hot chocolate in the cup. This means that there are many more particles of water in the bath than in the cup of hot chocolate. All those moving particles have greater total kinetic energy, even though their average kinetic energy is less. Therefore, the bath water has greater thermal energy than the hot chocolate.

Investigation 8.1

Investigating thermal energy

The specific heat capacity of a substance is the amount of energy that is required to raise the temperature of 1 kilogram (kg) of that substance by 1°C. For example, water has a specific heat capacity of 4200 J/kg/°C, meaning it takes 4200 J to raise the temperature of 1 kg of water by 1°C.

The amount of thermal energy stored or released in a system as the temperature is changed can be calculated using the following equation:

Be careful
Ensure general fire safety is followed.
Use appropriate personal protective equipment when handling hot equipment.

$$\text{change in thermal energy} = \text{mass} \times \text{specific heat capacity} \times \text{change in temperature}$$

$$\Delta Q = mc\Delta T$$

where:
ΔQ = change in thermal energy (J)
m = mass (kg)
Note: Δ means 'change in'.
c = specific heat capacity (J/kg/°C)
ΔT = change in temperature (°C)

continued ...

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Aim

To investigate the heating of different volumes of water when provided with the same amount of energy

Materials

- Bunsen burner
- heatproof mat
- tripod
- gauze
- matches
- 600 mL glass beakers × 4
- thermometer
- stopwatch

Method

1. Write a rationale about thermal energy.
2. Write a specific and relevant research question for your investigation.
3. Identify the independent, dependent and controlled variables.
4. Write a hypothesis for your investigation.
5. Write a risk assessment for your investigation.
6. Copy the results table below.
7. Put 200 mL of water in a beaker and measure the temperature. Record this in your results table.
8. Remove the thermometer and heat the water over the Bunsen burner for 2 minutes.
9. Stir the water and measure the final temperature after it has been heated. Record this in your results table.
10. Repeat steps 7–9 with 300 mL, 400 mL and 500 mL of water, using a new beaker each time. Make sure the initial temperature of the water is the same.

Results

Copy and complete the following table.

Table showing change in temperature and thermal energy for different volumes of water

Volume (mL)	Initial temperature (°C)	Final temperature (°C)	Change in temperature (°C)	Change in thermal energy (J)
200				
300				
400				
500				

1. Calculate the change in thermal energy (ΔQ) by using the equation given previously. Remember, 1 L of water weighs 1 kg, so 200 mL of water weighs 0.2 kg.
2. Plot a graph of volume against change in thermal energy.

Discussion: Analysis

1. Identify any trends or patterns in your results.
2. Predict what you think would happen if the following substances were used. You may need to conduct some research on specific heats of different substances. Explain the reasoning behind your predictions.
   a) Liquid mercury
   b) Sunflower oil
   c) Ethyl alcohol

Conclusion

1. Make a claim about the heating of different volumes of water with the same amount of energy.
2. Support your claim by referring to your experimental data, and include potential sources of error.
3. Explain how the data supports your claim.

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Try this 8.1

Testing water temperature

Take three large containers and fill one with room-temperature water, one with warm water (be careful that it is not too hot) and one with cold refrigerated water. Place one hand in the cold water and the other in the warm water for 2 minutes. Take your hands out and then place both of them in the room-temperature water. How does the water feel?

Something to think about:

1. Why did you leave your hands in the warm and cold water for 2 minutes?
2. Why did your hands detect different temperatures when you put them into the room-temperature water?

Quick check 8.2

1. **Define** 'thermal energy'.
2. **State** three factors that the total thermal energy of any object depends on.
3. **Explain** why a bath of warm water contains more thermal energy than a burning match.

Heat transfer

Heat transfer is the movement of thermal energy from an object at a higher temperature to an object at a lower temperature. Heat transfer is generally faster when there is a larger temperature difference between the two objects. As thermal energy is transferred to an object with a lower temperature, the particles within that object will begin to vibrate or move more quickly, which is indicated by an increase in the object's temperature.



Figure 8.3 Keeping warm around a camp fire is an example of a transfer of heat energy.

conduction the transfer of thermal energy through collisions between particles

convection the transfer of thermal energy due to the movement of particles in a liquid or gas

radiation the transfer of energy without the presence of particles

In Figure 8.3, three types of heat transfer are occurring simultaneously. As you roast your marshmallow over the flames, you notice that heat is travelling along the metal skewer, which is starting to feel warm in your hands – **conduction**. You might also notice that the air above the fire is hotter than beside the fire and will roast the marshmallows – **convection**. Finally, as you sit around the camp fire, you feel an intense warmth on your skin – **radiation**.

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Conduction

When energy is transferred between particles of matter by contact, the process is referred to as conduction. A particle, an object or a region with a higher temperature naturally transfers thermal energy to a particle, an object or a region with a lower temperature. When substances gain energy, their particles start to vibrate faster. If a faster vibrating particle bumps into a slower vibrating one, it transfers some energy to it (see Figure 8.4). This causes the slower vibrating particle to vibrate faster, increasing its kinetic energy. This increases the kinetic energy in the material as a whole, and therefore its temperature.

VIDEO
Conduction

conductor
(heat) a substance or material that allows heat to pass through it easily

free electron
an electron that is not attached to an atom

insulator
(heat) a substance or material that does not allow heat to pass through it easily

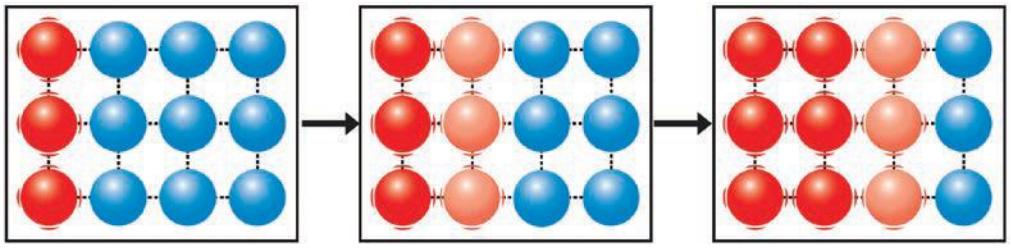


Figure 8.4 A time sequence showing heat flowing through the particles of a solid by conduction. The heat source (not shown) is on the left of the particles. At first, only the particles next to the heat source become hot and vibrate. They bump into particles next to them, which warm up, and so on.

Note that conduction does not only happen in the solid state. A solid surface with a high temperature transfers thermal energy to particles of a cooler gas or liquid that are in contact with it by conduction too.



Figure 8.5 Warming up your hands with a hot drink on a cold day is an example of heat transfer by conduction.

Conduction occurs when you warm up your hands when holding a hot drink. Your hands warm up because thermal energy is being transferred from the mug to your hand. How would holding the hot drink feel different if it was a polystyrene cup? Or a metal cup? Some substances, such as metals, are good **conductors** of heat. This is because the electrons in metals can leave their atoms and move around as **free electrons**. These free electrons move quickly, allowing vibrations (and the associated kinetic energy) to pass more quickly between particles in a metal. This means that thermal energy in metals spreads quickly from areas of higher temperature to areas of lower temperature (see Figure 8.6). Other materials, such as polystyrene, do not conduct heat well; these materials are called **insulators**.

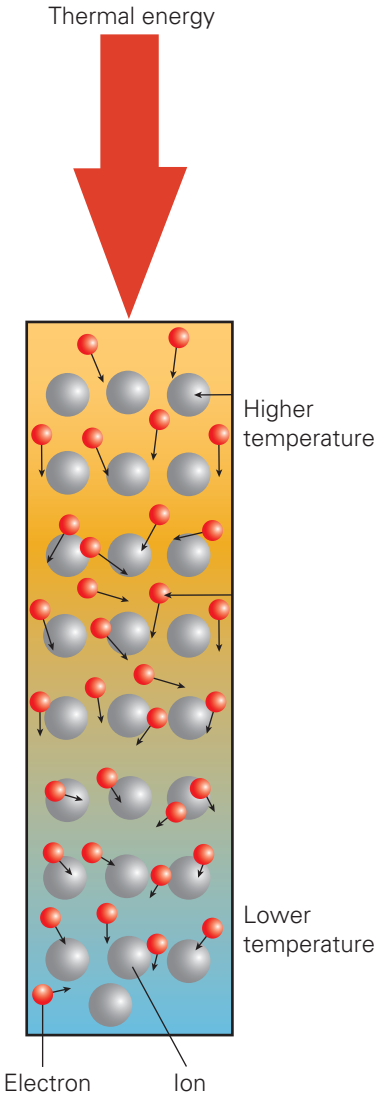


Figure 8.6 Free electrons can travel through metals and help thermal energy spread quickly from hot to cold areas.

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VIDEO
Convection

Convection

Convection is the flow of thermal energy through a liquid or a gas caused by movement of the liquid or gas itself. Heating water in a pot and warming up a room with a heater are both examples of heating by convection.

Have you ever heard the saying, 'Hot air rises'? In a building with two or more floors connected by an open stairwell, the top floor will be warmer if there are no doors to block the flow of air. When a liquid or a gas is heated, the particles vibrate faster and the space between them increases, causing the liquid or gas to expand. This means that the warmer regions become less dense than the colder regions, and so the colder regions sink and force the warmer regions to rise. Figure 8.7 shows water in a pot being heated from the bottom, causing the hot water to rise. Away from the heat source, at the top of the pan, the water cools again. The water becomes more dense and sinks back down to the bottom where it will be heated again. This cycle is called a convection current.

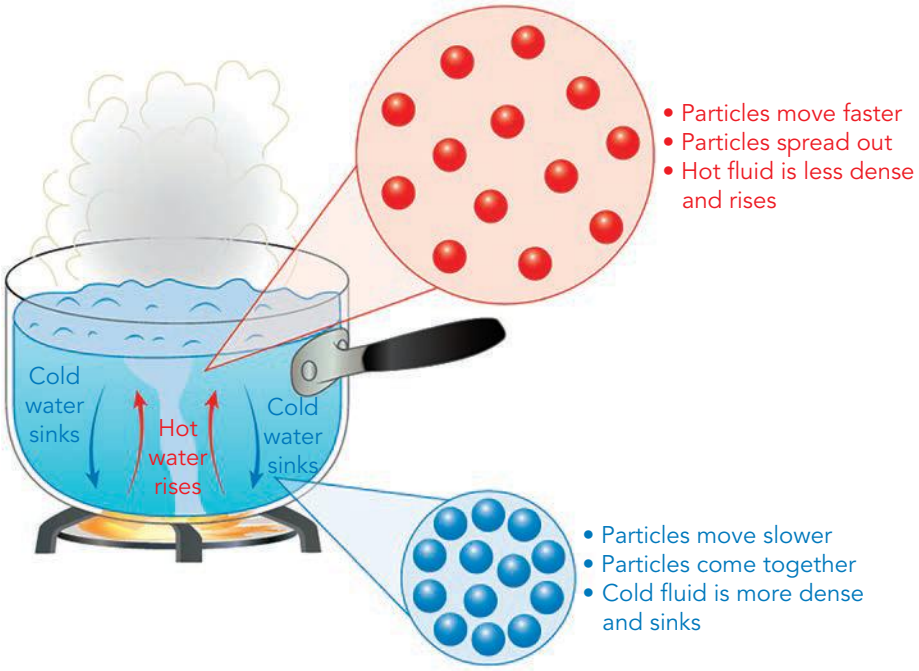


Figure 8.7 When water is heated, the hotter, less dense water at the bottom rises and the colder, more dense water sinks to take its place. Note that this drawing is not to scale. In reality, the particles are only slightly further apart.

Convection is a major factor driving weather patterns. The Sun heats Earth's surface, warming the air, which then rises, creating an upward current in the atmosphere. As the warmer air rises, cooler air from elsewhere flows in to replace it and we feel this air movement as wind. As the convection current continues, the air cools as it gets higher, potentially causing any water vapour within it to condense and form a cumulus cloud. Beneath Earth's crust, convection currents move layers of magma. In the oceans, convection creates currents.

VIDEO
Radiation

Radiation

Any object with thermal energy can radiate heat, which doesn't depend on particles to transfer the energy. This type of heat transfer occurs when you stand in direct sunlight or in front of a fire. Thermal radiation, or radiant heat, is a form of electromagnetic radiation (like light and radio waves) and travels in waves. This differs from convection and conduction, as it does not rely on particles and can travel through a vacuum.

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Figure 8.8 A pizza is baked using radiant heat in an oven

Explore! 8.1

How do animals stay warm?

Conduction, convection and radiation all play an essential role in nature. All warm-blooded animals can generate their own body heat, and they radiate heat energy. In contrast, cold-blooded animals do not generate their own body heat all the time, so they need to lie in the sunshine to get warm.

Conduct some research on how animals living in cold environments reduce heat loss from conduction, convection and radiation.



Figure 8.9 A cold-blooded eastern water dragon (*Intellagama lesueurii lesueurii*) sunbathing

Did you know? 8.1

Clothing technology

Australia has a large variety of climatic regions, and various First Nations Peoples have developed different technologies that enable them to live and thrive in even the most extreme climates. For warmth, traditional animal skin cloaks can be worn with the fur lining facing inwards, next to the body. This traps a layer of air and provides valuable insulation. However, during rainy seasons, the cloak is worn with the fur on the outside, because the hairs have water-repellent properties. Fat can be rubbed onto the outside of the fur to further increase insulation. These heat-conserving cloaks reduce thermal conduction, convection and radiation.



Figure 8.10 This artwork by William Barak (1824–1903), an influential First Nations Australian spokesperson, depicts the use of possum skin cloaks.

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Quick check 8.3

1. **State** the type of heat transfer that occurs when you burn your hand on a hot plate.
2. Use the particle model to **describe** thermal conduction in a solid.
3. **Describe** how thermal energy travels within a liquid or a gas.

Investigation 8.2

Modelling heat transfer

Be careful



Ensure general fire safety is followed.
Use appropriate personal protective equipment when handling hot equipment.

Aim

To design your own experiment that tests the effectiveness of different insulating materials

Materials

- soft drink cans
- hot water
- thermometer
- different materials such as wool, cotton, paper and bubble wrap
- stop watch

Method

1. Conduct some research into insulating materials. Find out some common materials and methods of insulation.
2. Identify the independent variable.
3. Identify the dependent variable.
4. Identify the controlled variables and describe how they will be managed.
5. Develop a hypothesis based on your research.
6. Design an experiment that measures the effectiveness of a range of insulating materials. In a group, discuss ways in which you could do this. Choose the best method and plan the experiments. You must include information on variables, a risk assessment and a step-by-step method for carrying out the experiment.

Results

Record your observations for each of the experiments in an appropriate manner.

Discussion: Analysis

1. Explain whether the results you gathered support your research on insulation.

Conclusion

1. Make a claim regarding your experimental findings about the effectiveness of different insulating materials.
2. Support your claim by referring to the data you gathered, and include potential sources of error.
3. Explain how the data supports your claim. Justify whether your hypothesis was supported or not supported.



VIDEO
Summary of heat transfer

Summary of heat transfer

The particle model can be used to explain conduction and convection, as they both involve the transfer of thermal energy through particles. Although radiation also involves the transfer of thermal energy, it does not require the presence of particles. Thermal radiation is an electromagnetic wave that can travel through empty space where there are relatively few particles. This is why we can feel the warmth of the Sun despite it being about 150 million kilometres (km) away. Therefore, radiation is explained by the wave model. Table 8.1 summarises the three types of heat transfer.

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Type of heat transfer	Description	Mechanism	Example
Conduction	Transfer of thermal energy by direct physical contact between particles	Atoms are always vibrating or moving, but when heat is applied to an object, the atoms closest to the heat source vibrate or move more, so their kinetic energy increases. They 'bump' neighbouring atoms, passing on this kinetic energy, thereby allowing heat energy to move through the object or substance.	Your hands warm up when holding a hot drink. This is because thermal energy is being transferred from the mug to your hand.
Convection	Transfer of thermal energy by molecular motion in a fluid (liquids and gases)	When a liquid or a gas is heated, the particles vibrate and move faster and the liquid or gas expands. This means that the colder regions are more dense than the warmer regions, and so the colder liquid or gas sinks to the bottom. As it is heated in turn, the material rises to the top, creating a convection current.	Heating water in a pot from the bottom causes the hot water to rise. The cold water sinks and replaces the hot water at the bottom, and is then also heated.
Radiation	Transfer of thermal energy through space which does not require particles in a medium	Radiant heat travels in waves because it is a form of electromagnetic radiation.	When making toast, the bread does not touch the source of heat. Rather, toasting relies on the transfer of thermal energy through space via radiation.

Table 8.1 A summary of the three different processes of heat transfer

Sound energy

Sound energy requires a medium to travel through and can be explained using the particle model of matter. However, when particles transfer sound energy, they move in a very different way compared to when they are transferring heat energy. While heat energy relies on the random movement or vibration of particles, the particles that transfer sound energy move in a repeated motion back and forth. The movement of each particle knocks the next one, creating waves that can carry sound energy over long distances. Sound can travel at about 343 metres per second (m/s) in air, but the speed of sound depends on both the temperature and the medium it travels through.



Figure 8.11 We can use our voice boxes to vibrate air particles. The sound waves we create can travel long distances.

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Sound travels faster through solids because the particles are closer together and the energy can be transferred from one particle to the next more quickly. Due to the distance between particles in a gas, sound travels slowest in air. The properties of sound waves will be considered in more detail in the next section.

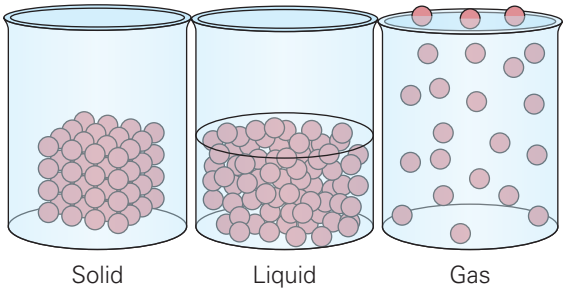


Figure 8.12 The particles in a solid are close together, so sound energy can be transferred quickly. In a gas, the particles are further apart, so sound energy moves more slowly.

Electrical energy

electricity
a form of energy that results from the accumulation or the flow of charge

electrostatic charge
a charge that stays on an object

insulator
(electricity) a substance or material that does not allow current to flow through it easily

Electrical energy can also be explained using the particle model of matter. Recall from Year 8 that **electricity** is a form of energy that results from either the accumulation of charge or the flow of electrons. The accumulation of charge is called **electrostatic charge** and can be seen in the example of lightning. In a storm cloud, collisions between ice crystals, rain and dust cause electrons to be transferred between them. This results in the top of the cloud becoming positively charged while the bottom becomes negatively charged. The huge accumulation of negative charge at the bottom of the cloud causes electrons on Earth's surface to be repelled, leading to a positively charged area beneath the cloud. Air acts as an **insulator** and prevents the electrons from flowing down to the ground, but as the electrostatic charge increases, it eventually overpowers the insulating effect of the air. A lightning strike occurs when the electrons from the cloud find a path to the ground and meet up with the positive charges on Earth.



Figure 8.13 Lightning is a stream of electrons finding a path to Earth.

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Try this 8.2

Electrostatic charge

Rub a plastic rod with a woollen cloth for 60 seconds. Hold the rod close to a thin stream of water and observe what happens. Can you explain what you observed?

Current electricity involves the movement of electrons, usually through a conductive material, over a period of time. Recall that metals are good conductors of heat because of their free electrons. Metals are also good **conductors** of electricity for the same reason. The free electrons can flow easily between atoms in the metal, which is why electrical wiring is usually made of metals such as copper.

How do we get electrical current to flow through a wire? The answer is the creation of a difference in electrical potential energy (known as **voltage**). Voltage pushes electrons in one direction around a circuit. Without voltage, the electrons would move randomly, and there would not be a useful electrical current. Voltage can be supplied by a chemical source such as a battery. The chemical reactions in the battery cause electrons to build up on one side of the battery (the negative terminal), creating a positive charge on the other side (the positive terminal). When a wire is used to connect the terminals, the excess electrons are pushed away from the negative terminal and are pulled towards the positive terminal, creating a flow of electrical current with direction. Free electrons in the metal wire carry electrical potential energy that can be transformed into useful forms of energy if devices are connected in the circuit.



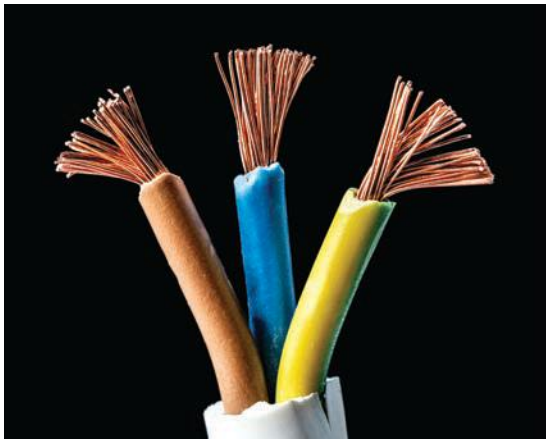


Figure 8.14 Metals are good conductors of electricity.



Figure 8.15 A battery has a positive and a negative terminal.

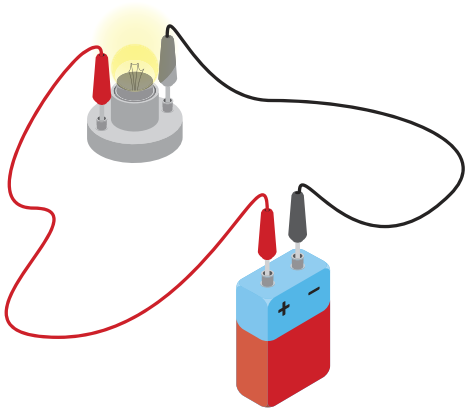


Figure 8.16 Electrons in metal wires will flow if connected to a battery. The voltage in the battery produces a current in the wire.

current
the flow of electric charge, which may continue in a steady manner for a period of time

conductor
(electricity) a substance or material that allows electrons to pass through it easily

voltage
the difference in electrical potential energy between two points in an electric circuit; measured in volts (V)

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Section 8.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 8.1 questions

Remembering

1. **Define** 'thermal energy'.
2. **State** the conditions required for conduction to occur.
3. **Recall** the three factors that determine how much thermal energy is present in an object.

Understanding

4. **Explain** how an object that has a higher temperature can have less thermal energy than an object that has a lower temperature.
5. **Explain** why energy is received from the Sun by radiation and not by convection or conduction.
6. Convection occurs in liquids and gases. **Explain** why convection does not (as a general rule) occur in solids.

Applying

7. An electric oven has a heating element underneath its bottom surface, and two wire racks (shelves): a top and a bottom. It does not have a fan to circulate the air inside. A recipe calls for the baking dish to be placed in the hottest part of the oven. **Explain** whether you should place it on the top rack or the bottom rack.



Analysing

8. **Classify** the following as heat transfer by either conduction, convection or radiation.
   a) Heat moving from the bottom of a cup of hot coffee to the top
   b) Heat from a stove plate transferring to a frying pan placed on it
   c) An ice cube melting in your hand
9. **Differentiate** between heat conductors and insulators in terms of their ability to transfer heat quickly.
10. Aria says insulation keeps out the cold. **Critique** this statement.

Evaluating

11. **Decide** at what point thermal energy transferring between two substances in contact will stop being transferred.
12. One litre (L) of gas in a cylinder is rapidly compressed by a piston until it occupies 0.1 L. As a result, the particles of gas have less space to move and they undergo many more collisions, which causes them to speed up. **Predict** what happens to the temperature of the gas.
13. The temperatures of two cups of water are measured. One is 20°C and the other is 30°C. Using your understanding of temperature and particles, **discuss** how the movement of the particles in these two cups of water will differ.

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8.2 Light and sound waves

Learning goals

At the end of this section, I will be able to:

1. Distinguish between mechanical and electromagnetic waves.
2. Identify different parts of a wave, including the wavelength, amplitude, trough and crest.
3. List the different types of electromagnetic radiation.
4. Label the compressions and rarefactions in longitudinal waves.

WORKSHEET
Waves

During a lightning storm, both light and sound energy are transferred by waves. When you see the lightning, your eyes detect light waves, and when you hear thunder, your ears detect sound waves. We see the lightning before we hear the thunder because light waves travel faster than sound waves.



Figure 8.17 Lightning and thunder are forms of light and sound energy that travel as waves.

Wave model

A **wave** is a carrier of energy that travels through space or matter without the movement of matter. Some waves require matter, known as the **medium**, to move through. These are called **mechanical waves**. Sound and water waves are examples of mechanical waves. Similar to conduction, these mechanical waves create a disturbance in the medium that transfers the energy without the matter moving as a whole.

Another kind of wave, called an **electromagnetic wave**, can travel through matter but can also travel without a medium, or through a **vacuum**. Visible light and radiant heat are examples of electromagnetic waves.

Mechanical waves transfer energy from the source of the wave (the origin of the disturbance in the medium). The disturbance results in the transfer of energy by the vibration, or **periodic motion**, of particles.

wave
a carrier of energy that travels through space or matter without the movement of matter as a whole

medium
the matter through which a mechanical wave travels

mechanical wave
a disturbance in a medium that transfers energy through that medium

electromagnetic wave
a wave with electric and magnetic components that can travel through matter or a vacuum

vacuum
a space completely devoid of matter

periodic motion
movement of a particle or an object that returns to its starting position and repeats in the same time interval, like a swing

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Mechanical waves require a medium, because there have to be particles for the energy to travel through matter. The medium can be in any state – solid, liquid or gas – as long as there are particles present. These particles do not move along the wave; they only transfer the energy of the disturbance to the particles next to them. For example, a fishing float will bob up and down in the water as a ripple passes, revealing the periodic motion of the water particles, but it returns to its original position – it does not travel with the wave (see Figure 8.18).



Figure 8.18 As a ripple passes through the medium (water), the fishing float is temporarily displaced, bobbing up and down before returning to its original position.

Depending on how the particles of the medium move relative to the direction of energy transfer, a mechanical wave can be classified as a transverse, longitudinal or surface wave.

DOC
WORKSHEET
Wavelength, frequency and amplitude

Quick check 8.4

1. **Define** 'mechanical wave'.
2. **Identify** the medium of a mechanical wave.
3. **List** three types of mechanical waves.

Transverse waves

transverse wave a wave in which the particles vibrate or move at right angles (perpendicular) to the direction of energy transfer

crest the maximum displacement of a particle at the top of the wave

trough the maximum displacement of a particle at the bottom of the wave

displacement the distance a particle has moved away from its rest position on the midline of the wave

A **transverse wave** is a wave in which the disturbance of the medium is at right angles to the direction of energy transfer (see Figure 8.19).

In mechanical transverse waves, the particles vibrate up and down, about their rest position, creating a series of **crests** and **troughs**. Crests and troughs represent the maximum **displacement** of a particle in the medium at the top and bottom of the wave, respectively.

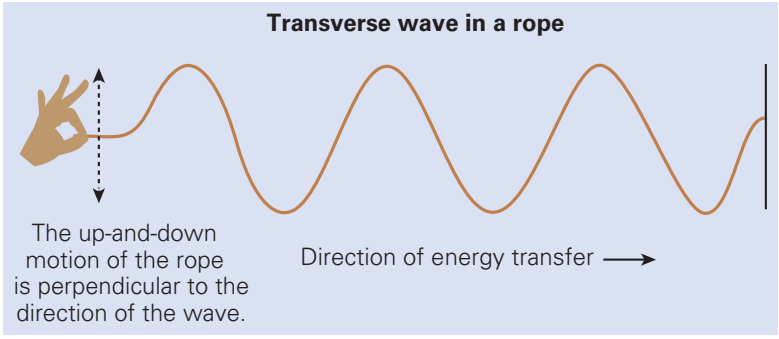


Figure 8.19 In a transverse wave, the particles move perpendicular (at right angles) to the direction of the energy transfer.

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The number of **cycles** of a wave per second is called the **frequency** and is measured in **hertz** (Hz). The distance measured in metres between two consecutive crests on a wave is called the **wavelength**. The **amplitude** of a wave is how far the wave displaces from its midline, the horizontal line that sits halfway between the crest and trough (see Figure 8.20).

Note that there are three measurements that describe the dimensions of a wave: frequency, wavelength and amplitude. The speed of a wave can be calculated by multiplying the wavelength by the frequency.

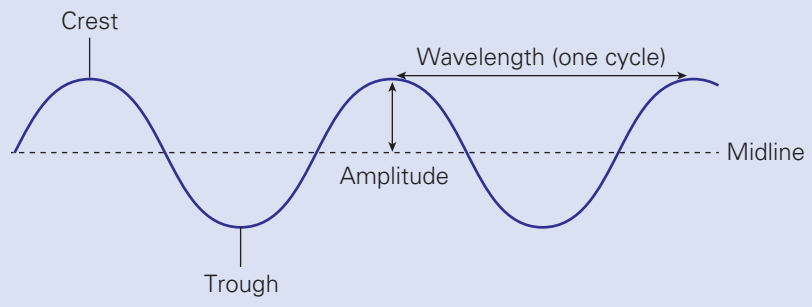


Figure 8.20 Describing a transverse wave

cycle
one complete vibration or periodic movement of a particle through the crest and trough of a wave and back to its starting position; the length of a cycle is the wavelength

frequency
the number of cycles of a wave per second; measured in hertz (Hz)

hertz
a unit for measuring the number of cycles that happen every second (frequency); abbreviation Hz

wavelength
the distance from one wave crest to the next; measured in metres (m)

amplitude
the distance (height) of a wave crest or the depth of a wave trough from the midline of the wave

seismic wave
a wave that travels through Earth and over its surface; caused by earthquakes

Try this 8.3

Looking at wavelength and amplitude

Copy the diagram in Figure 8.21, using a ruler to make the sides of the grid squares exactly 1 centimetre long. On your copy, label the wavelength and amplitude of the waves. Use a ruler to measure these features.

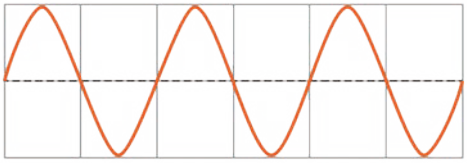


Figure 8.21 A depiction of a transverse wave

Quick check 8.5

1. **Explain** what 'transverse' means in relation to waves.
2. **Recall** the three measurements that describe waves.

Examples of transverse waves

The vibrating strings in musical instruments, deep ocean waves and secondary **seismic waves** are examples of transverse mechanical waves.



Figure 8.22 When the strings of a guitar are plucked, they vibrate up and down while waves travel along the string to its ends.

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Electromagnetic waves

oscillating moving back and forth with periodic motion, somewhat like vibration

electromagnetic radiation the transfer of energy by electromagnetic waves

self-propagating refers to a wave that (unlike mechanical waves) once started, keeps going at a constant speed forever without needing the input of more energy

photon an electromagnetic wave carrying a specific amount of energy related to its frequency or wavelength

Electromagnetic waves are another example of transverse waves. They consist of **oscillating** electric and magnetic fields, rather than disturbances in matter. **Electromagnetic radiation** is the transfer of energy by electromagnetic waves. The waves can transfer energy through a vacuum or through matter, such as when light from the Sun travels all the way to your skin through space, Earth's atmosphere and a glass window.

An electromagnetic wave can be emitted from an atom when an electron jumps from one energy level to a lower one. This creates a changing electric field, which also creates a changing magnetic field. The two vibrating fields combine to create a **self-propagating** electromagnetic wave. An electromagnetic wave carries energy in specific quantities (related to the frequency or wavelength). These packets of energy are called **photons** (of light).

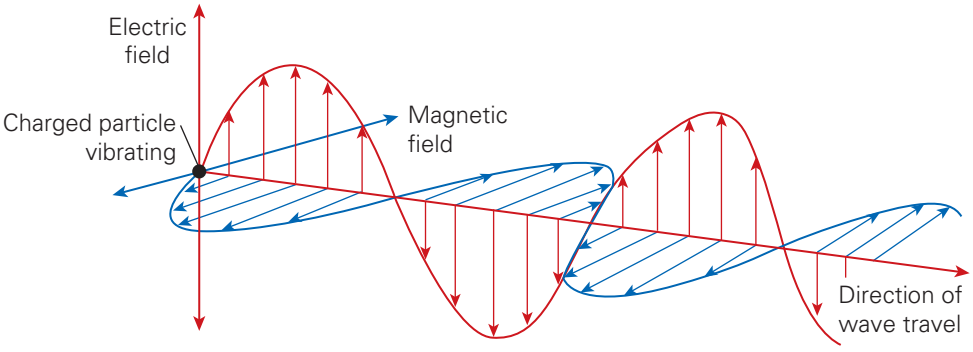


Figure 8.23 A vibrating charged particle generates vibrating electric and magnetic fields. These fields are perpendicular to each other and to the direction of the wave.

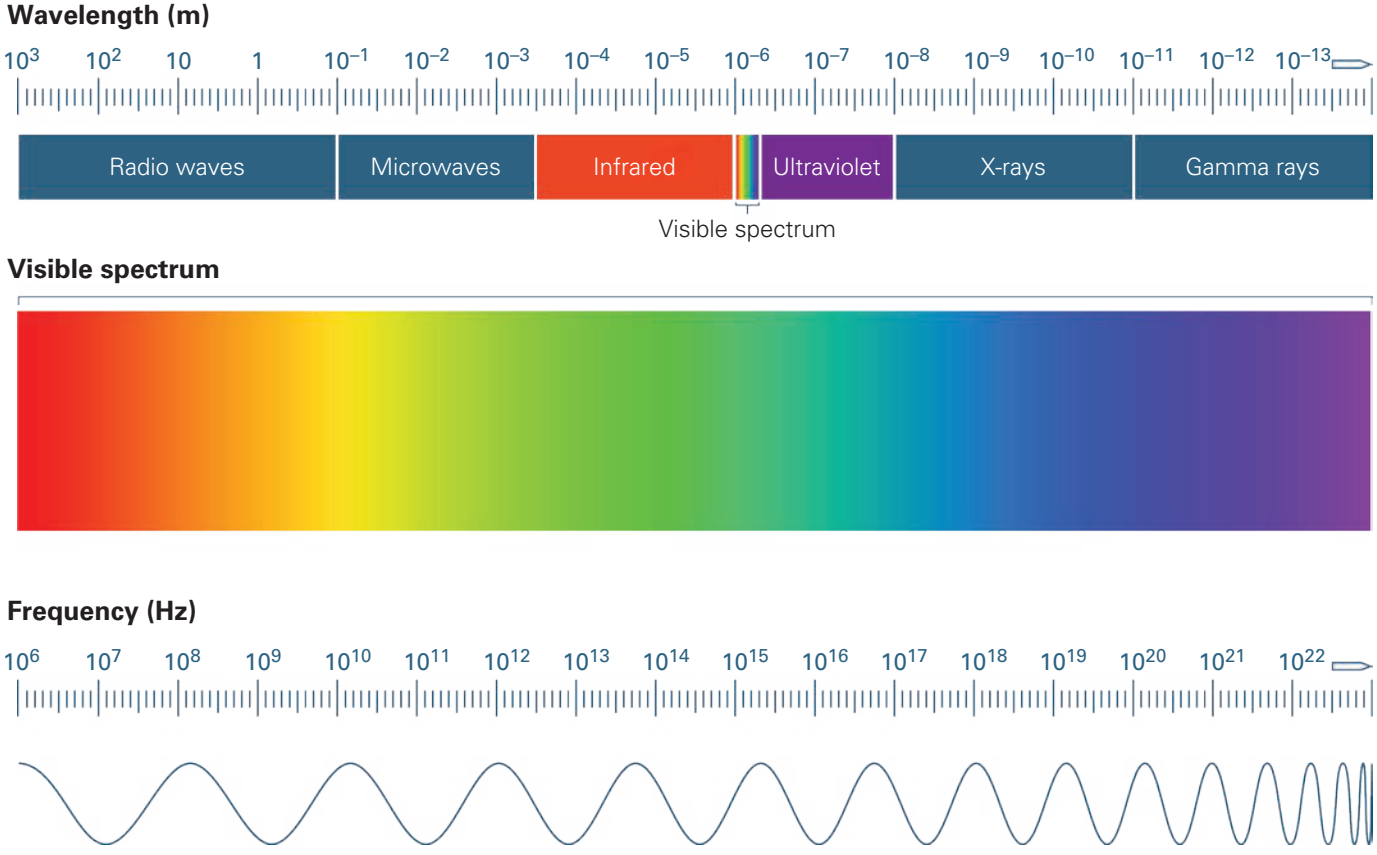


Figure 8.24 The electromagnetic spectrum extends beyond the visible spectrum (visible light).

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The directions that the electric and magnetic field oscillate in are perpendicular to the direction of the wave, so an electromagnetic wave is a transverse wave.

Unlike mechanical waves, electromagnetic waves all travel at the same speed through a vacuum – the speed of light, $c = 3 \times 10^8$ metres per second (m/s). The higher the frequency and the shorter the wavelength of an electromagnetic wave, the greater the energy carried by each photon. The relationship between frequency (f) and wavelength (λ) is described by the wave equation:

$$\lambda\,(\text{m}) = \frac{c\,(\text{m/s})}{f\,(\text{Hz})}$$

The different types of electromagnetic waves, from lowest to highest energy, and their uses are listed below and illustrated in Figure 8.24.

- **Radio waves** are useful for communications and signals over long distances (including for radar). Radio waves were originally used for communication with ships at sea, then broadcasts by radio and television stations. They are now also used to send communications around the world via satellites. Radio waves have very long wavelengths (some are several kilometres long), but their energy and frequency are very low.
- **Microwaves** are used for cooking, Wi-Fi communications and mobile phone technology. In a microwave oven, any water molecules present in food will vibrate at the same frequency as the microwaves and convert this energy into heat, cooking the food quickly. Much longer microwaves are used in mobile phone networks. When a mobile phone is switched on, it produces microwave signals (that you might know as 3G, 4G or 5G) that are picked up by receivers in mobile phone towers. The towers then transmit signals back to the phone for incoming calls, to connect to the internet and to download files, images and video.
- **Infrared radiation** is the radiation you feel immediately when you stand near a fire or when you feel warmed by the Sun. It is also used in TV remote controls. Objects at a higher temperature release more infrared radiation than similar objects at a lower temperature. Infrared cameras can be used to detect infrared waves being emitted by an object. The signals are then processed to produce a false-colour image showing the relative temperatures of different parts of the object. Similarly, higher-frequency infrared waves can be detected by night-vision technologies to produce false green coloured images.
- **Visible light** is the section of the electromagnetic spectrum that is visible to the human eye.
- **Ultraviolet light** is invisible radiation that can cause sunburn and skin cancer. Not all ultraviolet is bad though: skin cells use low-frequency ultraviolet light to make vitamin D.
- **X-rays** are high-energy electromagnetic waves. They can be used to create images of bones. X-rays pass through soft tissue, such as fat and muscle, but are absorbed by bone. This results in bones appearing white, soft tissue appearing grey and air appearing black in X-ray images. The development of imaging technologies has contributed greatly to our understanding of the functions and interactions of body systems. X-rays can cause cancer, although the radiation dose from medical scans is small.
- **Gamma rays** are high-energy, high-frequency waves with a short wavelength. They are released when atomic nuclei decay. Although they can cause cancer, they can also be used in its treatment. Gamma rays are also used to sanitise medical equipment or food products by killing any microorganisms that might be present.

radio wave
a type of electromagnetic radiation; it has the longest wavelength

microwave
the type of electromagnetic radiation used for cooking, communications and Wi-Fi; it lies between radio waves and infrared radiation

infrared radiation
the type of electromagnetic radiation that lies between microwaves and visible light; also known as heat radiation

visible light
the part of the electromagnetic spectrum that we can see

ultraviolet light
the type of electromagnetic radiation that lies between visible light and X-rays; it is needed by our bodies to make vitamin D; short-wavelength ultraviolet light can cause sunburn and cancer

X-ray
a type of electromagnetic radiation; it has short wavelengths and can pass through flesh to give images of bones; it is hazardous and can cause cancer

gamma ray
a type of electromagnetic radiation; it has high energy and a very short wavelength; it is produced when certain radioactive atoms decay

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ionising radiation higher-frequency ultraviolet rays, X-rays and gamma rays that can turn atoms and molecules into ions, and that can potentially damage living cells

The higher the frequency and the shorter the wavelength of an electromagnetic wave, the more energy its photons carry. Higher-frequency ultraviolet rays, X-rays and gamma rays have enough energy to knock electrons off atoms to form ions. This is referred to as **ionising radiation**, and it damages living cells.

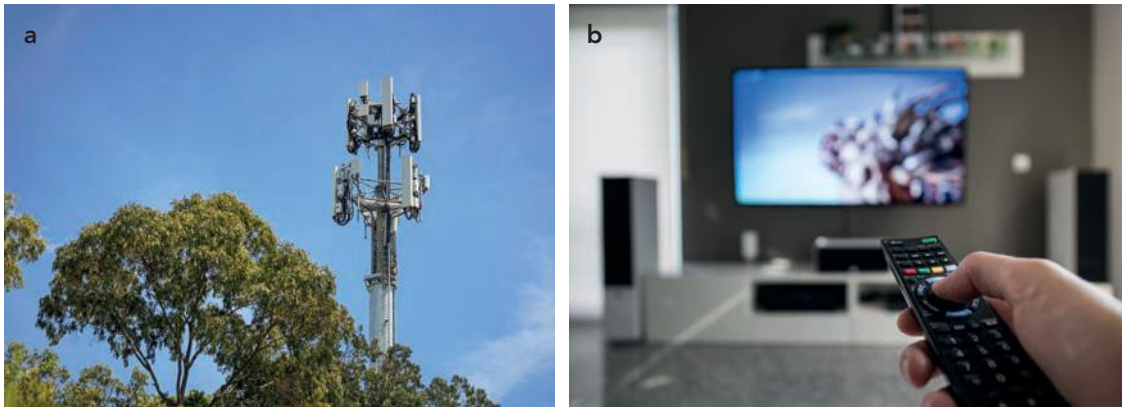


Figure 8.25 (a) Communication towers send and receive microwaves to mobile phones. **(b)** TV remote controls use infrared radiation to transmit signals to a TV. The remote must be pointed at the TV to work, because obstructions will block the infrared radiation from reaching the TV.

Try this 8.4

Bending light

Prepare a sachet of gelatine according to the packet instructions, except add only half of the indicated volume of water. Pour the gelatine into a square container or mould, ensuring that the container is small enough to make a thick gelatine shape. Leave it in the fridge to set overnight.

Carefully remove the gelatine from the container. If any edges get damaged, trim them with a straight-edge (non-serrated) knife so the faces of the block are smooth. Use a lightbox or a laser pointer to shine a beam of light through the gelatine. Record your observations about how the light is bent when it travels through the gelatine.

Repeat the experiment with different shapes of gelatine.

Explore! 8.2

X-rays and tissues

We are all exposed to small amounts of ionising radiation in daily life. This is commonly referred to as background radiation. Its effect on the body is negligible because the exposure is so low. Under controlled conditions, the use of X-rays on living tissue is safe. In fact, the radiation dose from an X-ray is not much greater than that of background radiation. For example, a chest X-ray is equivalent to 2.4 days of exposure to natural background radiation, while a CT (computed tomography) scan, which also uses X-rays, of the abdomen is equivalent to 2.7 years of natural background radiation. X-ray imaging has different effects on different tissues.

Conduct some research to find out the different X-ray procedures and their associated natural background radiation equivalents and discuss why they have different values.



Figure 8.26 X-rays are used as a diagnostic tool in medicine.

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Making thinking visible 8.1

See, think, wonder: The night sky

- *See*: Observe the night sky as seen from a town in Victoria in Figure 8.27.
- *Think*: Where does the light in the night sky come from? How long does it take for the light to reach your eyes from distant space?
- *Wonder*: What could the light from the night sky tell scientists about the age of the universe? What questions do you have after thinking about the lights in the night sky?



Figure 8.27 The night sky in Gunbower, Victoria

The *See*, *think*, *wonder* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Explore! 8.3

Wi-Fi

Did you know that an Australian invented Wi-Fi? This physicist and engineer was actually studying radio waves emitted from black holes and built a machine to detect these weak signals. This machine allowed computers to communicate wirelessly.

Conduct some research to answer the following questions.

1. Who is credited with inventing Wi-Fi?
2. When was Wi-Fi patented?
3. How does Wi-Fi work and what type of waves does it use?
4. What are some applications of Wi-Fi?

Science as a human endeavour 8.1

The bionic eye

The Monash Vision Group at Monash University in Melbourne has been developing their Gennaris bionic vision system, also called the 'bionic eye'. Functioning eyes detect visible light waves, and then nerve impulses are sent to the brain to construct an image. For many people who are blind, their optic nerves do not work and so nerve impulses are not sent to the brain when the eyes detect visible light waves.

The bionic eye consists of wearable glasses and a headset. The glasses contain a camera that detects visible light waves. The headset contains a vision processing unit, which wirelessly interacts with an implanted tile in the user's head. The implanted tile then sends nerve impulses into the brain in the same way that a functioning optic nerve would. It is predicted that users will gain enough sensory information to be aware of their surroundings in both indoor and outdoor environments!

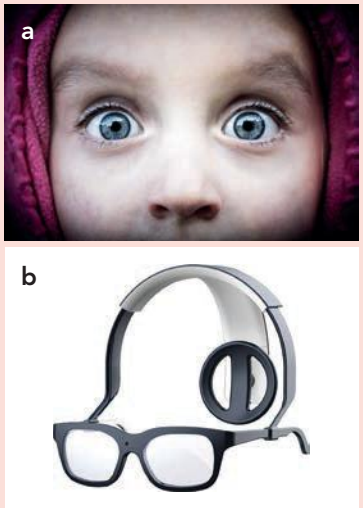


Figure 8.28 (a) Eyes detect light and send nerve impulses to the brain. **(b)** The Monash Vision Group's bionic eye.

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Did you know? 8.2

The 5G network

As wireless companies roll out their next-generation 5G networks around the world, people are both excited for the faster download speed and reduced delays and, in some cases, worried about possible impacts.

In Victoria, 4G networks work at frequencies between 700 megahertz and a few gigahertz. In contrast, 5G uses two bands: one below 6 gigahertz and another above 24 gigahertz. Waves above 1 gigahertz are classified as microwaves; waves below 1 gigahertz are classified as radio waves.

Some people fear that 5G may behave like ionising radiation, which has been linked to cancer. Any wave that has a higher frequency than violet light is ionising radiation. So, for 5G these fears are unfounded. The frequency of 5G is so low that it cannot ionise any atoms.

A more realistic concern, raised by meteorologists, is that 5G networks could disrupt weather forecasts from satellites because the frequencies used for 5G are extremely close to the frequency at which water molecules vibrate (23.8 gigahertz). Weather satellites use this frequency to track the water vapour in the atmosphere to give accurate weather forecasts. As the frequencies are so close, 5G networks may interfere with weather satellites, reducing the reliability of the models that predict dangerous storms. One implication of this is that early evacuation warning systems may be affected.



Figure 8.29 Meteorologists have raised concerns that the 5G network could interfere with weather satellites, which collect the data used to predict and monitor dangerous storms.

Transverse wave summary

Table 8.2 summarises information about transverse waves.

Type of wave	How energy is transferred	Is a medium required for propagation?	Examples
Mechanical wave	As vibrations in particles between adjacent particles in a medium	Yes	The strings in musical instruments, deep ocean waves, seismic waves
Electromagnetic wave	Carried as oscillating electric and magnetic fields	No	Radio waves, microwaves, infrared light, visible light, ultraviolet light, X-rays, gamma rays

Table 8.2 The two types of transverse waves

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Quick check 8.6

1. **State** which forms of radiation can be harmful to humans.
2. **State** two uses of radio waves.
3. **State** the wavelength range of microwaves.
4. **Compare** radio waves and microwaves.
5. **State** what property an object should have in order to emit a large amount of infrared radiation.

Longitudinal waves

A **longitudinal wave** is a wave in which the particles of the medium oscillate (i.e. vibrate) parallel to (in the same direction as) the energy transfer. The particles vibrate back and forth. As can be seen in Figure 8.30, longitudinal waves have areas where the particles (coils of a spring in this case) are close together and areas where they are spread apart. The places where the particles in a medium are closer together are called **compressions**, and the places where the particles in the medium are further apart from each other are called **rarefactions**. If a wave has more energy, then the particles in compressions are closer together and the particles in rarefactions are further from each other.

VIDEO
Light and sound waves

longitudinal wave a wave with vibrations that move in the direction of travel instead of transversely (e.g. sound waves)

compression the part of a longitudinal wave where the particles are squashed together

rarefaction the part of a longitudinal wave where the particles are spread out

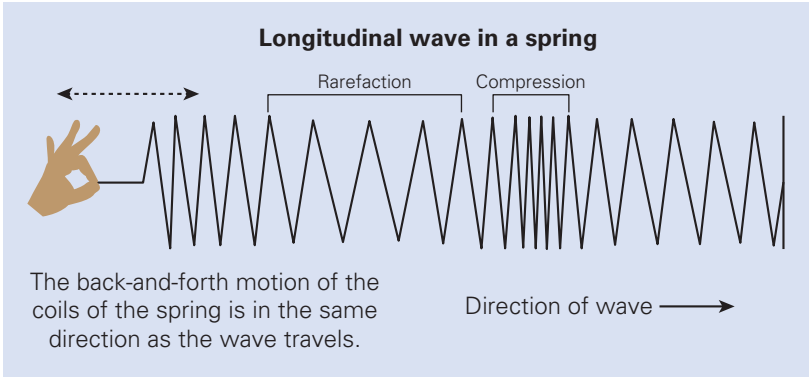


Figure 8.30 In a longitudinal wave, the particles move parallel to the direction of the wave.

Examples of longitudinal waves

Sound is a longitudinal wave because the air particles vibrate backwards and forwards in the same direction as the travelling sound wave. The motion of sound through the air is similar to when you move the end of a slinky forwards and backwards quickly to send a series of pulses through the spring (see Figure 8.31). When a sound wave passes through air, the movement of the particles is in a pattern that consists of regions of high pressure (compression) and regions of low pressure (rarefaction). Sound is a mechanical wave and therefore needs a medium to travel through, but the medium does not have to be air – it can also be a solid or a liquid. Sound travels faster through solids and liquids, where the particles are close together, than it does through air. It cannot travel at all through a vacuum (where there are no particles).

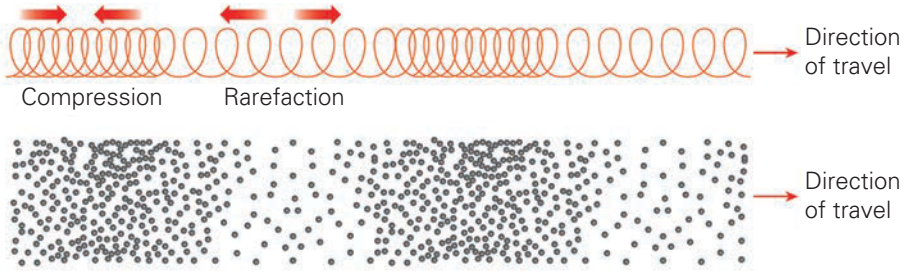


Figure 8.31 The longitudinal waves in a slinky can model longitudinal sound waves.

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Try this 8.5

Visualising sound

Stretch out a slinky along the floor until it is a couple of metres in length. Create vibrations in the slinky by moving the coils back and forth. Observe the areas of compression and rarefaction that move along the length of the slinky.

Explore! 8.4

Sound waves and the didjeridu

Aboriginal and Torres Strait Islander Peoples have developed various technologies and processes involving the transfer of sound. Some instruments are used for playing music; others are used for communicating or hunting. One well-known instrument is often called the didjeridu, a colonial term likely coined by British anthropologists in the early 20th century, based on how the instrument sounded to them. This term is not from an Aboriginal language. Across northern Australia, where the instrument originates, different First Nations communities have their own names and uses for it, grounded in cultural protocols, Law and ceremony.

Some of these names include:

- Yidaki, from Yolŋu Matha languages in Arnhem Land, Northern Territory
- Mago, from western Arnhem Land, Northern Territory
- Mandapul, used by some Yolŋu groups instead of Yidaki.

These names reflect diverse cultural contexts and meanings. The instrument's construction, use and sound are deeply tied to Country, ceremony and knowledge systems.



Figure 8.32 The didjeridu is traditionally made from a tree trunk or branch, most commonly eucalyptus, that has been naturally hollowed out by termites. In some regions, bamboo has also been used. The selection and preparation of the instrument require deep cultural knowledge, as the right piece must be carefully chosen, shaped and sometimes further refined to create the desired sound.

Conduct some research on the didjeridu to answer the following questions.

1. How old is the didjeridu thought to be?
2. Describe the materials used for the construction of a didjeridu.
3. How does the length and flare end of a didjeridu affect the sound it makes?
4. Outline how a didjeridu produces its unique sound, including all components that play a role.

Quick check 8.7

1. **Define** 'sound'.
2. **Define:**
   a) compression
   b) rarefaction.
3. **Explain** why sound travels faster in solids.
4. **Explain** how sound is an example of a longitudinal wave.

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Properties of sound waves

In the same way that we can describe the properties of the transverse waves of the electromagnetic spectrum, we can also describe the properties of the longitudinal waves of sound. First, let's review the terms 'wavelength', 'frequency' and 'amplitude'.

- Wavelength (unit = metre) is the distance between two compressions or rarefactions of a wave. The greater the distance between two points of maximum compression, the longer the wavelength.
- Frequency (unit = hertz) is the number of cycles (complete waves or vibrations) that pass a point each second. The more cycles or wavelengths that pass in a second, the higher the frequency.
- Amplitude (unit = metre) is the maximum displacement of particles from their undisturbed position. This is the displacement amplitude. In a sound wave, which has regions of high and low pressure, the pressure amplitude is the difference between the maximum pressure in a compression and atmospheric pressure.

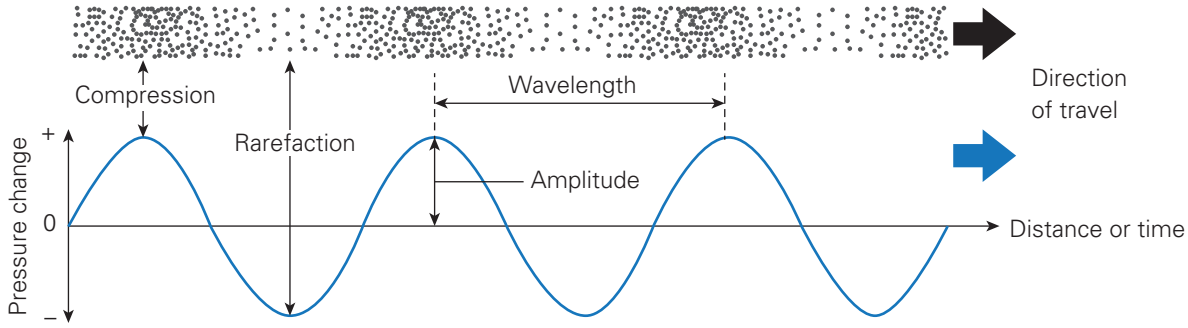


Figure 8.33 A sound wave represented as a graph of change in air pressure over distance or time. The air pressure change with no sound is 0, and + and – represent an increase or decrease in pressure. The diagram above the graph shows the space between the air particles and the regions of compression and rarefaction. Amplitude and wavelength now appear as they do for a transverse wave. Note that the graph is the same shape whether air pressure or the change in air pressure is plotted, and whether time or distance is on the horizontal axis.

The **pitch** of a sound is how high or low on a music scale (not sound volume) it seems to our ears. The pitch of a sound wave is determined by its wavelength and therefore its frequency. Decreasing the wavelength increases how many wavelengths pass each second (frequency), and this increases the pitch of the sound. Low-pitched sounds have a long wavelength, whereas high-pitched sounds have a short wavelength.

pitch
how high or low a sound seems to our ears on a music scale

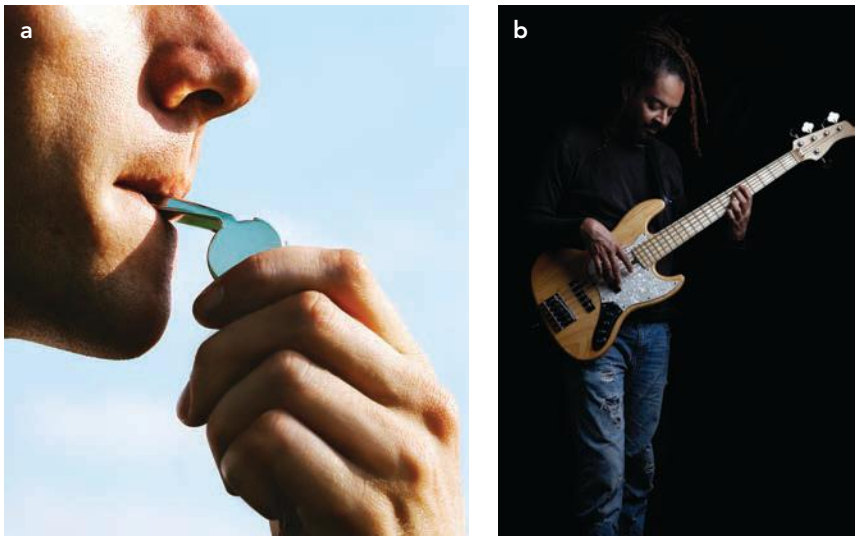


Figure 8.34 (a) A whistle produces a high-pitched sound. **(b)** A bass guitar produces a low-pitched sound.

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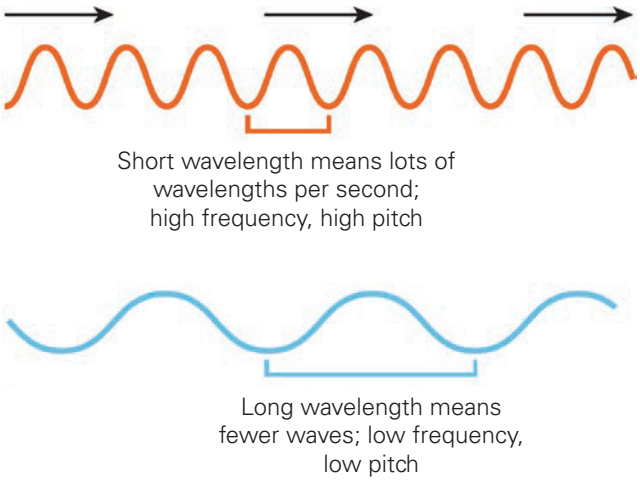


Figure 8.35 Which of the two waves do you think would be a whistle and which would be a bass guitar?

The energy of a wave depends on its amplitude as well as its frequency. You might notice that not all water waves look the same: some waves are bigger than others. Amplitude is the maximum height of a wave from its resting position. If you were able to see sound waves, you would notice that loud sounds have a higher amplitude than soft sounds. When a drum is hit harder with more energy, it sounds louder – the loudness of the sound is a measure of the amount of sound energy.

The unit of measurement for loudness of sound is the decibel (dB). The loudness of a normal conversation is usually about 60 dB. A rock concert is about 105 dB. Humans can hear sounds as low as 0 dB – this limit is called the threshold of hearing. Anything at around 85 dB can start to damage your hearing. Sounds louder than 120 dB can quickly cause irreversible damage.

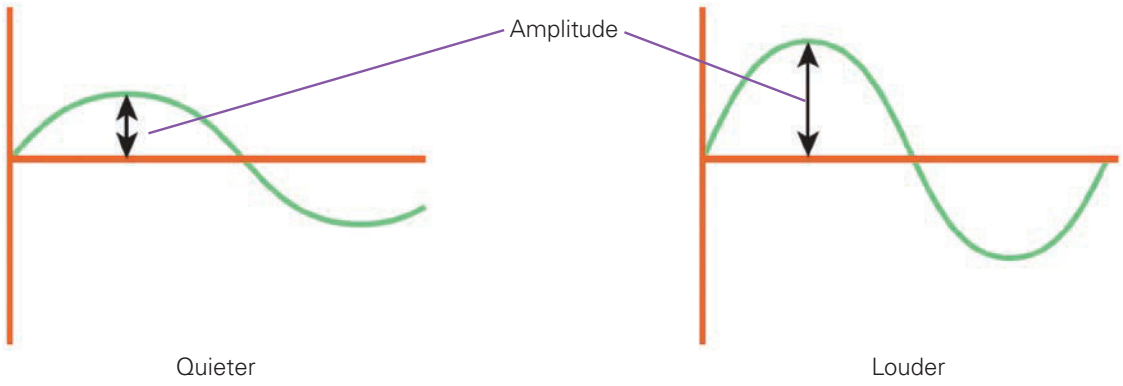


Figure 8.36 The amplitude of a sound wave indicates the loudness of the sound.



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Practical 8.1

Making sound

Aim

To hear and observe vibrations in the air

Materials

- tuning fork
- rubber stopper
- 100 mL beaker containing water

Method

1. Strike the tuning fork on a soft surface, such as the rubber stopper.
2. Place the tuning fork stem on the sounding board. Can you hear the sound clearly?
3. Repeat step 1 and lightly touch the vibrating ends of the tuning fork to the surface of the water.
4. Observe what happens to the water.

Results

Record your observations.

Discussion: Analysis

1. Explain what you heard when you held the tuning fork to the sounding board. How does it work? Note that pianos also have a sounding board to make the sound of their vibrating strings louder.
2. Describe what happened when you touched the ends of the tuning fork to the surface of the water. Explain why this happened.
3. Could you identify areas of compression and rarefaction in the water?

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising your observations.

Quick check 8.8

1. **Define** the following terms and include the units.
   a) Frequency
   b) Wavelength
   c) Amplitude
2. Consider the sound waves A–D, shown as pressure against time.

A.



B.



C.



D.



Identify which wave:

a) has the highest frequency
b) has the longest wavelength
c) would have the highest pitch
d) is the loudest.

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WIDGET
Lightning speeds

Explore! 8.5

Determining the distance to a lightning strike

During a storm, it usually takes a few seconds for the sound to travel from the lightning flash to your ears. This is because light travels about 1 000 000 times faster than sound, which travels at about 340 m/s.

Figure 8.37 shows the relationship between the distance to the flash of lightning and the time delay before hearing the sound. Do you see any pattern in the graph?

Look carefully and you will see that the line of the graph runs close to the points (3, 1000), (6, 2000) and (9, 3000).

This gives a simple rule for calculating the distance to a lightning strike: every 3 seconds is about 1000 metres (m) or 1 kilometre (km).

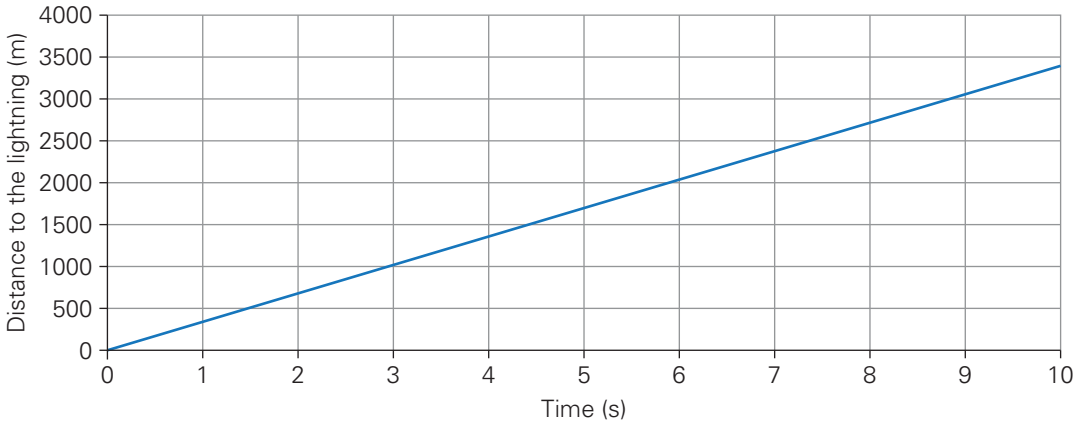


Figure 8.37 A graph of the time between seeing lightning and hearing thunder versus distance to the lightning

Explore! 8.6

Active noise cancellation

Earphone technology has now progressed to 'active' noise cancellation, in which a microphone on the earphone detects nearby sound waves and actively cancels them. This type of earphone technology can cancel sound waves up to about 75 dB, which provides users with a very immersive listening experience.

Conduct some research on how active noise cancellation works. Discuss the science with a partner.



Figure 8.38 New earphone technologies actively cancel background noise.

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Science as a human endeavour 8.2

The cochlear implant

Some people who experience mild hearing loss wear a hearing aid. Hearing aids make sounds louder so people with hearing loss can participate in everyday life more effectively. However, some people have severely impaired hearing and cannot hear any sounds at all. This kind of impairment can sometimes be solved with a cochlear implant, pioneered in Australia by Professor Graeme Clark.

Unlike a hearing aid, which is worn outside the ear, a cochlear implant is surgically placed inside the ear. It consists of a microphone worn outside the ear to detect sounds and a processor that can be worn in a pocket that converts the sound into electrical signals. These signals are sent to the implant in the **cochlea**, which stimulates the auditory nerve and allows the patient to hear.

cochlea
the part of the inner ear that produces nerve impulses in response to sound waves



Figure 8.39 A cochlear implant. A microphone outside the ear can be seen. The transmitter behind the ear sends electrical signals through to the implant in the cochlea.



Figure 8.40 A toddler wearing the cochlear implant

Did you know? 8.3

Protecting our hearing

Excessive noise can damage the delicate hearing cells in the inner ear. People who work with noisy machinery can be exposed to sounds above 85 dB, which can damage their hearing with prolonged exposure. If the delicate cells that detect sound in the inner ear are damaged, they cannot be replaced. This can cause hearing loss, or a disorder called tinnitus, in which a person hears a permanent ringing noise in their ears. To prevent this from occurring, people who are constantly exposed to loud sounds wear ear defenders to protect their hearing.

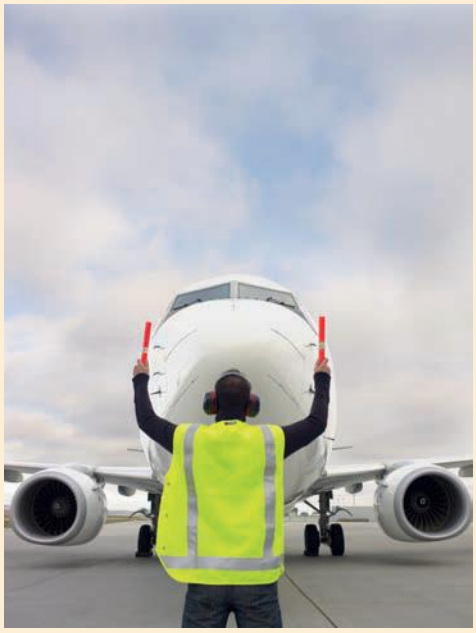


Figure 8.41 People who work with aircraft can be exposed to sounds above 140 dB, so they wear ear defenders.

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Try this 8.6

Sound insulation

Some students at a Victorian school were comparing the published sound insulation data of some materials found at school with data they obtained by experimenting in science class. Their results are as follows.

Material	Published sound insulation (dB)	Experimental sound insulation (dB)
Fibreglass	48	42
Textbook	35	28
Curtains	23	20
Brick wall	51	40
Wood desk	12	9

1. Construct a column graph to present this data.
2. Describe any trends in the data.
3. Explain a reason for any observed trends in the data obtained by the students in comparison to the published data.

Surface waves

Surface waves travel along the interface between two different surfaces. For example, water waves travel along the interface between water and air. Some surface waves are neither completely transverse nor completely longitudinal. For example, in a wave on the surface of a body of water, the individual particles move in a circle before returning to their original positions.

Making thinking visible 8.2

Connect, extend, challenge: The speed of light and sound waves

The speed of light and sound changes in different media, as shown in the table.

Medium	Approximate speed of wave (m/s)	
	Light wave	Sound wave
Vacuum	3×10^8	Cannot travel
Air	3×10^8	343
Water	2.25×10^8	1500
Glass	1.60×10^8	4500

1. What prior knowledge do you have that could help to describe the trends in the data?
2. Explain the trends in the table of data. Why is it that sound waves cannot travel in a vacuum?
3. Are there trends in the data that are difficult for you to explain? What are they?

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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Comparing the wave and particle models

In the previous section, you learned how energy can be transferred according to the particle model through conduction and convection. In this section, you have seen how energy can also be transferred in transverse or longitudinal waves. Table 8.3 compares the wave and particle models of energy transfer.

Feature	Wave model	Particle model
Carries/transfers energy	Yes Mechanical waves are carriers of energy through a medium, and electromagnetic waves can transfer energy as radiation.	Yes Particles can transfer energy through conduction and convection. They also play a role in mechanical waves.
Has a measurable speed	Yes The frequency, wavelength and speed are all related.	Yes The speed of a particle may relate to its thermal energy.
Has a frequency, wavelength and amplitude	Yes Frequency, wavelength and amplitude are properties of waves.	No Frequency, wavelength and amplitude are not properties of particles.
Carries matter from one place to another	No Electromagnetic fields do not need matter as they are oscillations in electric and magnetic fields. In mechanical waves, the particles vibrate or move with periodic motion, returning to their original position once the wave has passed.	Yes Particle collisions due to kinetic energy result in the movement of matter from one place to another.

Table 8.3 A comparison of energy transfer in waves and particles

Section 8.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 8.2 questions

Remembering

1. **State** the types of electromagnetic radiation that are beyond the visible spectrum.
2. **Identify** the wavelength range of radio waves.
3. **Recall** the terms for the high-pressure and low-pressure areas of a sound wave.

Understanding

4. **Explain** how microwaves heat up food.
5. **Explain** what is meant by the term 'longitudinal wave'.
6. **Explain** why sound cannot travel through the vacuum of space.
7. **Explain** why you see the flash of lightning before you hear the thunder.

Applying

8. **Identify** the correct words to complete the following sentences.
   a) Pitch is determined by the _____ of a sound wave.
   b) Loudness is determined by the _____ of a sound wave.

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9. The speed of light in air is 299 704 645 m/s. **Calculate** how long it would take for light to reach the following destinations from Melbourne. Hints: Convert the distances to metres, then divide each distance by the speed of light.
   a) Adelaide (726 km)
   b) Brisbane (1781 km)
   c) Canberra (662 km)
   d) Perth (3406 km)
10. You see a flash of lightning and 20 seconds later hear the thunder. Use Figure 8.37 to **calculate** how far away the storm is.

Analysing

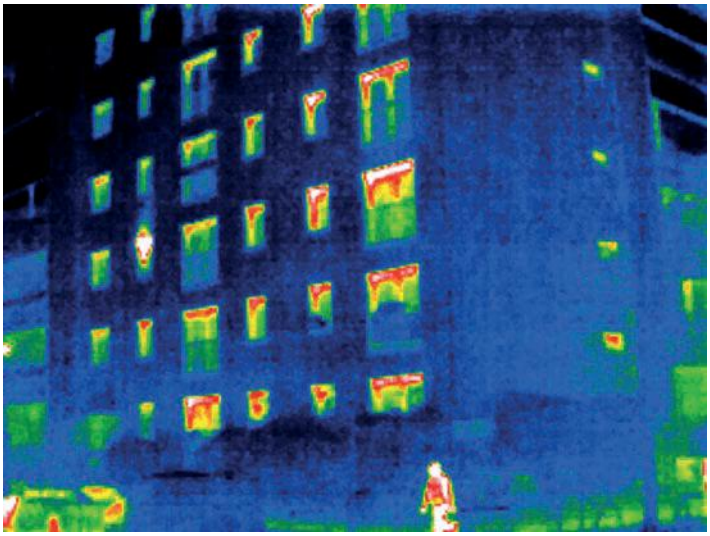
11. A wave has a frequency of 5 Hz and a wavelength of 3 m. **Interpret** what this means.
12. **Compare** microwaves and gamma rays.

Evaluating

13. Use the image below to **determine** why the loudness of a sound decreases as you move away from the source of the sound.



14. The thermal image below is of an apartment building at night. It has been produced using an infrared camera. **Deduce** what the different colours mean. HINT: Compare the colouring of the person walking in front of the building against the colouring of the concrete building.



15. **Decide** why it is important to find a balance between getting too much and too little ultraviolet radiation exposure.

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Chapter review

Chapter checklist

Success criteria		Linked questions
8.1	I can describe the difference between thermal energy and temperature.	4
8.1	I can explain heat transfer by conduction, convection and radiation.	11, 12
8.1	I can explain how sound and electrical energy are transferred.	9, 10, 17, 18
8.1	I can distinguish between forms of energy transfer that require a medium to travel through and those that do not.	3, 6, 7, 18
8.2	I can distinguish between mechanical and electromagnetic waves.	2
8.2	I can identify different parts of a wave, including the wavelength, amplitude, trough and crest.	1, 5, 13, 14, 15
8.2	I can list the different types of electromagnetic radiation.	16
8.2	I can label the compressions and rarefactions in longitudinal waves.	8

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Remembering

1. **State** the unit of frequency of waves and describe what it measures.
2. **Identify** the correct words related to the direction of wave travel to complete the following sentence.
   Sound waves are _____ waves, whereas electromagnetic radiation is made up of _____ waves.
3. **Recall** which types of energy need a medium to travel through.
4. **State** the difference between temperature and thermal energy.
5. **Define**:
   a) wavelength
   b) frequency
   c) amplitude
   d) pitch.

Understanding

6. **Explain** what is necessary for a sound wave to travel from one place to another.
7. Two astronauts are completing a space walk outside the International Space Station.
   a) **Explain** why radios are necessary for communication between the two astronauts.
   b) Imagine that the radios were broken. **Describe** some other ways the astronauts could communicate.
8. **Describe** the difference between compression and rarefaction.
9. **Explain** what a good electrical insulator is and give an example of where it may be used.
10. **Propose** a reason why electrical wires are made from copper, rather than gold or silver, when sending power from power stations into households.

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Applying

11. **Contrast** convection and radiation in terms of thermal energy transfer.

12. Radiant heaters work by emitting infrared radiation. **Explain** how these heaters can directly heat objects in front of it, rather than heating the air in the room like convection heaters.

Analysing

13. **Identify** whether altering the frequency or altering the amplitude would be required in the following situations.

- **a)** Singing a higher pitched note
- **b)** Going from a high note to a low note on the guitar
- **c)** Changing from talking to whispering

14. **Analyse** the graph in Figure 8.42 and determine the:

- **a)** amplitude
- **b)** wavelength
- **c)** frequency.

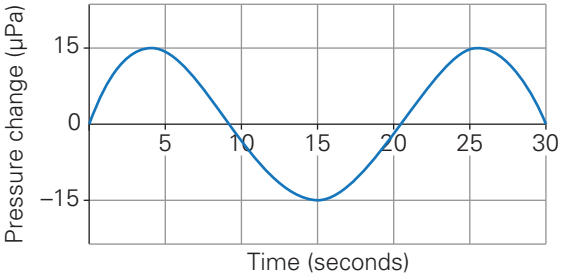
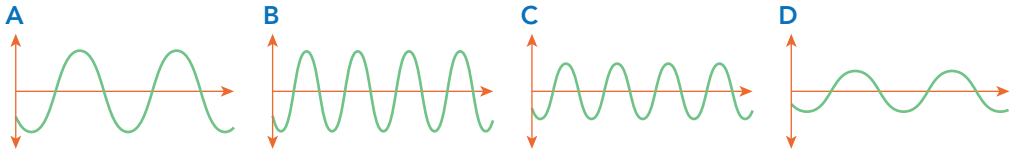


Figure 8.42 A sound wave travelling through the air

15. **Determine** which of the waves below has the:

- **a)** highest pitch and loudest sound
- **b)** quietest sound
- **c)** lowest frequency and loudest sound.



16. **Identify** some examples of objects that are similar in size to the wavelengths of the following types of radiation. One has been completed for you.

Type of radiation	Wavelength	Object
Radio waves	1 metre (m) to a few kilometres	Buildings
Microwaves	1 millimetre (mm) to 1 m	
Infrared	1 mm to 0.7 micrometres (μm)	
Visible light	700 nanometres (nm) to 400 nm	
Ultraviolet	400 nm to 10 nm	
X-rays	shorter than 10 nm	
Gamma rays	10 picometres (pm)	

Evaluating

17. **Propose** why household wires are coated in plastic.

18. A person standing 1 km away shoots a gun. You see the flash of light to indicate that the gun has been fired but you do not hear anything immediately.

- **a)** **State** why this is the case.
- **b)** If it takes 3 seconds from seeing the gun fire to hearing the gunshot, **calculate** the speed of the sound.
- **c)** **Discuss** how close this value is to the actual speed of sound.
- **d)** **Propose** some reasons why your calculated speed of sound may be different from the actual speed of sound.

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Data questions

A 20-year-old took their 80-year-old grandparent for a hearing-loss evaluation and decided to take the auditory test as well. An audiogram shows the lowest volume at which a person can hear a sound at a particular frequency. (Note that the values on the vertical axis are in decreasing order.)

The audiogram results for the 20-year-old and the 80-year-old are illustrated in Figure 8.43. Hearing is considered normal if you can hear sound volumes over 30 dB at a particular frequency. Hearing loss is considered moderate if you require volumes of 30–60 dB, and severe if you can only hear sound volumes over 60 dB.

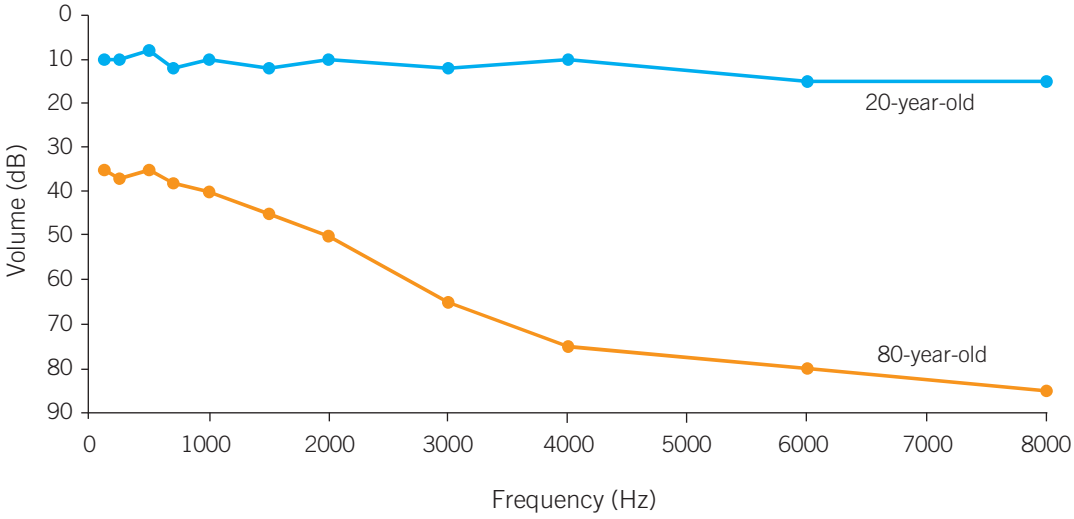


Figure 8.43 An audiogram for a 20-year-old and an 80-year-old

Applying

1. **Identify** which person required a louder sound to hear at a sound wave frequency of 2000 Hz.
2. **Determine** the lowest volume of the 1000 Hz sound wave that can be heard by the 20-year-old based on the test.
3. **Recognise** which person displays hearing loss.

Analysing

4. **Identify** a trend in volume and frequency for both the 20-year-old and the 80-year-old.
5. **Analyse** the plot for the 80-year-old and find any frequencies where the person experiences severe hearing loss.
6. **Contrast** the two datasets between the frequencies of 1000 Hz and 2000 Hz.

Evaluating

7. Following the trend in the data, **deduce** the lowest volume at which the 20-year-old can hear a frequency of 9000 Hz.
8. **Predict** whether the 80-year-old would more easily hear a person talking or a higher-pitch bird whistle of the same volume.
9. The outcome of the test was that the 80-year-old is living with 'moderate low-pitch hearing loss and severe high-pitch hearing loss'. **Justify** whether this statement is accurate.

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STEM activity: Accessible musical instruments

Background information

For most of us, music is part of our lives – whether you listen to music, play an instrument or even create your own music. Music can be defined as sounds that are organised in time and that vary in pitch (the frequency of the sound), dynamics (loudness and softness) and timbre (the tone of the sound).

All musical instruments have three main components:

- a primary vibrator that produces the sound (e.g. a violin string when you draw a bow across it, or a flute mouthpiece when you blow across it)
- a primary resonator that amplifies the sound (e.g. the space inside a violin or a flute)
- an opening for the sound to effuse (flow out) from (e.g. the f-holes of a violin or the open end of a flute).

Pitch is varied in different ways depending on the type of instrument. In a wind instrument, the pitch is varied by changing the length of the tube (usually by opening and closing holes). In a stringed instrument, the pitch can be varied by changing the tension in the string, the length of the string or the mass (thickness) of the string.

Musical instruments have been developed by every human culture in history – making music is a universal human trait. Studies have shown that listening to music can reduce anxiety, depression and even pain, and it can improve memory, mood and sleep. Learning to play an instrument has positive effects on the brain, which translate to other areas of learning. Because music strengthens neural pathways, it can also help to delay ageing of the brain.



Figure 8.44 In musical instruments, vibration produces sound, and this sound is often amplified in the body of the instrument.

Historically, people living with some types of disabilities have been limited in the ways they can engage with music, because of the fine motor skills usually associated with learning to play an instrument. Engineers have been able to modify existing instruments or design new ones to help people living with disability engage with music.

DESIGN BRIEF

Design and build an accessible musical instrument from recycled materials.

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Activity instructions

In small groups your task is to design and build a musical instrument that is accessible to people living with a disability or elderly people. The first step will be to decide the needs you would like to cater for. You may have to do some research to better understand the potential problems that elderly people or people with a particular disability may encounter in using traditional instruments.

Suggested materials

- plastic containers
- elastic bands
- bottles
- icy-pole sticks
- scissors
- cardboard

Research and feasibility

1. Discuss in your group which condition you will cater for, and research how this condition affects the ability to play a musical instrument.
2. Discuss in your group which type of instrument you will focus on. Will you build a woodwind, string or percussion instrument? (It might be difficult to find the resources to build a brass instrument.)
3. Research all the components required for the instrument you are going to build, and list all the ways you can change pitch and/or volume of sound.

Design and sustainability

4. As a group, make multiple sketches each and work out which design would be most effective.
5. Design your prototype and focus on how it can be made from sustainable materials.

Create

6. Build your prototype and test the sound quality produced by your instrument.

Evaluate and modify

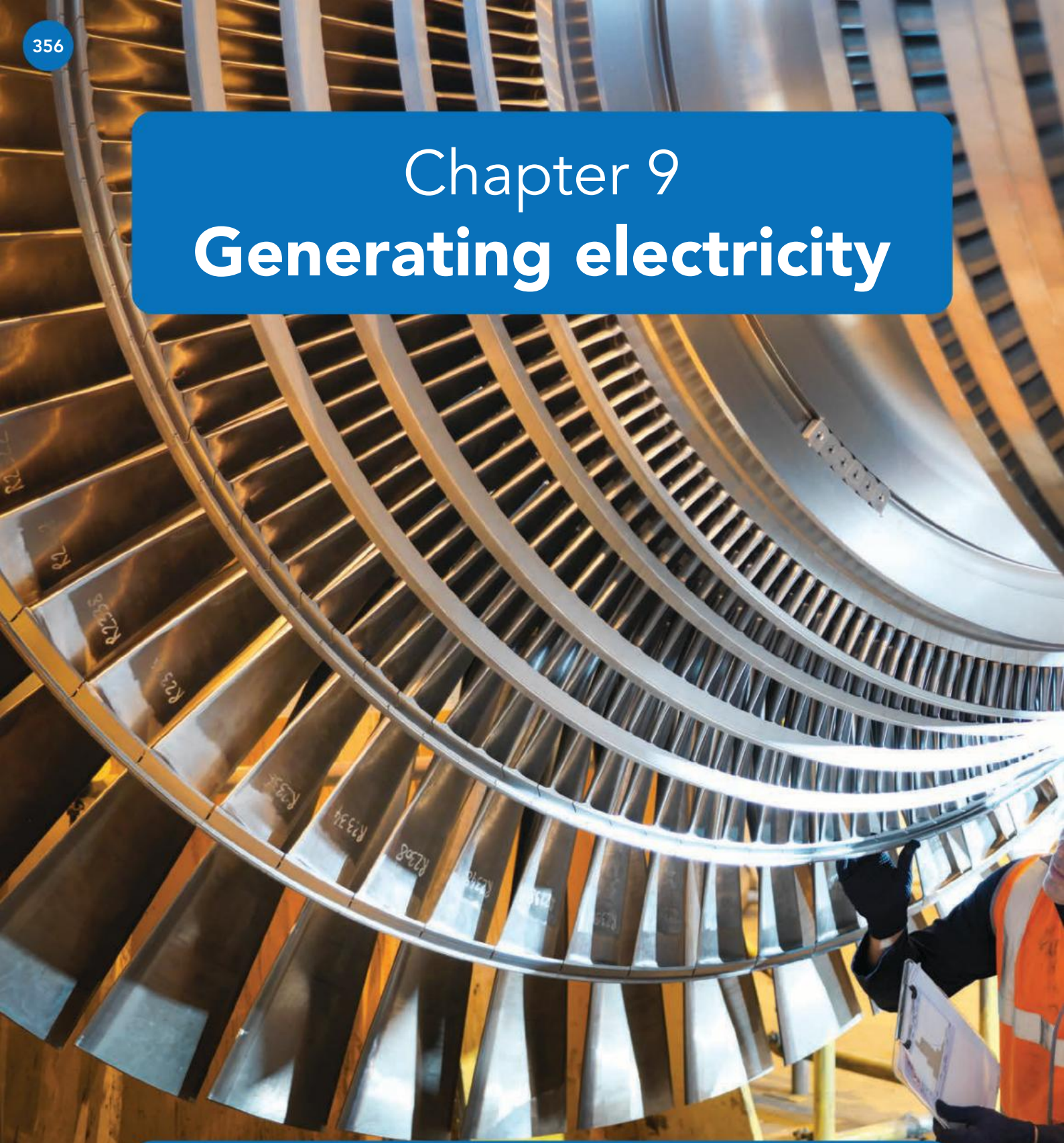
7. Discuss the challenges you experienced when designing and building your musical instrument and list the methods you used to overcome these.
8. Describe the method by which your instrument produces sound and changes pitch.
9. Evaluate how easy or difficult it is to use or learn your instrument.
10. Suggest some improvements to your instrument that could make it easier to use.



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Chapter 9
Generating electricity



Chapter introduction

This chapter is all about the generation of electricity. You will revise magnetism and learn how electromagnetism enables motion to be converted into electricity. You will look at how to build a simple alternating current generator and learn what sources of energy can be used to provide the motion to turn it. You will also learn how batteries and photovoltaic cells can be used to generate direct current. Alongside this, you will learn how scientists and electrical engineers contributed to our current understanding of how to generate electricity.

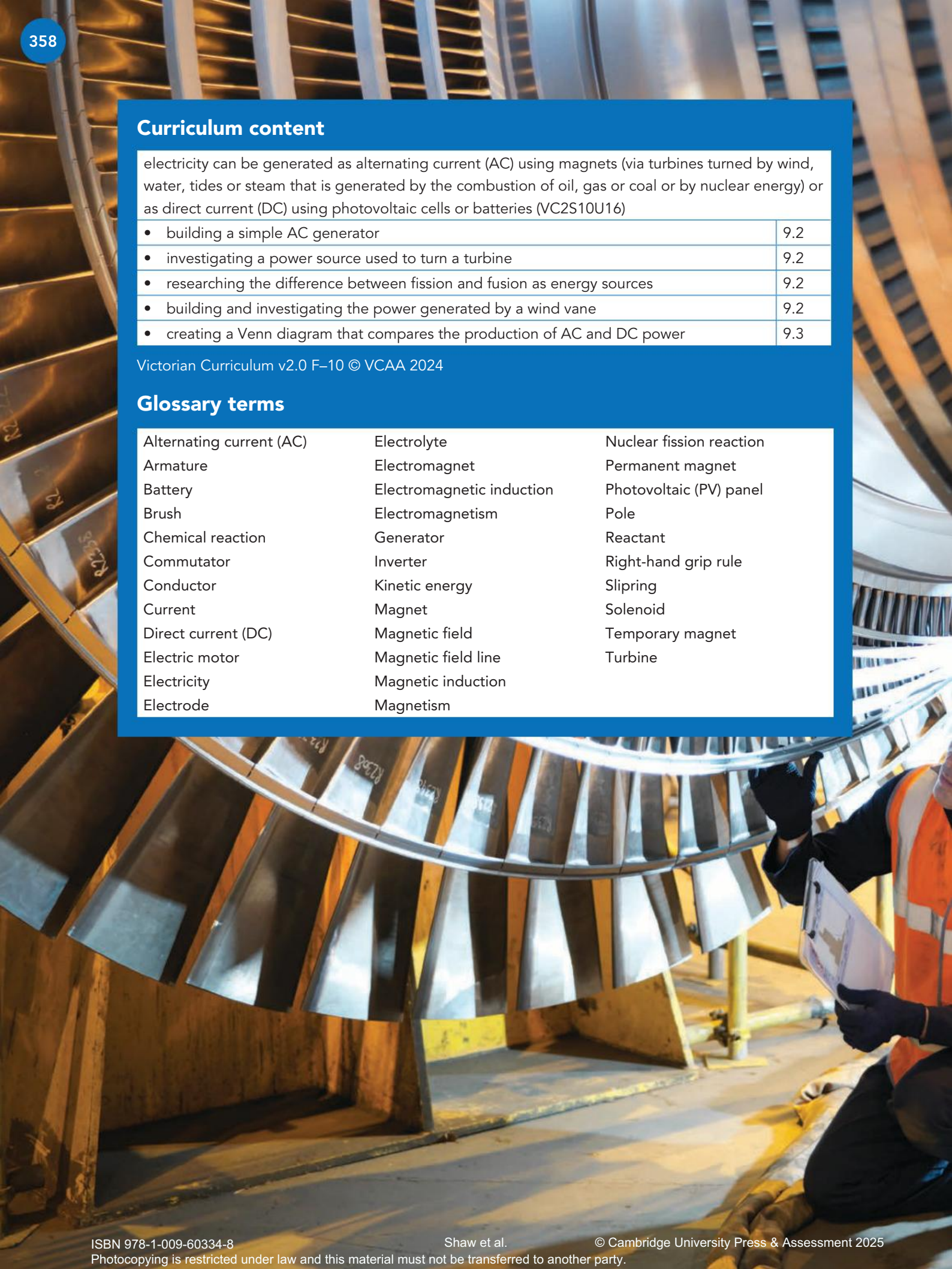
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Concept map



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Curriculum content

electricity can be generated as alternating current (AC) using magnets (via turbines turned by wind, water, tides or steam that is generated by the combustion of oil, gas or coal or by nuclear energy) or as direct current (DC) using photovoltaic cells or batteries (VC2S10U16)	
• building a simple AC generator	9.2
• investigating a power source used to turn a turbine	9.2
• researching the difference between fission and fusion as energy sources	9.2
• building and investigating the power generated by a wind vane	9.2
• creating a Venn diagram that compares the production of AC and DC power	9.3

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Glossary terms

Alternating current (AC)	Electrolyte	Nuclear fission reaction
Armature	Electromagnet	Permanent magnet
Battery	Electromagnetic induction	Photovoltaic (PV) panel
Brush	Electromagnetism	Pole
Chemical reaction	Generator	Reactant
Commutator	Inverter	Right-hand grip rule
Conductor	Kinetic energy	Slipring
Current	Magnet	Solenoid
Direct current (DC)	Magnetic field	Temporary magnet
Electric motor	Magnetic field line	Turbine
Electricity	Magnetic induction	
Electrode	Magnetism	

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9.1 Magnetism, electricity and motion

Learning goals

At the end of this section, I will be able to:

1. Define 'electromagnetism'.
2. Use the right-hand grip rule.
3. Explain the role of electromagnets in simple electronic devices.

VIDEO
How do magnets work?

Before we explore the generation of electricity, we will review the basic concepts of magnetism and electricity behind the supply of mains electricity.

Magnets

The discovery of magnetism begins, it is believed, with the ancient civilisations in Asia Minor (modern-day Türkiye) around 600 BCE. In a region known as Magnesia, stones were found that could attract each other. These stones were named **magnets** after their place of discovery. The word 'magnet' comes from the Greek language, *magnetis lithos*, literally meaning 'the stones of Magnesia'.

magnet
a material containing iron and other elements that attracts similar materials or objects; it aligns with an external magnetic field

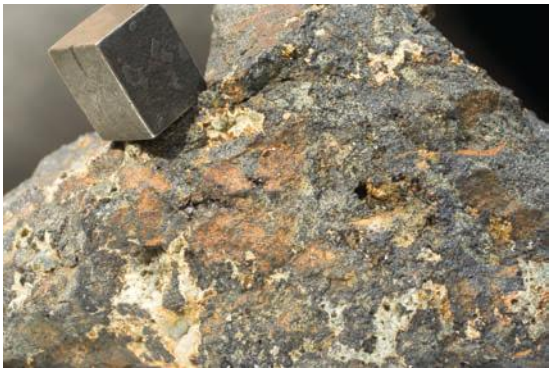


Figure 9.1 A piece of magnetic rock (magnetite) attracting an iron cube

The most magnetic of all the naturally occurring minerals on Earth is magnetite, an oxide of iron. Naturally magnetised chunks of magnetite are called lodestone – literally meaning 'the stone that leads'. The magnetic properties of lodestone were known to humans since the sixth century BCE at least, with the Greek philosopher Thales of Miletus (you might remember him or his student, Pythagoras, from your Mathematics course) making one of the earliest known references to it.

Did you know? 9.1

Young Albert Einstein's surprise present

In 1884 when Albert Einstein was 5 years old, his father Hermann Einstein bought him a magnetic compass. As Albert was sick in bed at the time, he fiddled around with it, but no matter how hard he tried to trick it to point elsewhere, the compass needle would always point to the same direction (magnetic north). He later wrote there was 'something behind things, something deeply hidden'. This was the beginning of Albert Einstein's lifelong scientific exploration. He was quoted saying, 'I have no special gift. I am only passionately curious'.

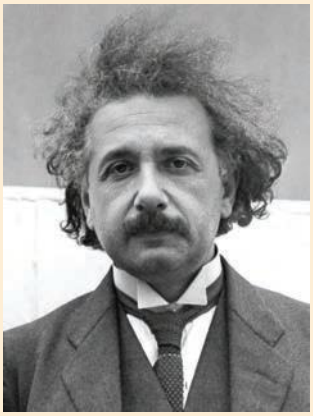


Figure 9.2 Albert Einstein – arguably the greatest physicist ever – was inspired by a compass.

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Other civilisations (the Chinese and the Anglo-Saxons, for example) noticed that these magnetic stones always pointed in the same direction when suspended from a fine piece of silk or cotton thread. These people had accidently discovered the compass and, inadvertently, evidence of the fact that Earth has a **magnetic field**. They created the first land compasses and they later used these lodestones to create compasses to navigate in ocean exploration.

magnetic field the region in which a magnet can exert a force on other magnets

magnetic induction the process by which an object is magnetised by an external magnetic field

temporary magnet a magnet that does not retain its magnetism outside an external magnetic field

permanent magnet a magnet that retains its magnetic properties outside a magnetic field

pole the end point of a magnet

An even more useful property of lodestones was that they could, simply by stroking, turn an iron needle or steel needle into a magnet. This process is called **magnetic induction**. These magnetised needles were then placed in non-magnetic containers and were used by mariners to navigate and explore the world.



Figure 9.3 A working model of the first instrument known to be a compass. The spoon is carved from magnetic lodestone, and the plate it sits on is bronze, a non-magnetic metal. It is believed that the Chinese used such compasses as Earth-based direction pointers over 2400 years ago.

Of course, as the name suggests, **temporary magnets** are temporary; that is, they only stay magnetic while they are in the presence of a magnetic field. You will be familiar with the fact that a **permanent magnet** attracts paperclips, steel nails and other objects made of iron. Magnets can also attract nickel and cobalt, which have magnetic properties. All magnets have two ends, which are called the north (N) and south (S) **poles** by convention. No matter the shape of the magnet, each one must have a north and south pole.



Figure 9.4 A magnetic compass will always align with Earth's magnetic field and point north.

The forces between magnets can be attractive (when unlike poles are placed near each other) or repulsive (when like poles are placed near each other).

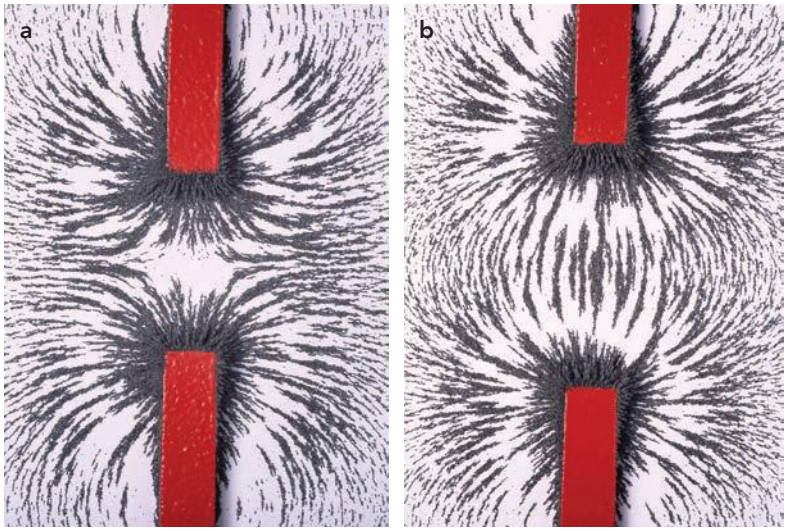


Figure 9.5 Iron filings show **(a)** the magnetic repulsion between like poles and **(b)** the magnetic field attraction between unlike poles

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These magnetic forces can be put to good effect; for example, they keep the door seal on the fridge closed (attractive) or raise and propel maglev trains (repulsive).

Try this 9.1

Making a compass

Fill a 250 mL beaker with water and place a cork or rubber stopper in it, making sure it floats. Take a sewing needle and stroke it 20 times with a bar magnet. You must stroke in *one* direction only and with one end of the magnet only. Place the needle on top of the cork or rubber stopper. Notice in which direction the needle points. Turn the beaker 90° and observe what the needle does. Use a compass to determine how accurate your needle is.

Quick check 9.1

1. **Describe** what is meant by the term 'magnetic field'.
2. **Explain** magnetic induction.
3. **Explain** how magnetism could be used to produce movement between objects that are not in contact, both towards each other and away from each other.

In 1846, to understand how magnets could attract and repel each other, the English physicist Michael Faraday (1791–1867) introduced the concept of **magnetic field lines**. Faraday referred to the region around a magnet where magnetic effects are experienced as the magnetic field. Using Faraday's ideas, the magnetic field surrounding a bar magnet can be represented using a diagram such as shown in Figure 9.6b. The arrows on the field lines indicate the direction of the magnetic field.

magnetic field line a visual tool to represent the direction of magnetic fields

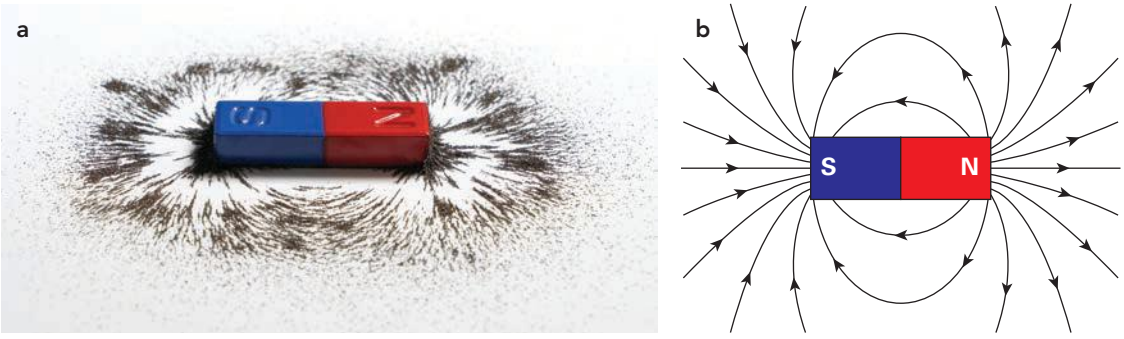


Figure 9.6 All permanent magnets have a north and south pole. The magnetic field surrounding a magnet can be: **(a)** visualised with iron filings and **(b)** represented using arrows.

In reality, the magnetic field exists in three dimensions. Figure 9.7 is a close-up photograph of the iron filings pattern between the north and south poles of a magnet; it shows the three-dimensional nature of the magnetic field.

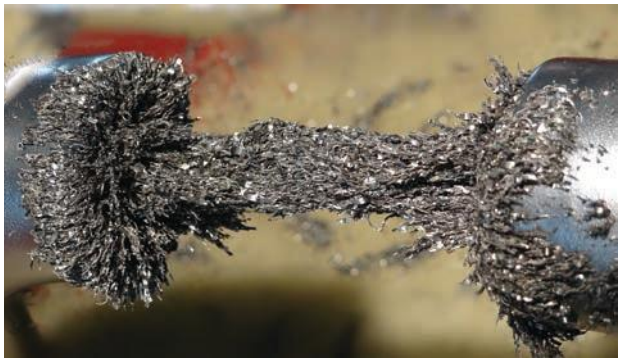


Figure 9.7 Three-dimensional magnetic field lines become visible when iron filings are gathered between the north and south poles of a magnet.

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Faraday's rules for magnetic field lines are listed below.

1. Each magnetic field line is a continuous loop that leaves the north end of the magnet, enters at the south end and passes through the magnet back to the north end.
2. Field lines do not intersect.
3. The closeness of the magnetic field lines represents the strength of the magnetic field.

Magnetic field diagrams can be used to explain why magnets attract and repel each other. When magnets attract each other, the magnetic field lines join the two magnets, as shown in Figure 9.8a. When magnets repel each other, the magnetic field lines push each other away, as shown in Figure 9.8b.

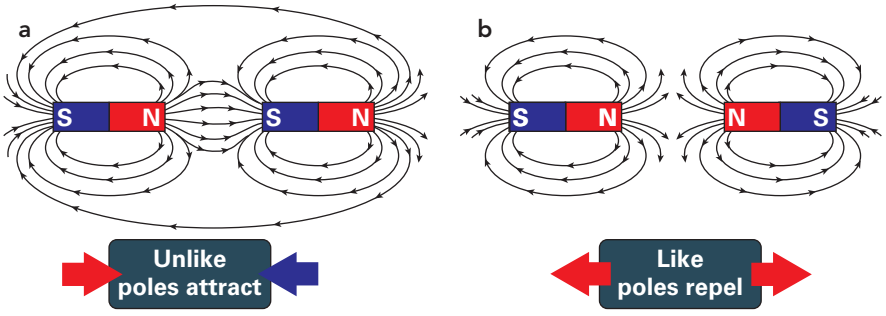


Figure 9.8 Magnetic field diagrams for **(a)** attraction: north–south magnets and **(b)** repulsion: north–north magnets

Try this 9.2

Visualising magnetic fields

1. Get two bar magnets, a horseshoe magnet, some iron filings and a sheet of A4 paper.
2. Place one of the bar magnets under the middle of the sheet of paper and sprinkle the iron filings on the paper. Try not to get filings on the magnets – they are difficult to remove. (Wrapping the magnets in cling wrap can reduce the removal problem.)
3. Observe how the filings position themselves around the magnet.
4. Repeat the experience with the horseshoe magnet. Do you notice any differences in the way the iron filings position themselves? Can you explain why the filings assume these distributions?
5. To go further, place the two bar magnets face to face and 2–3 centimetres (cm) away from each other, then sprinkle the filings. Observe the distribution of the filings.
6. Now turn one of the magnets over. How does the distribution of iron filings change? Can you guess, from the filings distribution, when two unlike poles face each other and when two like poles face each other?

Quick check 9.2

1. **Explain** what happens when you place the north poles of two magnets next to each other.
2. **Describe** the magnetic lines around a bar magnet.
3. **Explain** whether the magnetic field experienced by a paperclip becomes stronger or weaker as you approach it to one of the poles of a permanent magnet.

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Electric currents

Recall from Year 8 that **electricity** is a form of energy that results from either the accumulation or the flow of charge. This chapter is concerned with the flow of charge, called electric **current**, in the form of negatively charged electrons flowing in a **conductor**. For an electric current to flow in an electric circuit, wires need to be connected to a source of energy. In the circuits you studied in Year 8, this source of energy was a battery or power pack (which gets its electrical energy from the mains supply).

Here, we focus on two types of electric current:

- **Alternating current (AC)** (from mains electricity or an AC power pack): reverses the direction of the current about 50 times every second. This is the power supply most used for appliances.
- **Direct current (DC)** (from batteries and solar cells): flows in one direction only. Most of the electric circuits you studied in Year 8 used a DC power supply.

electricity
a form of energy that results from the accumulation or the flow of charge

current
the flow of electric charge, which may continue in a steady manner for a period of time

conductor
(electricity) a substance or material that allows electrons to pass through it easily

alternating current (AC)
a form of electricity in which the current reverses direction in regular cycles (though the electrical energy associated with the current flows in one direction)

direct current (DC)
a form of electricity in which the current flows in one direction

Quick check 9.3

1. **State** the definition of an electric current.
2. **List** the differences between direct current and alternating current.
3. A simple electric circuit is powered by a battery. **Identify** whether the current in the circuit is AC or DC.

Electromagnetism

In 1820, the Danish physicist Hans Christian Ørsted noticed that the needle of a compass, placed next to an electrical wire carrying a current, turned so that the needle was perpendicular to the wire. Ørsted had discovered a connection between electricity and **magnetism**. This phenomenon was named **electromagnetism**. He found that a wire carrying a current created a magnetic field, as shown in Figure 9.9.

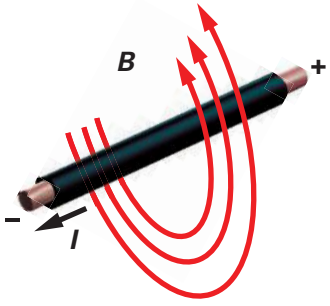


Figure 9.9 Ørsted discovered the existence of a magnetic field, *B* (red lines), around a wire carrying an electric current (*I*).

magnetism
the ability to attract or repel objects that are magnetic

electromagnetism
the interaction between magnetic fields and electric currents

Right-hand grip rule

The direction of the magnetic field produced by the wire can be remembered with the **right-hand grip rule**, as Figure 9.10 demonstrates. If your thumb represents the direction of the current, then your right-hand fingers curl in the direction of the magnetic field generated.

right-hand grip rule
a way to show the direction of the magnetic field of a current-carrying wire

As you will recall, electrons carry electrical potential energy from the negative to the positive terminal. However, current is often depicted as moving in the opposite direction – from the positive to the negative terminal. This is called 'conventional current' and reflects the fact that scientists in the 1700s thought it was the positive charges that carried electrical energy. When using the right-hand grip rule, we are using the direction of conventional current.

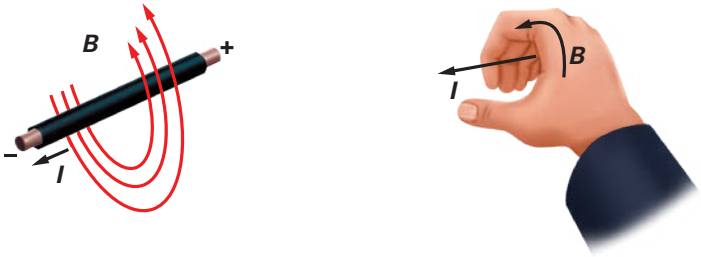


Figure 9.10 Diagram showing the right-hand grip rule where *I* is the current-carrying wire and *B* is the magnetic field. Recall the convention for current direction is from the positive to negative terminal.

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Amazingly, if you already know the direction of the magnetic field, and your current-carrying wire is in a coil, you can do the opposite of this rule to figure out the direction of the current in the wire. In this case, you would point your thumb in the direction of the magnetic field and then curl your fingers around to determine the current's direction.

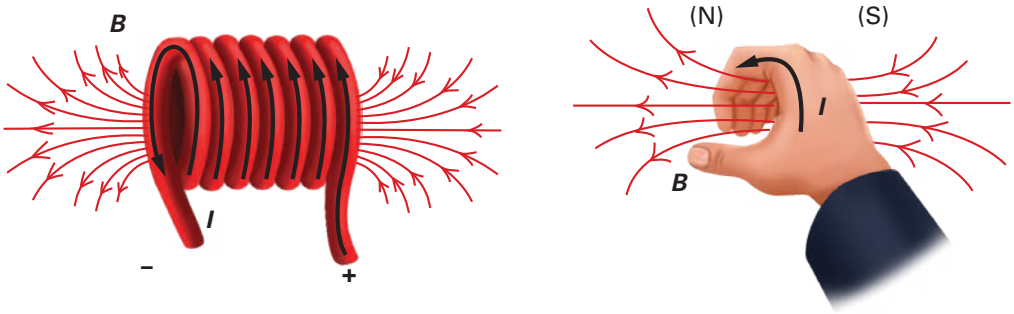


Figure 9.11 Diagram showing the right-hand grip rule where *I* is the current-carrying wire (fingers) and *B* is the magnetic field (thumb)

The arrow convention is often used to indicate the direction of the current in a diagram if the wires go into or come out of the page. A cross represents the tail feather of an arrow, while the dot represents the tip of an arrow. Applying the right-hand grip rule creates magnetic fields surrounding the currents, as shown in Figure 9.12.

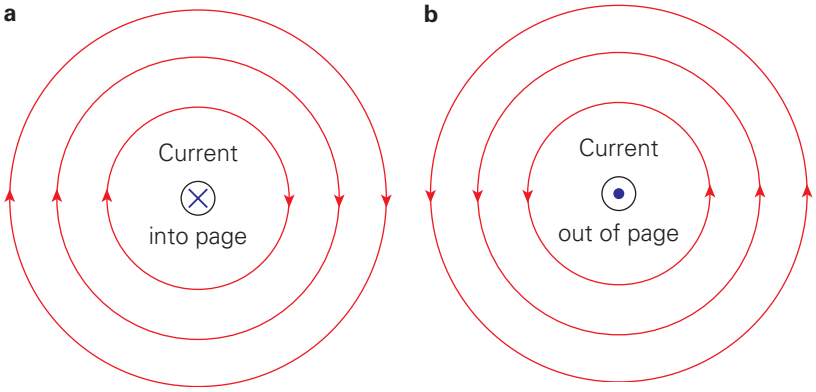


Figure 9.12 Diagrams showing the magnetic fields for current-carrying wires with the **(a)** current going into the page or **(b)** current coming out of the page

The arrow convention is also used for the magnetic field going into or coming out of the page, as shown in Figure 9.13.

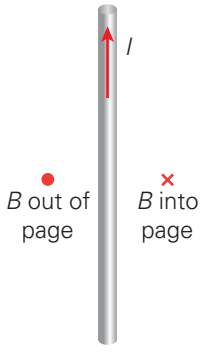


Figure 9.13 Diagram showing the direction of the magnetic field for a current-carrying wire where *I* is the current and *B* is the magnetic field

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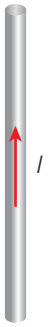
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Try this 9.3

Applying the right-hand grip rule

1. Determine the direction of the magnetic field for each of the following wires.

a) 

b) 

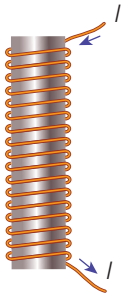
c) 

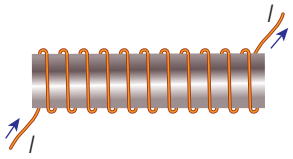
(into the page)

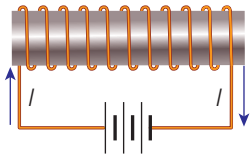
d) 

(out of the page)

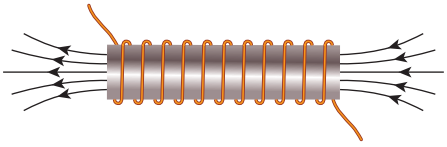
2. Determine the direction of the magnetic field for each of the following coils.

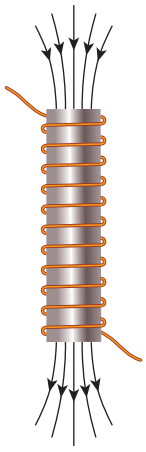
a) 

b) 

c) 

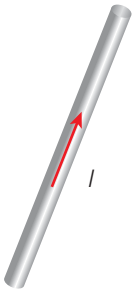
3. Determine the direction of the current in each of the following coils.

a) 

b) 

Quick check 9.4

1. **Describe** electromagnetism.
2. **Explain** why a compass needle moves when placed next to a current-carrying wire.
3. **Determine** the direction of the magnetic field in the wire shown here.



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VIDEO
How do electromagnets work?

WIDGET
Electromagnet properties

Electromagnets

The magnetic field generated by a current-carrying wire can be made stronger by forming a loop, as shown in Figure 9.14. The magnetic field is especially strong in the centre. When the wire is wound up many more times to form a coil, the magnetic field through the centre is even larger and more powerful (see Figure 9.15). A coil of wire with lots of loops in it is called a **solenoid**. A solenoid connected to a power supply or battery creates the simplest form of **electromagnet**, as one end of the solenoid forms the north pole and the other the south pole.

By adding an iron core (e.g. an iron nail) to the solenoid, the strength of the magnetic field is increased even further. One end of the iron core becomes the north pole and the other end becomes the south pole (see Figure 9.16). As you might expect, if you reverse the direction of the current, the poles of the electromagnet swap.

solenoid
a wire coil wrapped in the shape of a tube or cylinder; in engineering, a coil that moves an iron core in its centre for a mechanical purpose

electromagnet
a magnet consisting of a current-carrying coil surrounding a piece of iron

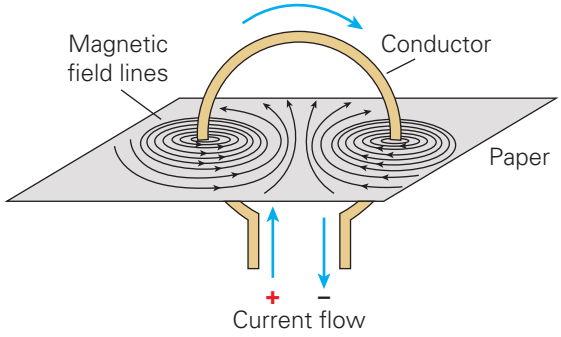


Figure 9.14 A single loop of wire concentrates the magnetic field.

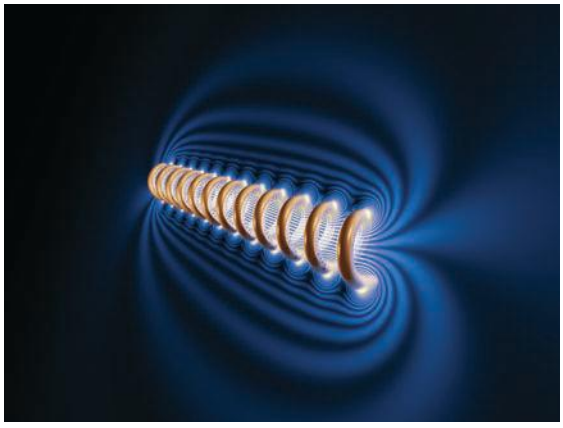


Figure 9.15 The magnetic field of a solenoid

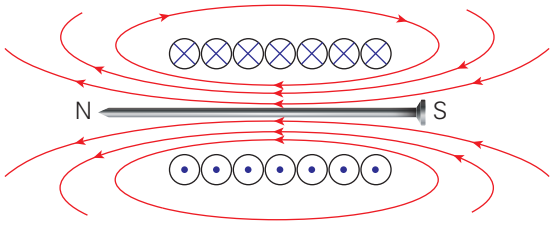


Figure 9.16 The magnetic field surrounding an electromagnet is similar to that of a bar magnet.

Try this 9.4

Making an electromagnet

A simple electromagnet can be made using a coil of wire, an iron nail and a battery.

See if your nail is magnetised by holding it near some paperclips.



Figure 9.17 A simple electromagnet or solenoid

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One advantage of using electromagnets rather than permanent magnets is that the magnetic properties can be switched on or off. The magnetic field strength can also be altered by changing the number of turns in the coil: more coils creates a stronger field. Changing the strength of the current is an even more convenient way to change the strength of the magnetic field.



Electromagnetism has a wide variety of applications in everyday life. Electromagnetic coils are found in many electronic devices, such as computers, mobile phones and their charging devices; while electromagnets are used in electric motors, doorbells, safety switches and, most importantly, the generation of electricity.



Figure 9.18 Electromagnets have a wide variety of uses in everyday life: in **(a)** industry, **(b)** transport, **(c)** cooking and **(d)** medicine.

Quick check 9.5

1. **Describe** a solenoid.
2. **Explain** the purpose of using an iron core in an electromagnet or wire coil.
3. **List** two advantages an electromagnet has over a permanent magnet.

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Practical 9.1

Electromagnets

Be careful
Hot wires can burn if there are short circuits.
Ensure voltage output is not exceeded.
Turn off power supply when changing the circuit.

Aim
To investigate the magnetic fields produced by an electromagnet

Materials
- 1 m of PVC-covered copper wire with the ends stripped and bare
- large iron nail
- iron filings
- paperclips
- wire stripper
- low-voltage DC power supply
- A4-size plastic sheet
- plastic compass

Method
1. Wind the insulated copper wire around an iron nail as shown in Figure 9.19.
2. Connect the ends of the wire to the low-voltage DC power supply while it is switched off. Once the ends are connected, switch the power supply on.
3. Using the compass, create a magnetic field diagram for the nail. To do this, position the compass at different points around the nail and record the direction and orientation of the field line based on the compass needle.
4. Place an A4 plastic sheet over the electromagnet. Sprinkle iron filings over the sheet. Turn on power to the electromagnet and note what happens to the iron filings. Draw the pattern created in your science book. Discuss what happens to the pattern of iron filings if you turn off the current.

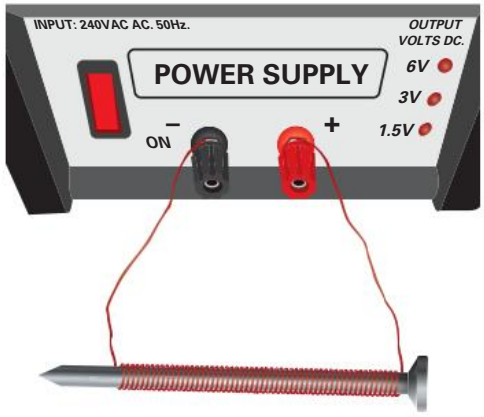


Figure 9.19 Experimental set-up

5. Collect and recycle the iron filings and remove the plastic sheet from the electromagnet.
6. Use your electromagnet to pick up the paperclips. How many can you pick up? Record this number.
7. Investigate two factors affecting the strength of the electromagnet: the number of coils and the current flowing in the wire. Use the number of paperclips that the electromagnet can pick up to indicate the strength of the electromagnet.

Results
1. Draw a diagram of the pattern of iron filings created by the electromagnet.
2. Create a table showing how many paperclips your electromagnet could pick up with different numbers of coils and amounts of current.

Discussion: Analysis
1. State the purpose of the iron nail in your electromagnet.
2. Explain why your electromagnet gets warm when you turn it on.
3. From your field diagram, work out which end of the electromagnet is north. Draw this on your field diagram.
4. Explain the pattern of iron filings created by the electromagnet.
5. Explain what happens to the pattern when you turn the electromagnet off.
6. Explain how the electromagnet can pick up paperclips.

Discussion: Evaluation
1. What sources of error might there be for this experiment and how could they be resolved?

Conclusion
1. Make a claim from this experiment regarding the magnetic field of electromagnets.
2. Support your claim by referring to your experimental observations.
3. Explain how your observations support your claim.

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Try this 9.5

Operating an electric doorbell

Use the following terms to write a description of how the electric doorbell shown in Figure 9.20 operates. Note that the switch in this circuit is a tap switch; when the switch is released, it goes to the off position.

- Current
- Electromagnet
- Magnetic field
- Tap switch
- Circuit
- Iron armature
- Hammer
- Bell

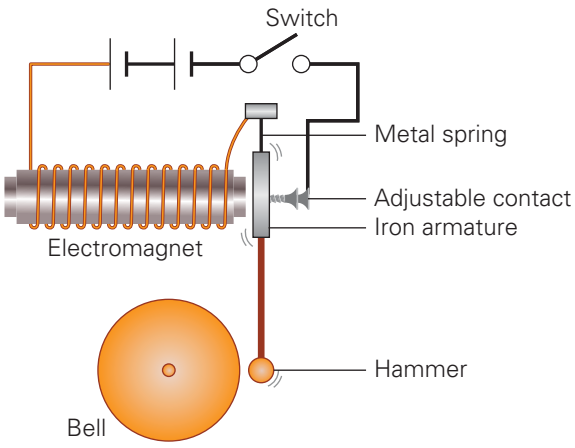


Figure 9.20 Simplified drawing of an electric doorbell

WORKSHEET
Comparing permanent magnets and electromagnets

Electric motors

In 1821, Michael Faraday used his understanding of magnets to create the world's first **electric motor**.

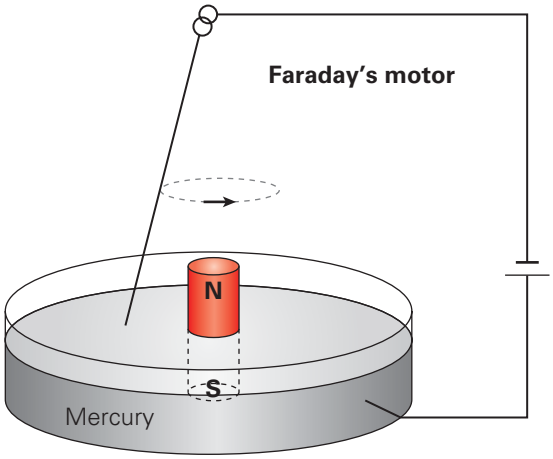


Figure 9.21 A schematic diagram of Faraday's electric motor

electric motor a device that converts electrical energy to kinetic (movement) energy

kinetic energy the energy an object or particle has due to its motion

Faraday used a wire, a permanent magnet, a battery and a dish of mercury (a liquid metal at room temperature and a good electrical conductor, but also highly toxic, including its vapour). One end of the wire hung free in the mercury. When current was applied to the circuit, a circular magnetic field was generated around the wire. The wire's magnetic field interacted with the magnetic field of the permanent magnet. This caused the wire to rotate around the magnet. Faraday had converted electrical energy into rotational **kinetic energy** (movement).

What Faraday had found was that, when a current-carrying wire (with its own magnetic field) is placed in an external magnetic field that exists around a magnet, both magnetic fields will interact and this results in a force being exerted on the wire. This force is what makes things move, and this is the basis of how electric motors, like the ones in a hair dryer or hand-held drill, work.

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Practical 9.2

A simple electric motor

Be careful

Electrical shocks may occur.
Ensure voltage output is not exceeded.
Turn off power supply when changing the circuit.

Aim

To build your own motor

Materials

- D-cell battery
- copper wire with a thin coat of insulation ('magnet wire' or enamelled wire)
- long sewing needles × 2 (with the eyes large enough to fit the copper wire through) or big paperclips × 2
- sandpaper or emery board
- modelling clay (or Blu-Tack)
- electrical (duct) tape
- small circular magnet
- marker pen

Method

1. Make a loop by wrapping the insulated copper wire several times (start with five or 10 times) around your D-cell battery. Then, remove the loop and wrap the ends of the wire around the loop, leaving them sticking out, as shown in Figure 9.22.

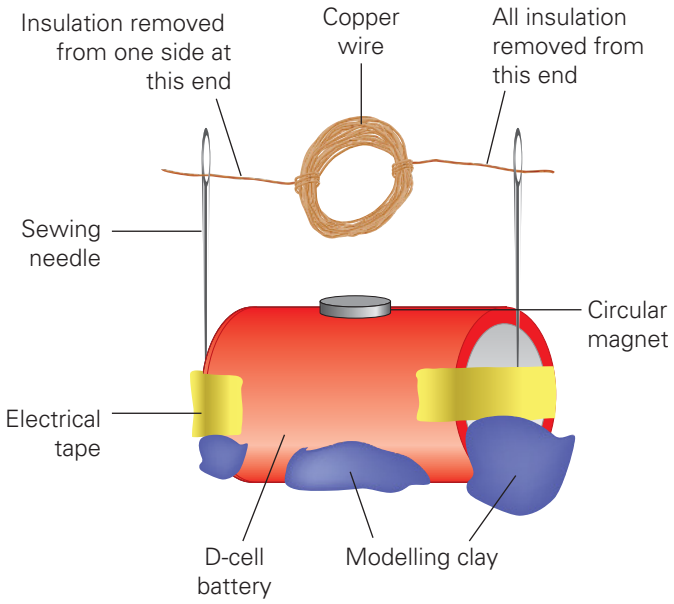


Figure 9.22 Experimental set-up

2. Using the sandpaper or an emery board, remove the insulation from:
   - one side of the last 2 cm of one end of the wire
   - both sides of the last 2 cm of the other end of the wire.
3. Lay the D-cell battery sideways on a flat surface and stick it in place with the modelling clay.
4. Make two small balls of modelling clay and impale them on the sharp end of each needle.
5. Place the needles upright near each of the terminals of the battery so that each needle touches one terminal of the battery, and fix them in place with the electrical tape.
6. Thread each end of the wire loop through the eye of a needle. Make sure the end of the wire where the insulation has been removed is in contact with the needle.
7. Your coil should be hanging above the battery. Place the small magnet on the battery, underneath the coil.
8. Give your coil a spin. If it does not keep spinning, try to spin it in the other direction.
9. Redo your coil with more loops. What changes when you spin the coil? Record your observations.

continued …

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Results

Insert a picture or diagram of your construction and record your observations regarding how your motor operates.

Discussion: Analysis

1. Explain why the insulation is removed from only one side of the wire at one of the ends. Why does this make it a DC motor?
2. Deduce what might happen if you used a smaller or larger battery.
3. Deduce what might happen if you used a larger magnet.
4. Explain how the number of loops or the intensity of the current delivered by the battery affects your motor.

Discussion: Evaluation

1. Identify any faults with this experiment and suggest how they could be resolved.

Conclusion

1. Make a claim from this experiment regarding the requirements for a functioning motor.
2. Support your claim by referring to your experimental observations.
3. Explain how your observations support your claim.

Quick check 9.6

1. **Describe** Faraday's 1821 electric motor experiment.
2. **Explain** how a permanent magnet can cause a current-carrying wire loop to move.

DC electric motors

Today, electric motors are everywhere. Electric fans, electric drills, washing machines, hairdryers, trains, electric cars and many other devices, all use electric motors.

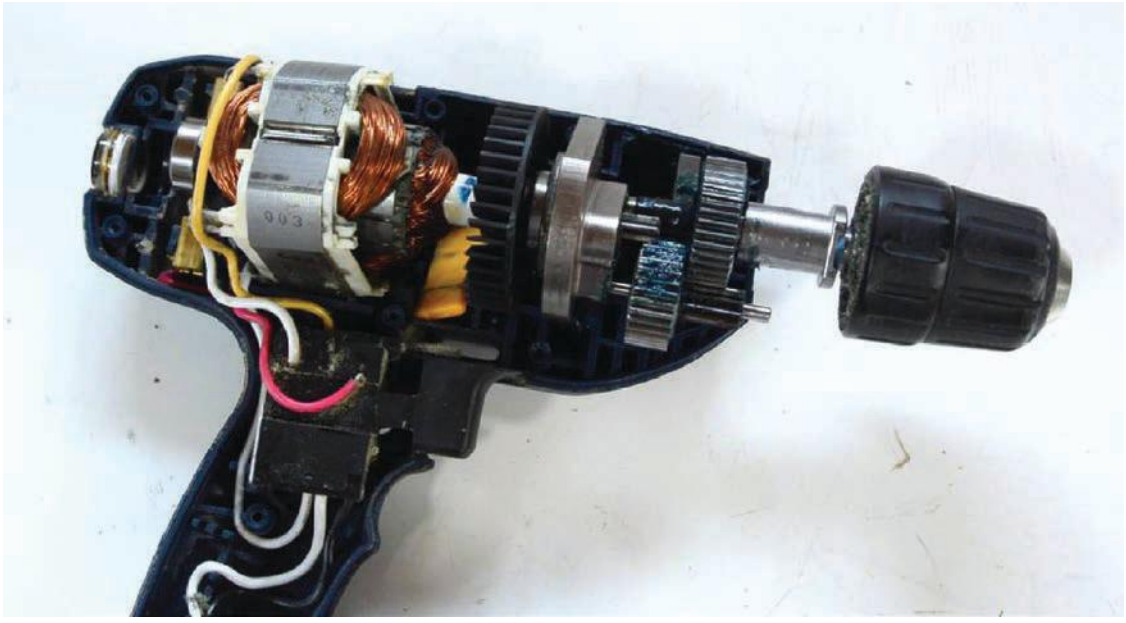


Figure 9.23 Cross-section showing the electric motor in a corded drill

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The simplified diagram in Figure 9.24 shows the magnetic forces (F) acting on the coil of wire in a simple direct current (DC) motor. Recall that DC current means the current flows in one direction around the circuit.

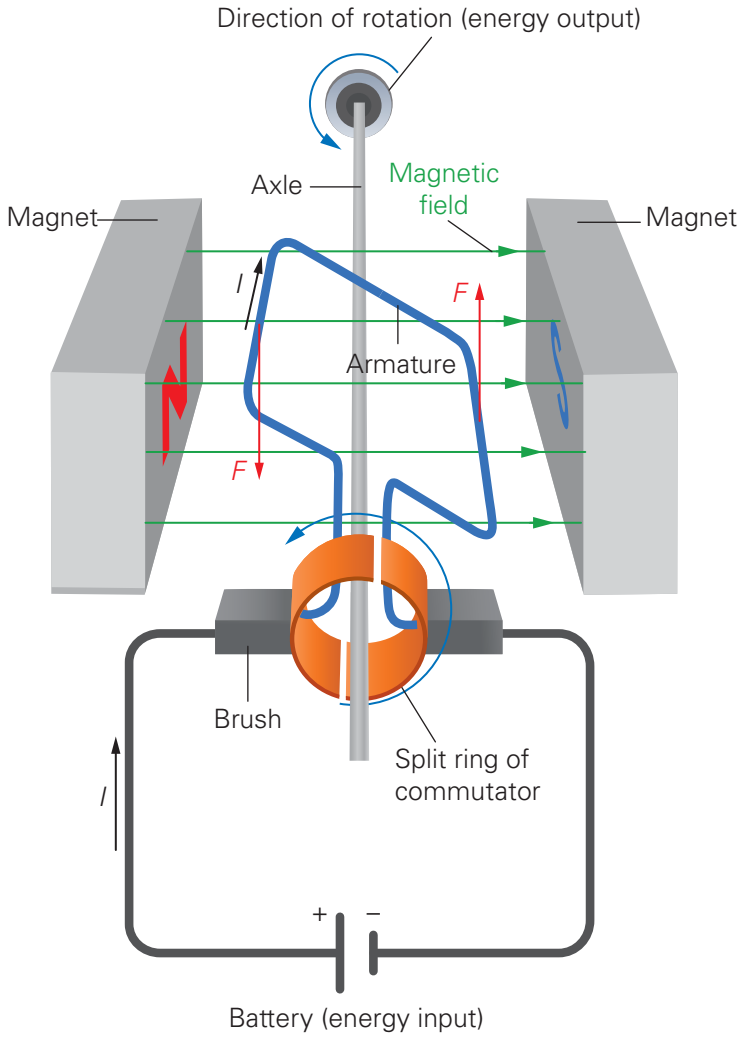


Figure 9.24 A simple DC motor, consisting of a single loop of wire in a magnetic field, produced by a set of permanent magnets. The battery supplies DC in one direction.

armature
the rotating coil that forms part of an electric motor

brush
the part of a motor that conducts current between stationary and moving parts

commutator
a split ring that reverses current at a point in a motor

To create a large and useful force, the wire in the motor is looped into coils similar to a solenoid. This coil of wire is called an **armature**. Figure 9.24 shows this as a single wire for simplicity. When electric current (I) flows through the armature, a magnetic field is produced. This magnetic field interacts with the magnetic field produced by the permanent magnets on either side of the armature. The magnetic forces in opposite directions on the two sides of the loop cause a turning force, making the armature rotate.

The **brushes** connected to the power source lightly touch the split ring of the **commutator**, which is fixed to the armature and axle, turning with them. This allows current to continue being supplied to the armature as it rotates. Consider the situation where the armature in Figure 9.24 has made a half turn (180°). The two halves of the commutator have swapped position, so the direction of the current around the loop is reversed. However, since the loop has turned, the flow of current relative to the magnetic field is the same as before, and therefore the forces on the loop act in the same direction. This allows the armature to continue rotating in the same direction rather than oscillating back and forth between the two magnets.

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Quick check 9.7

1. **State** what DC stands for.
2. **State** which parts of a simple DC electric motor are moving and which parts are stationary.
3. Write down a list of five electric motors that you have around your home. **Explain** what each electric motor does and what the general purpose is of the motor.
4. **Explain** the role of the brushes and commutator in a simple DC motor.

One disadvantage of the simple motor shown in Figure 9.24 is that it can stick at the point where there is a gap between the split rings. In this case, no current flows through the coil and it does not turn.

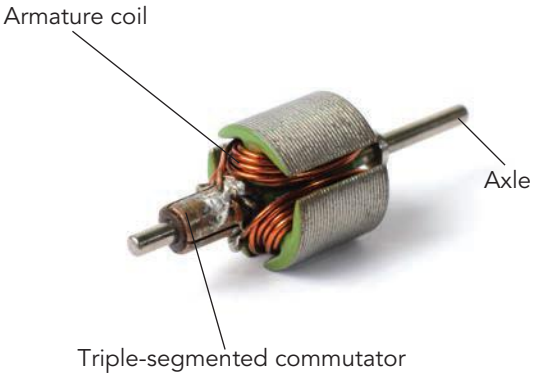


Figure 9.25 The rotating part of a DC motor that fits inside the static permanent magnets (not shown)



In an attempt to overcome this disadvantage, there are many different designs for simple DC motors. One common design used in some schools for practical work is shown in Figure 9.25. Note that the motor has three sets of armature coil windings and a triple segmented commutator (a commutator with three splits rather than two). This means that at any point in the rotation, two of the three commutator segments are in contact with the brushes. This design ensures that the DC motor does not have a 'dead spot', where the motor does not turn and which could cause the coils to overheat.

Try this 9.6

Simple DC motor

Look at a permanent magnet DC electric motor set up for you.

Be careful

Hot wires can burn if there are short circuits.
Ensure voltage output is not exceeded.
Turn off power supply when changing the circuit.

Using only 2 V DC for the DC electric motor, turn it on and answer the following.

1. Which way is your motor turning – clockwise or anticlockwise? What effect would reversing the current through the coils have on this DC motor? Try it.
2. The current is put back to its original direction. What effect would swapping the permanent magnets have on this DC motor? Try it.
3. You may have noticed some electrical sparking where the brushes made contact with the commutator. What causes this?
4. If the DC current was replaced with an AC current, the motor would vibrate rather than rotate. Explain, in detail, why this happens.

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Section 9.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 9.1 questions

Remembering

1. **Recall** what material makes some rocks magnetic.
2. **Describe** magnetic induction.
3. **Recall** Faraday's three rules for magnetic field lines.
4. **Describe** the arrow convention for current and magnetic fields.
5. **Recall** what energy changes are associated with an electric motor.
6. **Recall** what forces Faraday used to create the world's first electric motor.

Understanding

7. **Describe** the concept that is used to explain magnetic attraction and repulsion between magnetic poles.
8. **Explain** why iron cores are added at the centre of coils to create electromagnets.
9. **Explain** how a DC motor works.

Applying

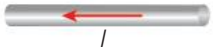
10. **Draw** the magnetic field lines for the following two configurations. Use arrows to **indicate** the direction of the magnetic field.

a) 

b) 

11. **Draw** the magnetic field generated by the following wires.

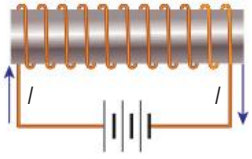
a) 

b) 

12. **Describe** what happens to both magnetic fields when a current-carrying wire is placed in an external magnetic field.

Analysing

13. **Determine** the direction of the current and **draw** the magnetic field lines for the following solenoid. **Identify** the north pole.



14. **Analyse** the energy conversions occurring in a DC motor.

Evaluating

15. Imagine a world where electromagnets have not yet been discovered. **Propose** what this would be like. Suggest some appliances that would not be available and explain why.
16. **Deduce** why increasing the number of coils in a solenoid increases the intensity of the magnetic field generated.

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9.2 Generating AC electricity

Learning goals

At the end of this section, I will be able to:

1. Define 'electromagnetic induction'.
2. Explain the generation of alternating current using magnets.
3. Explain the function of turbines in the generation of electricity.
4. List and describe sources of energy and energy transformations to use to generate electricity.
5. Describe the parts and functions of a simple AC generator.
6. Describe the difference between fission and fusion as energy sources.
7. Build a wind vane and use it to investigate the power generated by wind.

Electromagnetic induction

Ten years after Michael Faraday created the electric motor, he returned to his electrical research and discovered how to create electricity using a magnet and a coil of wire. Faraday connected his apparatus to a galvanometer (an instrument that detects electric current), in a set-up similar to that shown in Figure 9.26. He discovered that when he moved the magnet back and forth through the coil of wire, which remained stationary, a current was created. Moving the magnet to the left into the coil created a current in one direction and moving the magnet right out of the coil created a current in the opposite direction. The magnetic field of the magnet exerted a force on the electrons in the wire, causing them to move, generating current. The production of a current in a wire by changing the magnetic field is called **electromagnetic induction**.

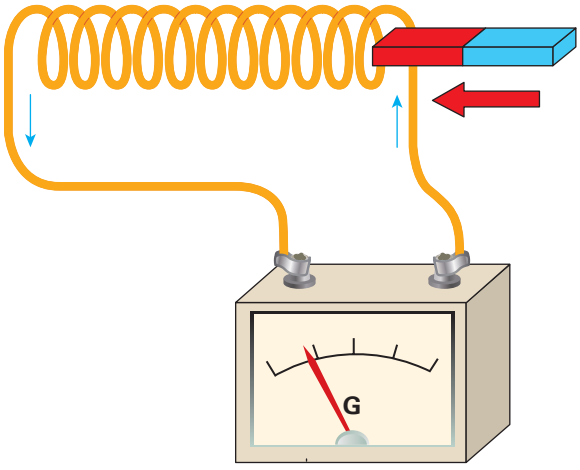


Figure 9.26 Using a magnet and a coil to generate electricity, detected on the galvanometer

electromagnetic induction the production of current in a wire due to a moving magnetic field

generator a device that converts kinetic (movement) energy into electricity

Faraday's induction coil was the world's first alternating current (AC) **generator**, although it did not have practical applications. A current is generated if there is movement between the coil and the magnetic field in relation to each other. The movement could be from just the magnet, just the coil or both. Therefore, it could be the magnet that is fixed and the coil that moves.

To generate sufficient electrical energy to run domestic appliances, tram and train networks, street lighting, hospitals, factories and so on, electrical energy must be produced on a massive scale. This could be done using the back-and-forth motion of a magnet in a coil, but producing this motion would require a mechanism that would also produce significant vibration and noise, and that would lose energy through friction. Fortunately, there is a much simpler form of motion that can be harnessed without these disadvantages.

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WORKSHEET
Faraday's Law

Quick check 9.8

1. **Explain** the term 'electromagnetic induction'.
2. **Describe** the first AC generator.
3. **Explain** the outcome of moving a magnet in one direction then the other through a wire coil.

Practical 9.3

Magnets can generate current

Aim

To generate current with a magnet

Materials

- bar magnet
- copper wire with a thin coat of insulation ('magnet wire' or enamelled wire)
- galvanometer
- cardboard tube
- wire stripper

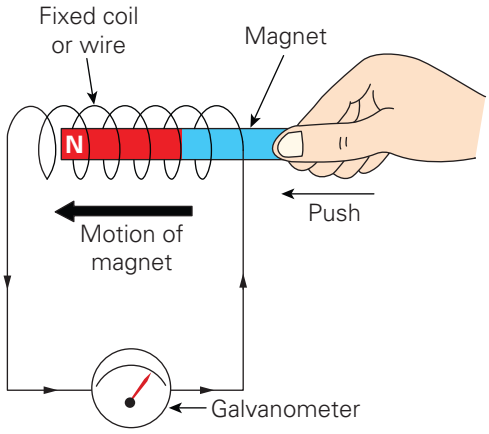


Figure 9.27 Experimental set-up

Method

1. Make your own solenoid by neatly wrapping the insulated copper wire around the cardboard tube, as shown in Figure 9.27.
2. Using the wire stripper, remove around 2 cm of insulation from each of the free ends of the wire.
3. Connect the free ends of the wire to the positive and negative terminals of the galvanometer.
4. Predict what you think will happen when you put the magnet bar inside your coil. Do it and observe the galvanometer needle.
5. Move the magnet back and forth inside the coil. What happens to the galvanometer's needle? Move the bar magnet faster or slower. Does it have an effect?
6. Now move the magnet bar back and forth outside the coil. How does this affect the galvanometer's needle?
7. Add more turns to your solenoid. What happens?

Results

Insert a picture or diagram of your construction and record your observations regarding how your current generator works.

Discussion: Analysis

1. Explain whether it was possible to predict how the galvanometer's needle would move, based on the movement of the bar magnet.
2. Explain how and why the speed of movement of the bar magnet affected the intensity of the current generated.
3. Describe what happened to the current generated when more coils were added.

Conclusion

1. Make a claim from this experiment regarding generators, current and magnets.
2. Support your statement by explaining how the data you gathered supports your claim.

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AC generators

Recall how the simplest type of electric AC generator, or alternator, consists of a coil of wire and a bar magnet being moved through the centre of the coil. The current flows in one direction as the magnet enters the coil and reverses direction as the magnet is pulled out, creating an alternating current. Another way of generating current is to rotate a magnetic field around a coil or rotate a coil inside a magnetic field.

Let us have a look at a simple AC generator, as shown in Figure 9.28. In an AC generator, there are two brushes and each brush makes contact with a **slipring**. The slipring passes the current from the rotating coil to the stationary circuit. These sliprings are electrically insulated from each other to complete the electric circuit around the coil. The circuit includes a load such as a lamp, a resistor or a motor.

slipring
a copper ring at the end of the armature of an AC electric motor or generator that rotates in contact with the brushes

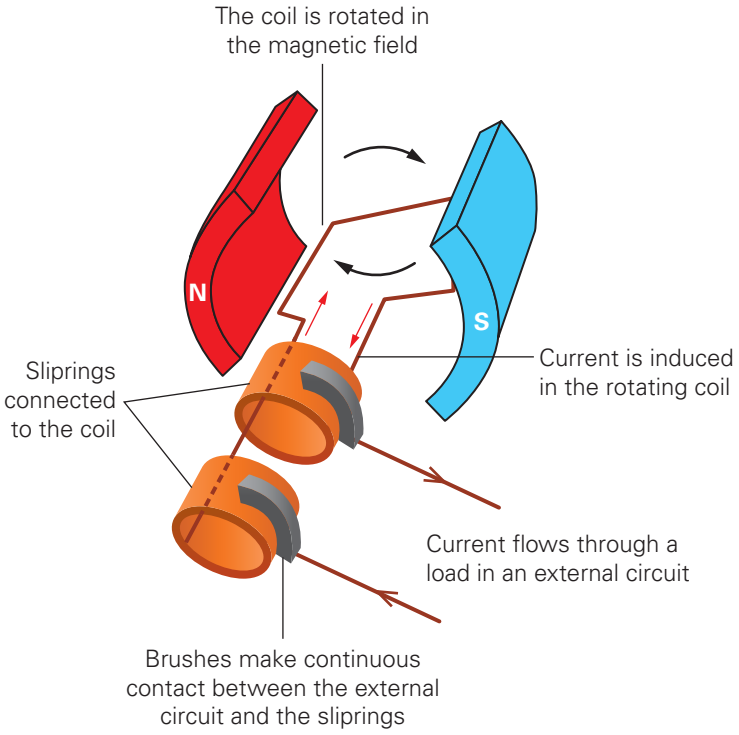


Figure 9.28 A simple AC generator (alternator) – a single coil rotating in the magnetic field of permanent magnets, inducing a current

The load for an AC generator could also be:

- a *transformer* that changes an AC input to a different voltage in a separate circuit
- a *rectifier* that contains an electronic circuit to convert AC to DC in order to power DC devices.



Figure 9.29 This smartphone charger has a mains AC input but a low-voltage DC output. The plug therefore contains electronic transformer and rectifier circuitry.

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The current produced by an AC generator is alternating as a natural consequence of the rotation of the coil in the magnetic field. The energy conversions of this process are that mechanical (kinetic energy) is transformed into electrical energy in the coil (see Figure 9.30). The electrical energy flows to the load, where it is transformed into some other kind of energy (e.g. kinetic, light or heat), depending on the device, to serve a useful purpose.

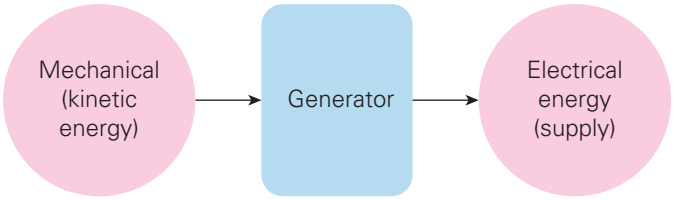


Figure 9.30 An energy-flow diagram showing the transformation of energy by an AC generator

For transmission and distribution of AC mains electricity, step-up transformers are used to increase the voltage for transmission over long distances (which reduces energy loss), then a step-down transformer is used to decrease the voltage for use by customers (see Figure 9.31).

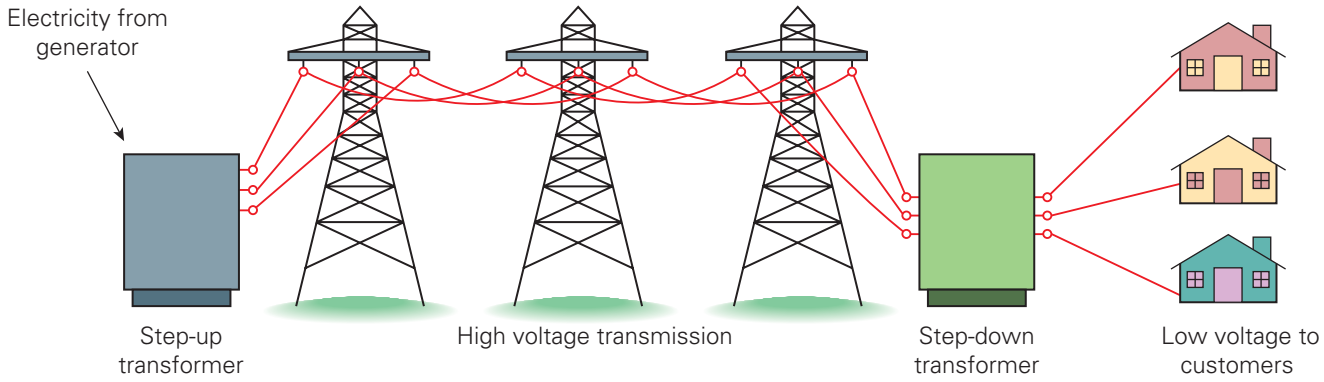


Figure 9.31 It is more efficient to use higher voltages to send electricity long distances.

Practical 9.4

Build a simple AC generator

Aim

To build a simple AC generator

Materials

- thick copper wire with a thin coat of insulation ('magnet wire' or enamelled wire)
- long sewing needles × 2 (with the eyes large enough to fit the copper wire through) or big metal paperclips × 2
- sandpaper or emery board
- modelling clay (or Blu-Tack)
- electrical (duct) tape
- strong bar magnets × 2 or strong U-shaped magnet × 1
- grain-of-wheat bulb with thin electrical wires to connect in a circuit
- a sensitive multimeter or galvanometer able to detect AC and DC

Method

1. Make a wire coil by wrapping the insulated copper wire 20 times around a cylindrical object of at least 2 cm diameter, leaving at least 5 cm of straight wire at each end of the coil. Slip the coil off and wrap the ends of the wire around the coil once to hold it together, leaving the ends sticking out, as shown in Figure 9.32. The same coil can be used as in Practical 9.2, but it should have at least 20 loops.

continued ...

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2. Remove all the insulation from 2–3 cm of both ends of the wire, all around, with the sandpaper.
3. Make two small balls of modelling clay and impale them on the sharp end of each needle.
4. Place the needles upright in a position to support each end of the coil as shown in Figure 9.32, ensuring that bare copper wire makes contact with the metal eyes of the needles.

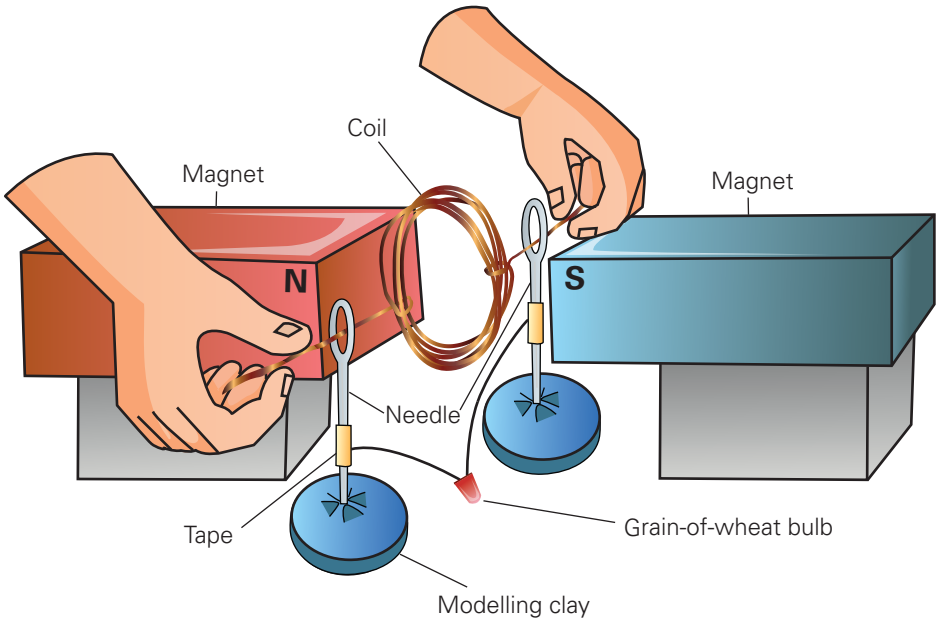


Figure 9.32 Experimental set-up

5. Hold each end of the coil between thumb and forefinger and rotate the coil by sliding thumb and forefinger in opposite directions. Make sure it rotates freely and contacts the needles all the time. Practise doing the motion alternately with each hand so that the coil rotates continuously in the same direction.
6. Connect the bulb between the needles by winding the ends of the wires around each one and fixing in place with electrical tape.
7. Place a magnet on each side of the coil, with opposite poles facing each other. You may need to use modelling clay to keep the magnets in place. If using a U-shaped magnet, it should be held by a clamp so the coil is between the ends of the magnet.
8. Rotate the coil, making sure the wire contacts the needles all the time by applying light downwards pressure against the needles.
9. Observe if the bulb lights. If it does not, check the connections in the circuit, and check that the coil is between opposite poles of the magnets and close enough to them.
10. When you have observed that the bulb lights, connect the multimeter across the needles, following its instructions for the detection of AC current. Rotate the coil constantly in one direction and record if AC is detected.

Results

In your science book, draw a picture or diagram of your construction and record your observations regarding how your motor operates.

Discussion: Analysis

1. Deduce what might happen if you used a coil with more loops.
2. Deduce what might happen if you used a stronger magnetic field.
3. Explain how the number of loops or the intensity of the magnetic field affects your generator.
4. Explain how the generator produces AC current.

Discussion: Evaluation

1. What faults might there be for this experiment and how could they be resolved?

Conclusion

1. Make a claim about the requirements for a functioning AC generator based on this experiment.
2. Support your claim by referring to your experimental observations.
3. Explain how your observations support your claim.

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Science as a human endeavour 9.1

Nikola Tesla and an invention inspired by poetry

In Budapest, Hungary in 1882, Serbian electrical engineer Nikola Tesla was walking in a park reciting to a friend some verses from the play *Faust* by the great German writer Goethe. This included the lines translated here:

> *The glow retreats, done is the day of toil;*
> *It yonder hastes, new fields of life exploring;*
> *Ah, that no wing can lift me from the soil*
> *Upon its track to follow, follow soaring!*
>
> Source: Johann Wolfgang von Goethe, *Faust: A Tragedy, Part I*, Translated by Bayard Taylor, Oxford University Press, 1988.

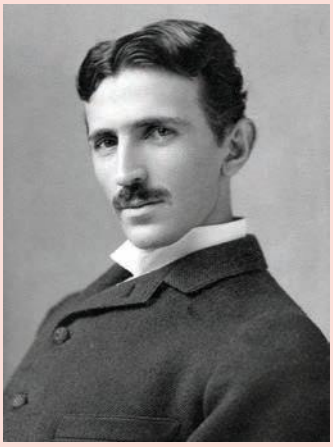


Figure 9.33 An 1890 photograph of Nikola Tesla (1856–1943) at age 34

In his work, Tesla had been trying to improve the electric motors of the time, which were DC-powered and so needed commutators to reverse the current direction in the coil. He had been wondering if AC, which reverses direction, could be used instead.

In the park that day, somehow, the poetic lines he was reciting made him think of rotating magnetic fields – perhaps it was the words about *new fields of life exploring*, coupled with the notion of *soaring*. He realised a motor using AC current without a commutator could exploit rotating magnetic fields to keep it turning. He excitedly drew a diagram with a stick in the dirt to explain the idea to his friend. This became one of his greatest inventions – the AC induction motor, which was both more energy-efficient and more reliable than DC motors. But of course, for widespread use, it needed an AC generation and transmission system.

In 1884, Tesla emigrated to the United States to work for the famous inventor Thomas Edison in New York. Edison had developed the world's first commercial power station in 1882, using DC, supplying users up to a kilometre away. While working for Edison, Tesla tried to persuade him that AC would be more efficient as there were lower energy losses during transmission, meaning that electricity could be transmitted much further. AC generators had been recently developed in Europe, but Edison thought AC was unnecessarily complex and more dangerous, since AC generators produced higher voltages. Having failed to persuade Edison, in 1885 Tesla left to start his own company. So began the 'War of the Currents', the more than decade-long rivalry between the two inventors. This rivalry has been featured in several documentaries and movies.

Tesla spent the next few years perfecting a complete *generation* → *transmission* → *usage* system. Our mains electric power system today is descended from Tesla's system, which itself was inspired by poetry.

Quick check 9.9

1. **Explain** how a simple AC generator produces alternating current.
2. **List** the energy transformations that occur with an AC generator.

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Turbines

Table 9.1 shows the main energy sources that are used to drive AC generators and where they are found in Australia.

Source	Sustainability	Energy transformations	Conversion devices	Type of power station
Water at a height	Renewable	Gravitational potential energy → kinetic	Water turbine	Hydroelectric power stations (dams and 'diversion' plants)
Tides	Renewable	Gravitational potential energy → kinetic	Water turbine	None currently operational in Australia
Waves	Renewable	Gravitational potential energy → kinetic	Water turbine (and other devices)	Some in Western Australia
Wind	Renewable	Kinetic	Wind turbine	Wind farms
Geothermal	Renewable	Heat → Steam (kinetic)	Steam turbine	None in Australia; some in New Zealand
Biomass fuel (plants or organic waste)	Renewable	Chemical → Heat → Steam (kinetic)	Furnace, boiler, steam turbine	Small-scale only
Coal (fossil fuel)	Non-renewable	Chemical → Heat → Steam (kinetic)	Furnace, boiler, steam turbine	The oldest type of industrial power station
Oil (fossil fuel)	Non-renewable	Chemical → Heat → Steam (kinetic)	Furnace, boiler, steam turbine	More modern industrial power stations
Gas (fossil fuel)	Non-renewable	Chemical → Heat → Steam (kinetic)	Furnace, boiler, steam turbine	Newest type of industrial power station
Nuclear (uranium)	Non-renewable	Nuclear → Heat → Steam (kinetic)	Reactor, steam turbine	None in Australia

Table 9.1 Energy sources to drive AC generators

You may notice in Table 9.1 that most large-scale production of electric power uses **turbines** to turn the generators. These turbines can be turned by steam (similar to the turbine in Figure 9.34), by falling water (hydroelectricity) or by wind (wind farms).

turbine
a type of machine that turns a wheel with blades to produce power

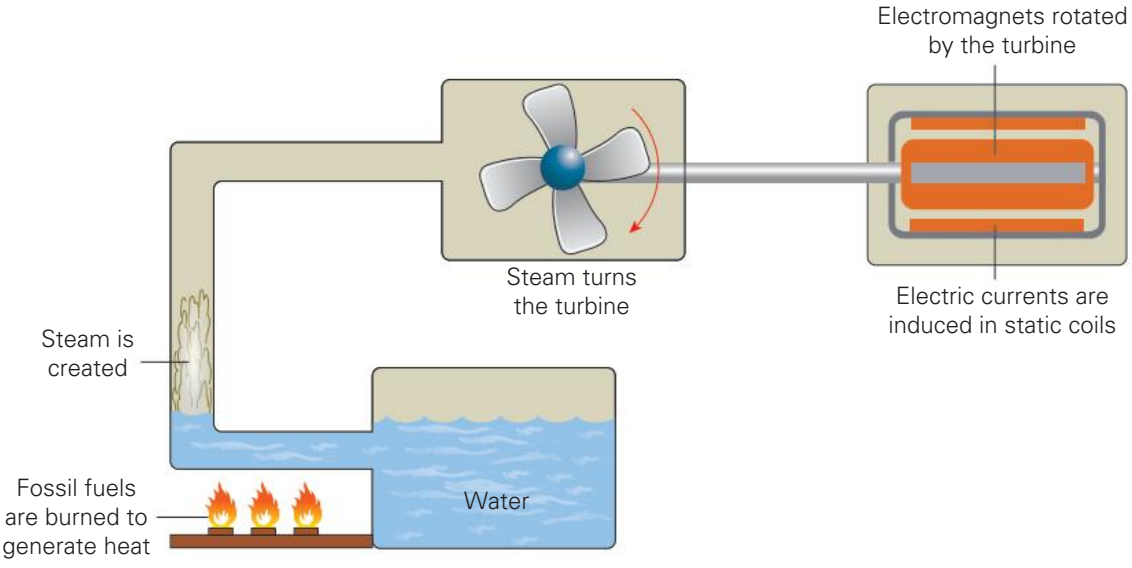
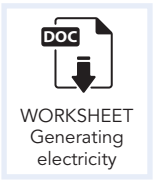


Figure 9.34 A typical steam turbine generator

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The turbine blades turn due to the expanding steam's considerable force on them. They, in turn, rotate the large electromagnets in the centre of the generator. The rotation of the magnetic field induces a large electric current and a high voltage in the static coils arranged around the rotating electromagnets.



WORKSHEET
Generating electricity

Steam-driven turbines

For steam turbines, the steam can be generated using various methods, such as burning coal, burning gas and harnessing nuclear energy.

In Australia, as at 2023, about 46% of our electrical energy is generated by coal-fired power stations. Coal-fired power stations transform the chemical energy stored in coal into electrical energy. Burning the coal produces intense heat, which is used to boil water to create very high-temperature (500°C) and high-pressure steam. The superhot steam applies force on the turbine blades, which then rotate electromagnets at 3000 revolutions per minute (3000 rpm) inside a static array of coils, inducing current in the latter. A typical modern coal-fired steam generator can generate 500–1000 million watts (500–1000 MW) of electric power per hour, with advanced generator types capable of producing 1000–1500 MW per unit per hour. The average power generated by the coal-fired power stations in Australia is around 1000 MW per hour.

nuclear fission reaction
the process by which an atom splits into two parts

In nuclear power stations, the energy required to boil water to produce the steam that turns the turbine blades is released in **nuclear fission reactions**. Australia does not have any nuclear power stations.

Quick check 9.10

1. In power stations that generate alternating current, **identify** the form of energy that is the direct input into the generators.
2. **Determine** whether the following statements are true or false.
   a) Some electric generators transform heat energy directly into electrical energy.
   b) The use of gravitational potential energy in electricity generation involves the use of water.
   c) Turbines in power stations are driven by AC electric motors.
   d) All AC power generation involves heat energy as an essential intermediate step.
   e) The output of AC power stations is kinetic energy.

Explore! 9.1

Fission versus fusion

Harnessing nuclear energy involves either splitting atoms (fission) or combining atoms (fusion). Nuclear power stations use fission to generate large amounts of energy, which is used to heat water and generate steam to turn a turbine. Use the internet to research the difference between fission and fusion as sources of energy. Find out why fusion is not yet used to generate power.

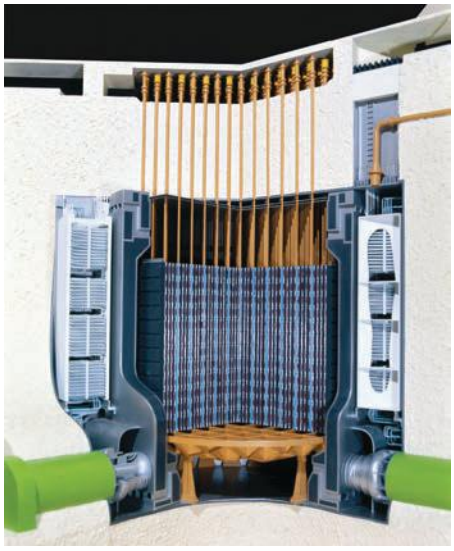


Figure 9.35 A cutaway model of a nuclear reactor, in which uranium fuel rods fit into a graphite core and produce heat by nuclear fission reactions. Gas circulates to extract the heat and heat water in a boiler (not shown) to produce steam to drive turbine generators.

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Water-driven turbines

In hydroelectric power stations, the energy used to turn the turbines is obtained from gravitational potential energy. Water falling from a great height turns the turbines directly with no need for high-pressure steam. This is how Australia's Snowy Mountains hydroelectric scheme generates approximately 7.5% (in 2018) of Australia's total electricity demands.



Figure 9.36 Turbines in Murray 1 power station. Murray 1 is the second-largest power station in the Snowy Mountains hydroelectric scheme. It has 10 turbine generators, each producing 95 megawatts of power (95 MW). Each turbine generates enough electricity to power 95 000 homes.

Similarly, tidal energy is a reliable source of energy. Huge amounts of water move around Earth as tides go in and out. The movement of this water can be used to turn turbines (see Figure 9.37). Since tides are caused by the interaction of gravitational forces between the Earth, Moon and Sun, as long as the Moon continues to orbit Earth and Earth orbits the Sun, there will be tides to generate electricity.

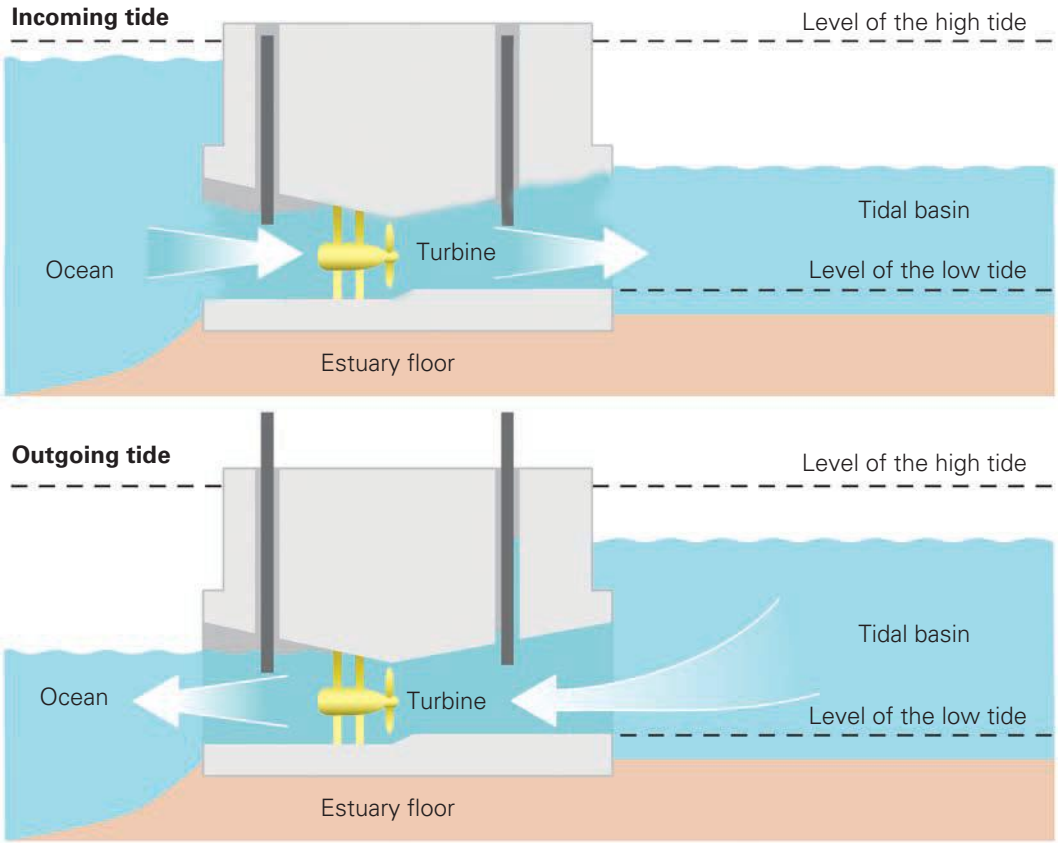


Figure 9.37 The movement of the water during incoming and outgoing tides is driven by gravitational potential energy due to the height difference of the water. This turns the turbines to generate electricity.

The energy of waves can also be harnessed. Waves are caused mainly by wind and wind is ultimately caused by differential heating of Earth by the Sun, and so originates as solar energy, which is transformed to kinetic energy. In some places on Earth, there are consistent winds that produce continuous waves. As they rise and fall, waves contain a tremendous amount of energy and various structures have been devised, some containing turbines, to convert this up and down motion into electric power.

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Wind energy

Wind energy is gaining popularity around the world. Australia is perfectly placed to construct and use wind farms to create electricity as there are extensive areas where wind harvesting is a viable option. Currently, Australia relies heavily on coal-fired power stations for a large portion of its electricity and this comes at a significant environmental cost. Australians produce massive amounts of greenhouse gases per head of population and are contributing to climate change. Figure 9.38 shows a modern wind turbine used to generate electricity. As of 2024, the cost to produce and install one of these turbines was estimated at between $2.6 and $4 million. Each turbine can produce around 2 MW of electricity.

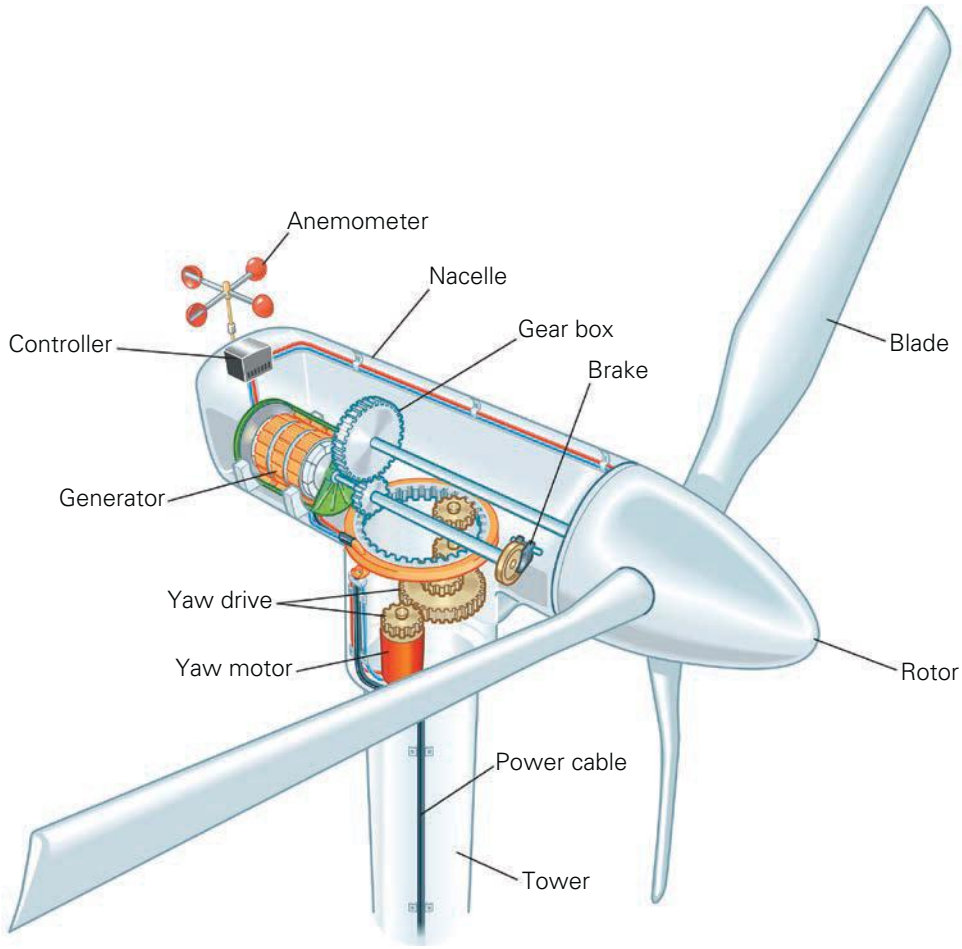


Figure 9.38 A modern wind turbine used to generate electricity. The wind power turbine-housing box sits 70 m above the ground, and each of the three blades is 35 m long. Each aerodynamically constructed blade has a mass of about 20 tonnes.

Although the blades on a wind turbine appear to rotate fairly slowly (about 20 revolutions per minute, 20 rpm), gearing inside the housing box increases this speed to 1800 rpm, as required by the electrical generator.

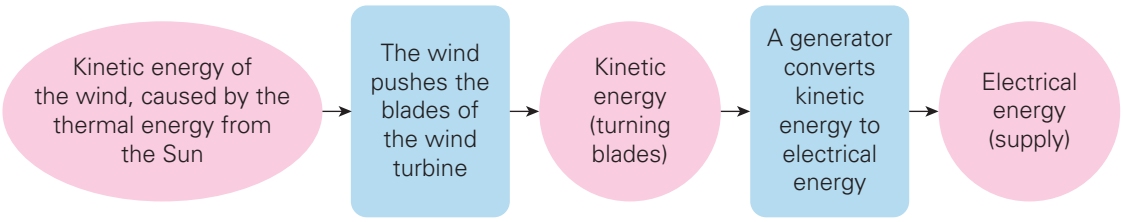


Figure 9.39 An energy-flow diagram for a wind turbine

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Practical 9.5

Constructing a wind turbine

Aim

To investigate the factors that affect power generated by a wind turbine

Materials

- small DC toy motor to be used as a dynamo
- pieces of insulated copper wire × 2, each about 50 cm long, with alligator clips
- rubber band
- 30 cm ruler
- cylindrical-shaped cork or Styrofoam ball
- paperclips × 4
- sticky tape
- cardboard
- fan or hairdryer
- DC voltmeter

Method

1. Use the rubber band to attach the DC motor to the end of the ruler.
2. Use the wires to connect the DC motor to the voltmeter.
3. Straighten the end of the paperclips and stick them into the cork so that they are equally spaced around it.
4. Cut four pieces of cardboard to act as the wind turbine's blades. Ensure that the pieces of cardboard are all the same size. Measure and record the length and width of the blades.
5. Use sticky tape to attach each blade to a paperclip.
6. Attach the cork to the shaft of the motor, ensuring that the shaft is in the centre of the cork.
7. Rotate the blades so that they are on a 45° angle, as shown in Figure 9.40.
8. Use the fan or hairdryer as a wind source to spin the wind turbine and record the voltage produced.
9. Repeat step 8 with the wind source at four different distances from the turbine.

Note that the motor does not spin the blades like a fan, the blades spin the motor, which acts as a dynamo. However, since it is not designed to be a dynamo, the voltage it produces will be small.

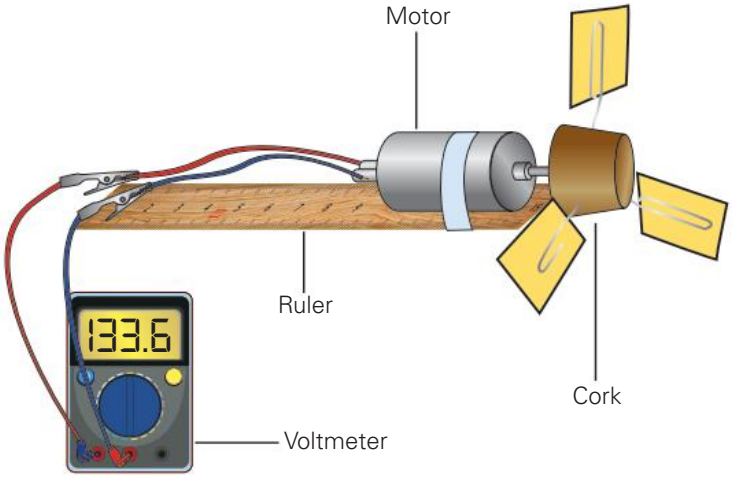


Figure 9.40 Experimental set-up

Results

Copy and complete the following in your science book.

Blade measurements:

Width: _____ Length: _____ Area: _____

Voltage generated:

Table showing the voltage generated at different distances from the wind source

Distance from wind source	Voltage generated

continued …

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Discussion: Analysis

1. Explain the relationship between the distance of the turbine from the wind source and the voltage generated.
2. Compare your results with those of another group with different-sized blades.
3. Summarise what factors affect the amount of voltage generated by a wind turbine.

Discussion: Evaluation

1. Describe the limitations of this practical.
2. Explain how this practical could be improved.

Conclusion

1. Make a claim about the factors that affect power generation by a wind turbine based on this experiment.
2. Support your claim by referring to your experimental data.
3. Explain how the data supports your claim.

Explore! 9.2

Generating electricity

Section 1: Energy sources – coal, solar and nuclear

For each energy source, investigate and report on the following.

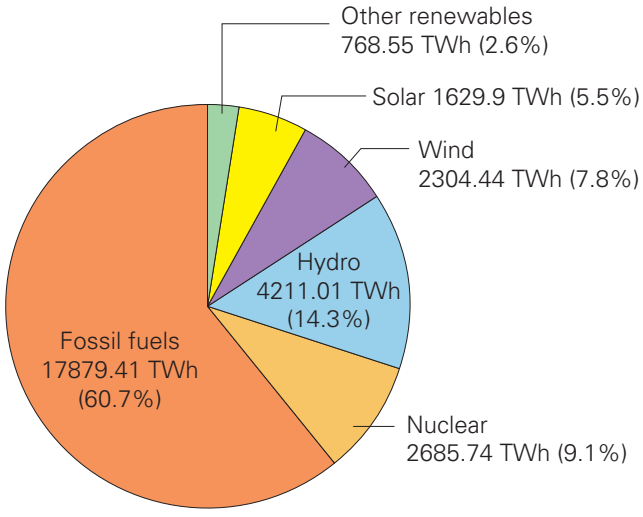
1. How is electricity generated?
2. What are the advantages and disadvantages of each method of electricity generation?
3. What are the environmental issues (good and bad) associated with each method of electricity generation?

Section 2: Australian states

1. Research the electricity production methods and their percentages for each state. Compare this with the percentages of electricity generated by each of these methods nationally. Present the data in a table or graph.
2. Which state in Australia is the biggest consumer of electricity? What percentage of the nation's electricity production does it consume, and what sector contributes most to that state's consumption?

Section 3: Australia and the world

1. Make a table to compare the methods of electricity generation and their percentage of total generation for each of the following countries: Australia, the United States, India, China and France.
2. Comment on the pie chart of global electricity generation by source (see Figure 9.41) with regard to the world's dependence on fossil fuels and the implications for climate change.



1 TWh = 1 terawatt-hour = 1 trillion watts for 1 hour.
1 TWh would run two million fridges for a whole year.
1 TWh is equal to 3.6×10^{15} joules.

Figure 9.41 Global electricity generation in 2023 by source. (Note: A watt is 1 joule of energy per second, so is a rate of energy; a watt-hour (Wh) is a unit of energy equal to 3600 J; the prefix 'tera-' means 10^{12}.)

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Making thinking visible 9.1

Compass points: New electricity generators

Life on Earth is mainly dependent on the renewable energy of the Sun, yet humans have been relying heavily on fossil fuels since the Industrial Revolution. Since the beginning of this century, however, due to growing environmental awareness, renewable energies have started to gain traction. The production of electricity using wind power-driven turbines, for example, has dramatically increased over the last two decades. Such technologies, however, are not practical for personal use by the average person.

Fortunately, work is being done to develop microgeneration technologies, such as small-scale wind turbines, micro hydro and solar PV systems, to enable small businesses and communities to meet their energy needs. This search for new ways to produce energy is a continuous endeavour, and researchers sometimes draw their inspiration from nature. For example, one area of research interest is on developing biomimetic trees (i.e. structures that mimic nature) that produce electricity as their artificial leaves bend in the wind. Prototypes of these trees are already undergoing field tests in urban environments for small-scale applications such as powering power sensors and streetlights.

Another interesting area of research for small-scale energy production involves wearable thermoelectric generators, where the temperature difference between the body and the outside environment creates a thermal gradient, which can be converted into electricity. South Korea currently leads the way in the design of wearable thermoelectric generators, making improvements in the stretch, durability and efficiency of this technology to the point that, in the near future, it might be possible to self-power small electronic devices using only our body heat.

In your book, draw a compass with North (N), South (S), East (E) and West (W) directions.

Thinking about the information above, next to each compass direction, answer the following questions.

1. E = Excited: What *excites* you about these ideas or propositions? What's the upside?
2. W = Worrisome: What do you find *worrisome* about these ideas or propositions? What's the downside?
3. N = Need to know: What else do you *need to know* or find out about these ideas or propositions? What additional information would help you to evaluate things?
4. S = Stance or suggestion for moving forward: What is your current *stance* or opinion on these ideas or propositions? How might you *move forward* in your evaluation of this idea or proposition?

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

Quick check 9.11

1. **Explain** the various ways in which electricity is currently generated.
2. **Explain** the new ways in which scientists and engineers are trying to generate electricity.

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Science as a human endeavour 9.2

Wireless charging

Wireless charging can transmit power without cables through electromagnetic induction. Nikola Tesla discovered this effect, and his early work is the basis of modern wireless charging. When AC flows through the coils in the wireless charging device, it creates an oscillating magnetic field. When a smartphone is placed on the charger, the magnetic field causes electrons to oscillate in a receiver coil inside the phone, creating an alternating current. This current is converted by a rectifier to DC to recharge the device's battery. However, wireless charging is not as efficient as corded charging; the current generated is lower, meaning it takes longer to recharge your device fully. In addition, if the coils in the device and the wireless charging pad are misaligned, more energy is wasted as heat instead.



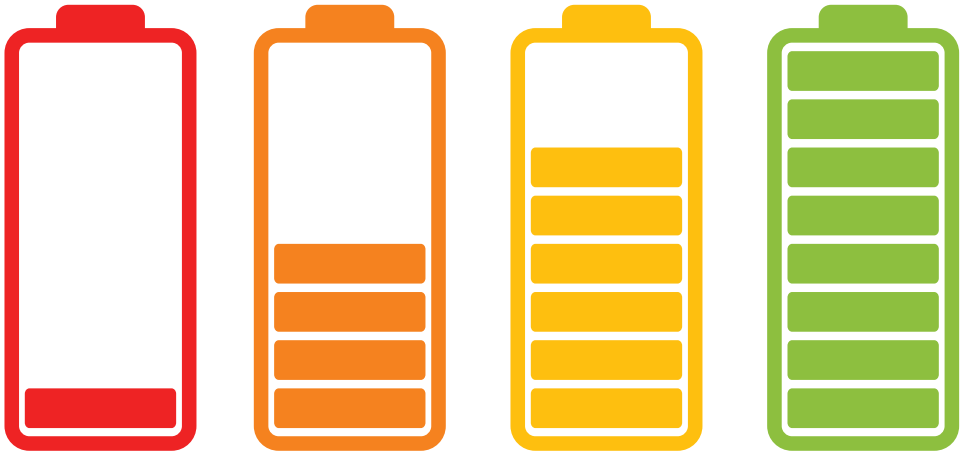
Figure 9.42 A smartphone on a wireless charging pad

A different approach to transmitting power uses electromagnetic waves, such as radio waves or light. Tesla himself tried unsuccessfully to transmit power by low-frequency radio waves. In 2022, researchers transmitted power to a device over 30 m away using lasers. Instead of using electromagnetic induction, this form of wireless charging converts light energy from the lasers into electricity using miniature solar panels (covered in the next section) as receivers. While this technology has a long way to go, it is likely that corded charging will eventually be a thing of the past.

Try this 9.7

Simple DC motor and AC generator: Venn diagram of parts

List the names of the parts of a simple DC electric motor and an AC generator, each in its own column, side by side on a sheet of paper. Add the names of the form of energy inputs and outputs for each one. Use different colours to highlight or circle the parts, inputs and outputs that are the same. Use this to create a Venn diagram showing the parts that are the same and the parts that are different for each one. Finally, write a one-sentence statement for each one that summarises what its distinguishing parts or inputs/outputs are.



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Section 9.2 review

Online quiz

Section questions

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Section 9.2 questions

Remembering

1. **State** the energy changes associated with an electric generator.
2. **Consider** if it is possible to have a device that is both an electric motor and an electric generator. Give an example.

Understanding

3. Faraday passed a magnet through a coil to generate electricity. **Explain** whether it is possible to keep the magnet stationary and have the coil move to make electricity.
4. **Explain** how a turbine can be made to rotate.
5. **Explain** how the rotation of a turbine can be used to produce electricity.

Applying

6. **Explain** why an AC generator does not need a commutator to produce AC current. **Outline** what it uses to transfer electric current from moving coils to a static circuit.
7. In the science laboratory you see a circuit set up with a switch and a battery labelled as rechargeable, connected to an enclosed, cylindrical device (which you can't see inside) on a stand. The cylindrical device has a drive shaft connected to a fan wheel with blades, which can turn. Without operating the circuit, **analyse** what the cylindrical device might be, and what function the circuit has. **Justify** your answer.

Analysing

8. **Discuss** how the energy of waves can be harnessed.
9. In Australia about 46% of our electrical energy is generated by coal-fired power stations. **Describe** how coal-fired power stations transform the chemical energy stored in coal into electrical energy.

Evaluating

10. **Evaluate** the level of take-up of solar and wind power generation given Australia's considerable solar and wind power potential.
11. **Evaluate** whether hydroelectric power is renewable and **list** the advantages and disadvantages of creating and using hydroelectric power.



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9.3 DC power generation

Learning goals

At the end of this section, I will be able to:

1. Describe the function and energy transformations of batteries.
2. Describe the function and energy transformations of photovoltaic panels.
3. Explain why batteries and photovoltaic panels produce direct current.
4. Compare the production of AC and DC power.

Did you know? 9.2

Dynamos

A bicycle headlight is an example of a DC generator called a dynamo. As the bicycle moves, the rotating wheels turn a magnet inside a stationary coil. This induces a current in the wire that generates enough electricity to power the headlight.



Figure 9.43 A simple DC generator can power a bicycle headlight.

As we learned in the last section, generators (alternators) can be used to produce electricity as AC power. Generators can also produce electricity as DC power (dynamos), although their large-scale use is not common today, except in some industrial applications. Modern DC generation is chiefly carried out by solar panels and batteries.

Batteries

chemical reaction a process or chemical change that transforms one set of substances (the reactants) into another set of substances (the products)

battery an electrical energy storage device that produces a direct electric current (DC) by means of chemical reactions

reactant a substance that is reacting in a chemical reaction

It was noted at the beginning of this chapter that to produce an electric current, electrons need to be moved. Besides using magnets, another way to move electrons is through **chemical reactions**. Chemical reactions occur when reactants interact and change into products. Some chemical reactions involve the movement of electrons and this can create a steady electric current. This is the basis of **batteries** (electrical cells), which transform chemical energy in a reaction to electrical energy. When the **reactants** are used up, the current stops. In so-called primary batteries, the electricity originates with the reactants, meaning that the battery has not previously been charged up with electricity. Batteries that can't be recharged are discarded (which has safety and environmental issues) or recycled.



Figure 9.44 A great variety of batteries power modern devices, and all supply direct current.

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The reaction that produces the electricity in a battery may be reversible, in that electrical energy can be supplied to the 'dead' battery to regenerate the reactants, thus recharging the battery. It may be possible to recharge a battery hundreds of times, but eventually most stop working effectively, and should then be recycled.

The first batteries were 'wet cell' batteries (see Figure 9.45). In this kind of battery, the reactants are placed in the container (the cell), one of which is liquid – an acid or alkaline solution, called the **electrolyte**. The electrolyte reacts with the two solid **electrodes** in the battery (i.e. the negative anode and the positive cathode), causing ions to pass between them through the electrolyte, and electrons to flow through a conductor placed between the electrodes. The resulting electric current can drive a load, such as a light or a small motor. The current produced is direct current (DC) because the reaction is steady and proceeds in one direction, from reactant to products.

electrolyte
a liquid or paste in a battery through which ions travel to take part in the chemical reactions that power the battery

electrode
a structure, usually solid, that makes contact with the electrolyte in a battery and takes part in the chemical reactions that power the battery; it serves as a terminal, where a load can be connected; one is positive (the anode) and the other is negative (the cathode)

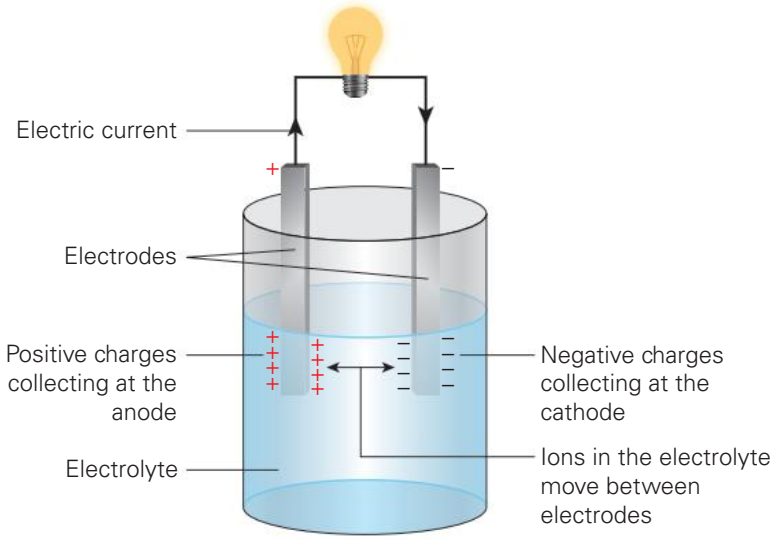


Figure 9.45 A wet cell battery, also called a galvanic or voltaic cell. Chemical reactions between the electrolyte and electrodes cause electrons to flow in the wire from the negative electrode (the cathode) to the positive electrode (the anode). Remember, when electrons flow, electricity is being produced.

Lead-acid batteries, based on reactions between lead and lead oxide electrodes and sulphuric acid electrolyte, are the most common wet cells today. You may have seen one connected to your car engine. They are used to start internal combustion engines, so they are found in many vehicles. These batteries are rechargeable.

Wet cells have a major disadvantage: the electrolyte can leak out, making them susceptible to damage. Further, the electrolyte is usually hazardous – corrosive or toxic. However, there is another kind of battery, a 'dry cell', in which the electrolyte is a paste, gel or other semi-solid, making it spill-resistant (see Figure 9.46). Despite their name, however, dry cell batteries are not completely dry or solid.

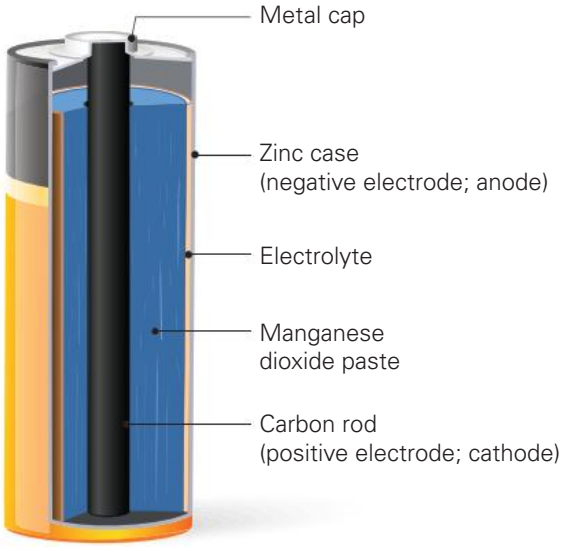


Figure 9.46 A modern 'dry cell' battery. Chemical reactions between the manganese dioxide electrolyte (in paste form) and zinc and carbon electrodes cause an electric current to flow when a circuit is connected.

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Explore! 9.3

Rechargeable battery types

Research types of rechargeable batteries used in electronic devices as well as smartphones, laptops and electric vehicles. Search for advances in battery technology. Write a brief report that:

1. analyses how these battery types compare to the zinc-carbon-manganese dioxide dry cell shown in Figure 9.46
2. lists the advantages and disadvantages of each type
3. evaluates three future improvements being developed in battery technology.

Did you know? 9.3

Other electricity storage devices

Experimentation with electricity was inspired by curiosity about static electricity and lightning. In the case of lightning, electrostatic charge builds up in thunderclouds and discharges via lightning due to the voltage difference between Earth's surface and the cloud base. Certain organisms, such as the electric eel, can also separate and store charges using capacitor-like structures in their bodies. These charges can then be released as a devastating shock for defence or to stun prey. These early experiments led to the invention of the Leyden jar (see Figure 9.47), which could store a significant electrical charge and discharge it when connected to a conductor.

However, capacitors are poor storage devices compared to batteries, storing less energy and releasing it faster, with less control. Nevertheless, capacitors remain a critical part of modern electrics and electrical systems, where they are used to smooth out fluctuations in electrical current by filtering and stabilising voltage. In circuits, they can block unwanted signals, store energy for quick bursts (like in camera flashes) and help manage power for devices like smartphones and computers.

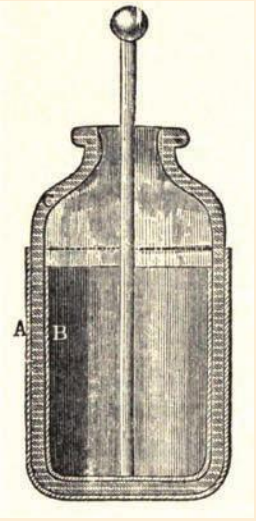


Figure 9.47 The Leyden jar was one of the first capacitors. The jar could store a significant electrical charge and discharge it when connected to a conductor.



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Quick check 9.12

1. a) **Describe** the main components of batteries, including their role in an operational battery.
   b) **Draw** a flow chart showing the energy transformation that occurs in a battery when it is powering a circuit.
2. **Explain** why batteries produce direct current rather than alternating current.
3. **Explain** why the electric current produced by a battery eventually stops.

Solar panels

You have probably seen solar panels or **photovoltaic (PV) panels**, powering garden lights, on a calculator or on top of houses. These panels contain an array of photovoltaic (PV) cells, which capture the Sun's energy and convert it into useable electricity. As in the case of batteries, electricity is produced by PV cells without any mechanical parts. The functional part of the PV cell is made of two types of silicon material. When photons of light (with sufficient energy) are absorbed by the top silicon material, the electrons become excited and dislodge from their atoms. The top material's surface is treated during manufacturing to make it more attractive to free electrons, causing them to move there. This creates a charge imbalance between the front and back surfaces of the cell, much like the positive and negative terminals of a battery. When connected in a circuit, the free electrons can flow (i.e. electricity is produced). The current in the circuit is DC because the electrons can move in only one direction.

photovoltaic (PV) panel
a thin flat structure made of two materials (usually silicon-based) that, when photons of light are absorbed, have the property of separating electric charges; it creates a flow of electrons that produce a direct current

inverter
an electronic device that converts DC to AC

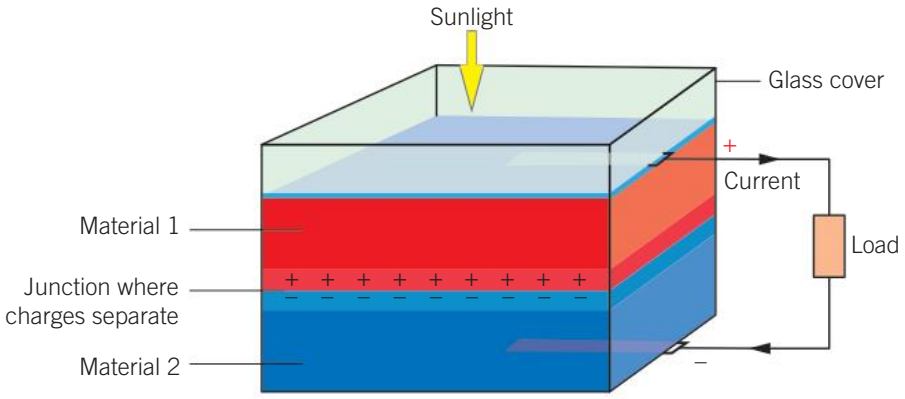


Figure 9.48 A 3D cross-section through a photovoltaic panel, with a circuit diagram. The electron flow is in the opposite direction to the current flow shown here.

Where solar panels are used to feed power into the main electricity grid, a building's mains supply or AC appliances, a device called an **inverter** is needed to convert DC to AC.



Figure 9.49 Solar or photovoltaic (PV) panels on the roof of a house produce DC. Each panel is made up of a number of smaller PV cells, which are typically 150–200 mm in size.



Figure 9.50 An inverter installed in a house to convert the DC from its solar panels to AC to feed into the mains electricity supply.

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Try this 9.8

Solar panels

Write a simple practical report for each of the following investigations.

1. Investigate, under the same lighting conditions, how different numbers of cells, different ways of connecting the cells and different orientations of the cells change the electric output the cells produce.
2. Using the set-up from (1) that gave the highest electric output, investigate what electric output can be obtained under different lighting conditions, such as full sunlight, shade from clouds, shade from trees or buildings, and indoor lighting.

For this activity, you will need:

- a solar panel kit with several solar cells that can be connected in different ways
- a load (e.g. light or spinning fan)
- a bright light source or access to sunlight
- a multimeter (optional).

Explore! 9.4

Efficiency of photovoltaic cells

A single domestic PV panel with a size of 1 m by 1.6 m typically produces about 400 W of power (400 joules of energy per second) with a voltage of 15–30 V. Panels can be connected in series to increase the total power and voltage produced. In 2024, commercial domestic panels had an efficiency of about 20%, meaning that to produce 400 W of power, around 2 kW of sunlight must have fallen on the panel. Increasing the efficiency of solar panels would be beneficial in terms of the number of panels required, their power output and the energy captured.

Using reliable and trustworthy websites, research the following.

1. Commercial domestic panels in Australia: compare the efficiency of three different types or brands.
2. Advances in photovoltaic panel efficiency: compare three different approaches or technologies, stating the efficiencies reached.

Quick check 9.13

1. **Describe** how a PV panel generates electricity.
2. **Explain** why a PV panel produces DC, and what is needed to enable an AC appliance to be powered by a solar panel.
3. **Justify** why research should be carried out to improve the efficiency of PV panels.



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Integration of solar panels and batteries

Unlike hydroelectric, fossil fuel and nuclear power generation, solar power uses an intermittent energy source. That is, there is not a constant supply of sunlight for solar panels to capture. Wind has a similar problem.

The solution is to integrate solar and wind power with battery technology into a complete system. Excess power in sunny and windy conditions can then be stored in batteries for use at night or on calm days. Figure 9.51 shows a domestic battery installed on the wall of a house.



Figure 9.51 A Tesla Powerwall 2 installed on a residential home. Energy generated by solar panels can be stored in the lithium-ion battery.

Households with solar panels but no domestic battery, or not enough storage capacity, can feed electricity from their solar panels into the mains grid, often receiving a credit against their electricity bill.

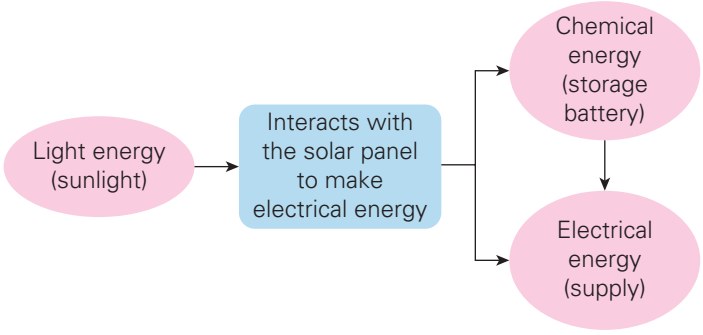


Figure 9.52 An energy-flow diagram for a photovoltaic solar panel with a storage battery

In addition to domestic batteries, there are larger batteries that can be used by a whole community, and even grid-scale battery installations the size of warehouses.

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Try this 9.9

AC and DC power: Venn diagram

Reflect on what you have learned about the generation of electricity. Create a Venn diagram that compares the production of AC and DC power. Think about their characteristics, how they are produced, their applications, and their advantages and disadvantages.

You may wonder why Venn diagrams are a teacher's best friend. The benefit of using one is that you, the student, have to organise your thoughts and make decisions, while your teacher can see what you are thinking and help you with any tricky ideas. You end up with a lovely diagram summarising key similarities and differences, and a much better understanding of the concepts.

Go online to access the interactive section review and more!

Section 9.3 review

Online quiz 

Section questions 

Teachers can assign tasks and track results 

Section 9.3 questions

Remembering

1. **Describe** the energy changes associated with a battery.
2. **Describe** the energy changes associated with a photovoltaic panel.

Understanding

3. **Explain** whether the process by which a battery generates an electric current is reversible. Provide an example of the 'normal' and 'reverse' operation for a battery.
4. **Explain** what 'efficiency' means with regard to photovoltaic panels. **State** the typical efficiency of a domestic solar panel.

Applying

5. A photovoltaic panel is going to be used to provide the electrical energy for an emergency AC radio for hikers. This emergency radio will be fixed to an information point in a wilderness area. **Identify** and **justify** two other devices that need to be placed in the circuit to ensure the radio works at any time of the day or night.
6. A toy company wants to design an electrically powered model plane. **Analyse** what characteristics the battery should have. **Suggest** the best type of battery to use in this plane.

Analysing

7. **Analyse** the issues that need to be addressed for the following situation: A populated island, with no external connections to a power source, wants to use 100% renewable energy sources to generate a reliable electricity supply 24 hours a day.
8. **Identify** and **justify** the benefits for the environment in adopting solar panels for large-scale electricity generation in the country and in urban areas.

Evaluating

9. A family uses 5200 kWh of electricity per year (kWh = kilowatt-hours, a measure of electrical energy used by power companies). They pay 35 cents per kilowatt-hour for their electricity. They install a 6 kW solar panel system for $6250, which saves them 4000 kWh per year. They start the system at the beginning of the year. To the nearest month, **evaluate** how long it will take for their savings on the electricity bill to pay for the cost of the installation.
10. **Evaluate** the hazards posed by batteries and suggest measures to reduce these hazards.

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Chapter review

Chapter checklist

Success criteria		Linked questions
9.1	I can define 'electromagnetism'.	1
9.1	I can use the right-hand grip rule.	6
9.1	I can explain the role of electromagnets in simple electronic devices.	7
9.2	I can define 'electromagnetic induction'.	2
9.2	I can explain the generation of alternating current using magnets.	9
9.2	I can explain the function of turbines in the generation of electricity.	10
9.2	I can list and describe sources of energy and energy transformations to use to generate electricity.	3
9.2	I can describe the parts and functions of a simple AC generator.	9, 11
9.2	I can describe the difference between fission and fusion as energy sources.	4, 14
9.2	I can build a wind vane and use it to investigate the power generated by wind.	10
9.3	I can describe the function and energy transformations of batteries.	5
9.3	I can describe the function and energy transformations of photovoltaic panels.	18
9.3	I can explain why batteries and photovoltaic panels produce direct current.	8, 12
9.3	I can compare the production of AC and DC power.	9, 10, 11, 12, 13, 19

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Remembering

1. **Define** 'electromagnetism'.
2. **Define** 'electromagnetic induction' and provide an example of what happens when a magnet is moved inside a wire coil.
3. **List** three sources of renewable energy and three sources of non-renewable energy that can be used to generate electricity.
4. **State** the two types of nuclear energy and **describe** two differences between them.
5. **List** three essential components of a battery.
6. **Recall** what the right-hand grip rule tells you.

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Understanding

7. **Explain** how an electromagnet works.
8. **Explain** what devices are needed, and why, in a charger to charge the battery in an electronic device from the mains supply.
9. A device with rotating coils and permanent magnets has a metal ring split into segments that contact carbon brushes attached to a circuit. **Explain**, with reasons, whether this is an AC or DC device.
10. **Explain** how the blades of a turbine function to rotate the turbine, and **contrast** a turbogenerator with an electric fan.

Applying

11. Use Figure 9.53 to answer the following questions.
    a) If the coil is kept rotating in the same direction, **identify** whether the current through the load will be AC or DC.
    b) **Justify** your answer to (a) with reference to the alternator.

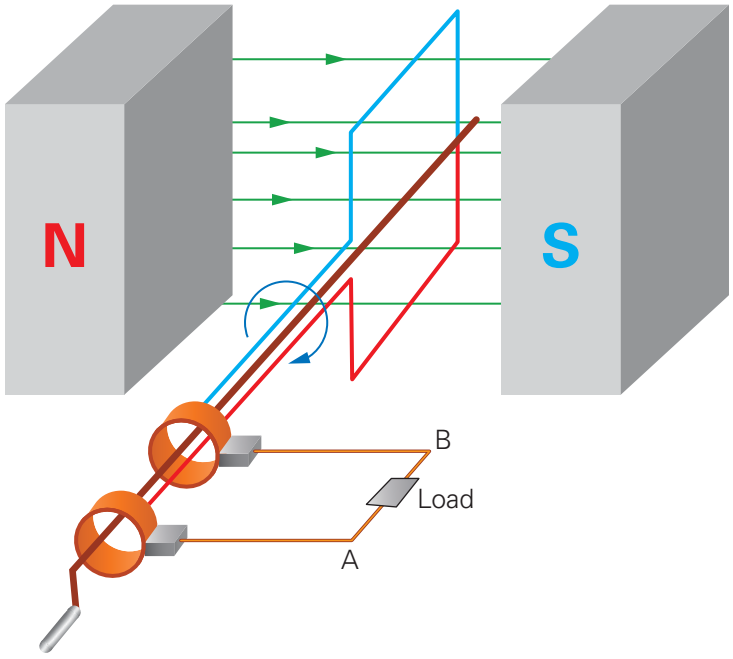


Figure 9.53 A simple electric generator



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12. Figure 9.54 illustrates a simplified flow diagram of the electricity supply for a house. It shows three inputs (supplies), four outputs (powered devices) and a house battery. **State** whether the following supplies and devices are likely to be AC, DC or either.

- **a)** Mains supply
- **b)** Wind turbogenerator
- **c)** Solar panels
- **d)** Appliances (e.g. for heating, cooking and washing)
- **e)** Mains voltage power sockets
- **f)** Lighting
- **g)** House battery
- **h)** Electric vehicle charging outlet

13. The boxes labelled i, j and k in Figure 9.54 represent the devices other than transformers that need to be integrated into the circuit. **Suggest** what each of these devices are, giving reasons.

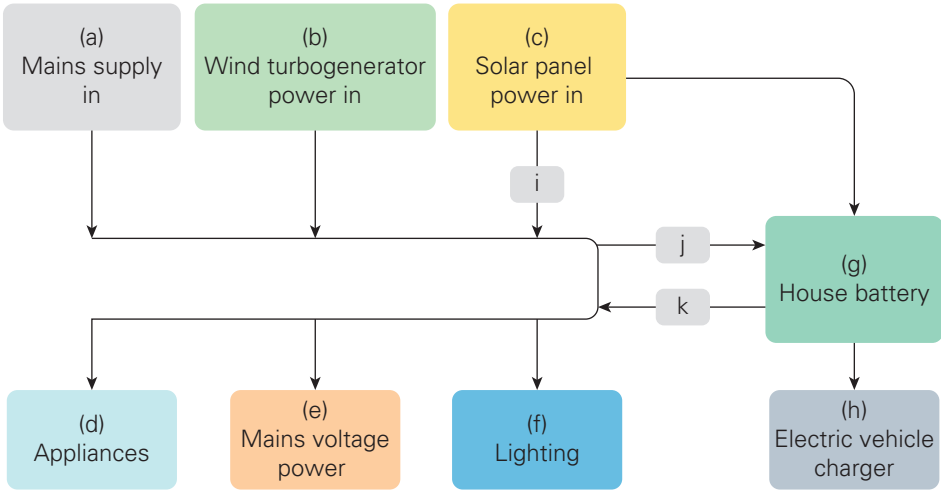


Figure 9.54 Electricity flow diagram

Analysing

14. Copy and complete the following table to **compare** the advantages and disadvantages of AC and DC power generation and distribution.

	AC	DC
Advantages		
Disadvantages		

15. **Discuss** the extent to which nuclear fission and fusion energy could be considered renewable or non-renewable sources of energy. In your discussion, compare these with non-renewable sources such as coal and gas.

16. **Discuss** the extent to which electromagnetism, discovered by Ørsted in 1820, and electromagnetic induction, discovered by Faraday in 1831, are opposite effects.

17. In the simple AC generator studied in this chapter, the magnetic field was supplied by permanent magnets. **Explain** whether the magnetic field could be supplied by electromagnets.

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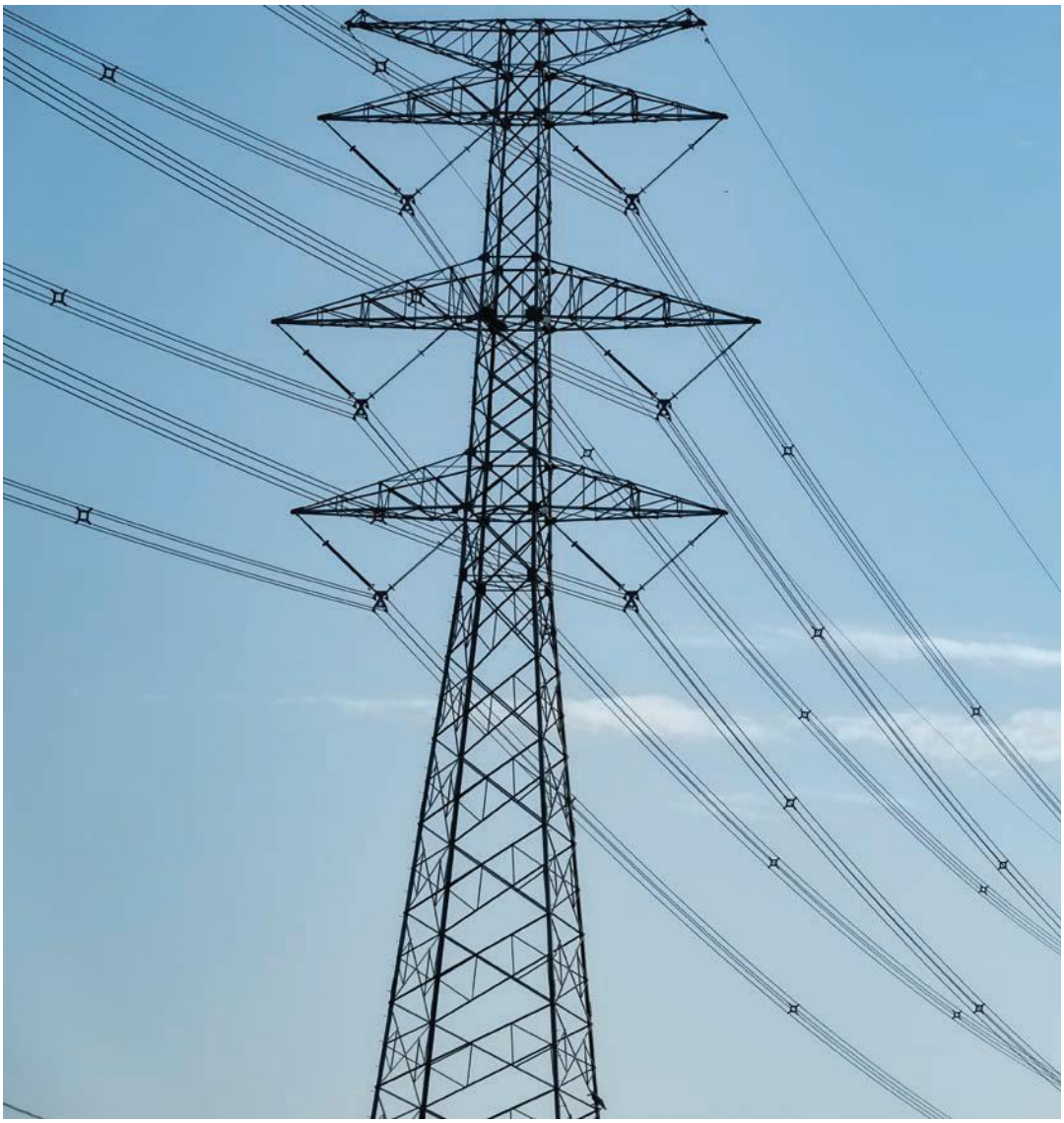
Evaluating

18. A single solar panel produces 400 W of power in full midday sun with an efficiency of 20%.

- **a)** **Convert** the power output of the panel to joules of energy per second.
- **b)** If the panel is upgraded to one with an efficiency of 30%, **calculate** how much power it will produce in watts when the same level of solar energy falls on it.
- **c)** The average power output for the panel for a 12-hour day is 200 W. **Calculate** how much energy in kilojoules it produces in a 12-hour day.
- **d)** If the mains electricity company charges 40 cents per kilowatt-hour for mains electricity, **calculate** how much the owner saves per day on their electricity bill by using the solar panel. Use the conversion 1 kWh = 3.6 MJ.

19. **Evaluate** what source of energy, type of generator and extra connected devices would be best for the following situations, giving reasons.

- **a)** A remote holiday cabin to provide basic lighting and sockets for charging phones and laptops; no electric appliances or heating
- **b)** A holiday home that is off the main grid but needs to be fully equipped with domestic appliances
- **c)** A community of homes, shops and rural industries in a valley in a hilly area with plenty of rain



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Data questions

A family living in rural Victoria is considering installing solar panels on the roof of their house. They are trying to rely less on fossil fuel energy sources and move towards more sustainable sources of energy.

The average solar panel energy generation over a 2-week period in summer and winter is illustrated in Figure 9.55. The average daily energy usage for a family of their size is around 20 kW/h.

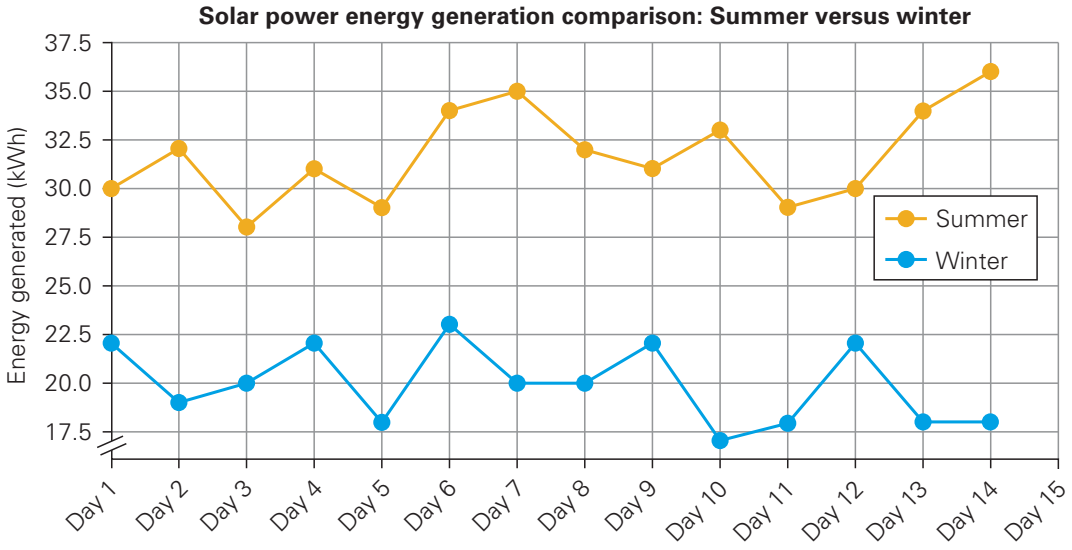


Figure 9.55 Solar panel energy generation over a 2-week period in summer and winter

Applying

1. **Identify** in which season the solar panels produced the most energy.
2. **Determine** which day had the lowest energy production in summer and **explain** why this may have happened.
3. Using data from the graph, **calculate** the average amount of electricity generated over days 1–7 in both summer and winter and **explain** the difference.

Analysing

4. **Identify** which day in summer and in winter shows the highest energy production.
5. **Determine** the difference in energy production in summer and winter on day 9.
6. If an energy supply company pays 10c per kWh of power that is fed back into the grid, and assuming an average use of 20 kWh per day, **calculate** how much money this family could earn over the summer months.

Evaluating

7. **Discuss** whether this family would be able to rely solely on solar panels for their energy needs. Use data from the graph to **justify** your response.
8. **Suggest** whether or not this data is sufficient for the family to make a decision about whether it is worth the cost of installing solar panels.
9. **Propose** a question about how the data in Figure 9.55 was collected that would help to **determine** whether it is useful to the family or not.

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STEM activity: Building a prototype to use the heat energy from the Sun

Background information

In today's world, much of the electricity we use is generated by burning fossil fuels such as coal, oil and natural gas. While these resources have powered the world for decades, they come with significant environmental costs, including air pollution and the release of large amounts of carbon dioxide, which contributes to climate change. As we become more aware of these impacts, there is a growing need to reduce our reliance on fossil fuels and shift towards renewable energy sources.

One promising alternative is solar energy. The Sun provides an abundant and renewable source of energy in the form of light and heat. One common method of harnessing this energy is through solar panels, which convert sunlight into electricity using photovoltaic (PV) cells. These cells capture sunlight and transform it into usable electrical power. Solar panels are increasingly being used in homes, schools and businesses to reduce dependence on fossil fuels and lower energy costs.

In addition to solar panels, there are other ways to capture and use the Sun's thermal energy directly. For this activity, you will design a method to capture thermal energy from the Sun and explore how this energy could be used in your school. Your solution could involve anything from heating water to using thermal energy in the school's tuckshop. The goal is to reduce the school's reliance on fossil fuels and make it more environmentally friendly.

DESIGN BRIEF

Design a method of capturing thermal (heat) energy from the Sun and propose a method of using this energy in your school.

Activity instructions

In this activity, you and your colleagues will collaborate and build a prototype that uses the heat energy from the Sun and transforms this into a usable form.



Figure 9.56 Solar energy has the potential to revolutionise the energy sector worldwide as we work towards mitigating the effects of climate change.

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Suggested materials

- clear beaker that holds at least 200 mL of water
- thermometer that reads between 0°C and 100°C
- black or blue water-soluble ink
- stopwatch
- scales accurate to at least 1 gram
- mirrors
- cardboard
- rubber/plastic tubing
- black paint

Suggested location

School oval or soccer pitch on a sunny day

Research and feasibility

1. Research solar thermal energy and how technology is used to capture heat energy.
2. Research the number of sunny days in your area and sunlight hours available for energy capture.
3. List all the ways heat energy is captured and how the energy is used.

Purpose of heat energy capture	Heat transfer
(e.g. heating pool) Water in pool	Pool water will increase in temperature.
(e.g. heating pool) Black plastic tubing on house roof	Water is pumped through the black tubing, which absorbs the heat energy from the Sun and pumps this into the pool.

Design and sustainability

4. Decide how you and your group plan to use the heat energy and discuss the sustainability aspects of your prototype creation. For example, will the energy captured from the Sun be greater than the energy required to build the device?
5. Design a prototype that will use heat energy from the Sun and be usable in your school.
6. Annotate your design and list all the heat transfers and transformations.

Create

7. Build your prototype and test your design using a thermometer.
8. Extension: Create a business logo that matches your prototype idea.

Evaluate and modify

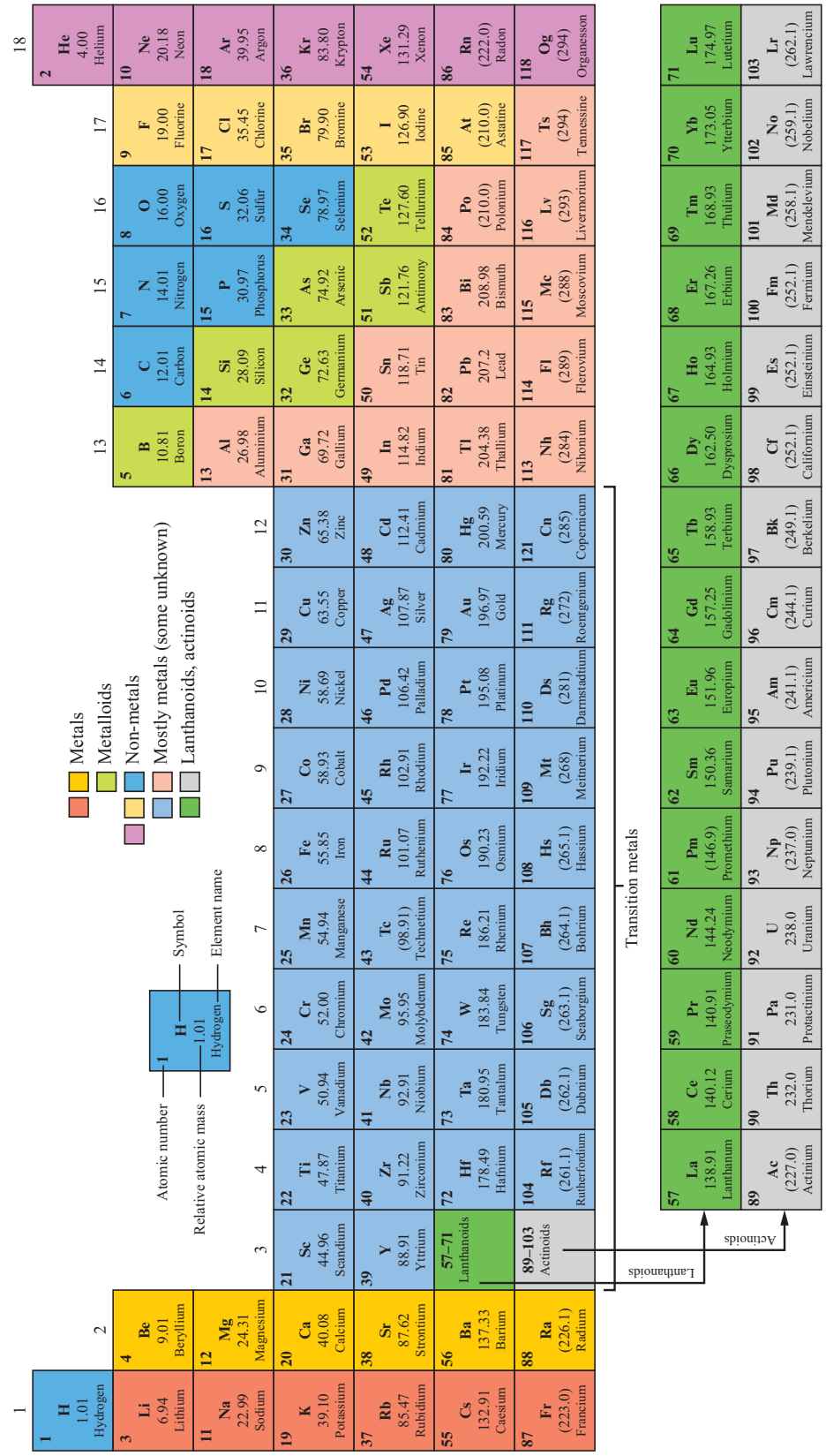
9. Present your prototype to the class with your measured energy capture.
10. Discuss the suitability of your design for a school and whether it could be used in other locations.

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Appendix

The periodic table



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Glossary

accurate measures closely match the 'true' or accepted values

action potential the electrical impulse (message) that is transmitted along a neuron

alpha particle a positively charged particle that is emitted from the nucleus of some radioactive elements during the radioactive decay (or disintegration) of an unstable atom

alternating current (AC) a form of electricity in which the current reverses direction in regular cycles (though the electrical energy associated with the current flows in one direction)

amplitude the distance (height) of a wave crest or the depth of a wave trough from the midline of the wave

anthropogenic caused or influenced by people

antibiotic a type of medication used to treat bacterial infections

antibody a Y-shaped molecule that binds to specific antigens

antifungal a type of medication used to treat fungal infections

antigen a substance that induces an immune response in the body

antiseptic a substance that stops or slows down the growth of microorganisms; used externally on skin

antiviral a type of medication used to treat viral infections

armature the rotating coil that forms part of an electric motor

asexual reproduction a method of reproduction in which a single parent produces offspring genetically identical to itself

atmosphere the mixture of gases above the surface of Earth

atoms the building blocks of matter

atomic number the number of protons in an atom of an element

autonomic nervous system the part of the peripheral nervous system involved in involuntary physiological processes such as heart rate and digestion

bacteria (singular: bacterium) microscopic, unicellular (single-celled) organisms

balanced when a chemical equation has an equal number of atoms of each element on both the reactant and product side of the equation

battery an electrical energy storage device that produces a direct electric current (DC) by means of chemical reactions

beta particle a negatively charged particle (electron) that is emitted from the nucleus of some radioactive elements during radioactive decay (or disintegration) of an unstable atom

binary fission a type of asexual reproduction in which the cell divides, creating two identical cells; the most common form of reproduction in prokaryotes, such as bacteria

bioaccumulate when the concentration of a substance increases inside a living organism, as intake exceeds excretion

biodiversity the variety of species, ecosystems and genes that exist in a particular area

biomass the material produced by the growth of plants, animals and microorganisms

bioplastic a type of plastic made from renewable resources, such as plants

biosphere all the areas on Earth and in its atmosphere that contain life

brush the part of a motor that conducts current between stationary and moving parts

budding a type of asexual reproduction, used by organisms such as yeast and hydra; it involves the daughter offspring growing off the side of the parent and then dropping off

carbon sequestration the process of storing carbon in a carbon sink

carbon sink an area where carbon is stored (e.g. oceans, forests or fossil fuels)

carbon source a process or an area that releases carbon

catalyst a chemical that speeds up a chemical reaction; it is not a reactant and is not used up during the reaction

causation where one event is caused by another event occurring

cellular respiration the chemical process through which cells release energy by converting glucose and oxygen into carbon dioxide and water

chemical change a rearrangement of atoms that is often irreversible

chemical reaction a process or chemical change that transforms one set of substances (the reactants) into another set of substances (the products)

cilia (singular: cilium) hair-like structures that line the respiratory tract and sweep microbes and debris out of the airways

climate the average or prevailing weather conditions of an area over a long period



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cloaca a hole used for defecating, urinating and reproduction that is present in some amphibians, reptiles, birds, fish and monotremes

closed system an environment from which matter cannot escape

cochlea the part of the inner ear that produces nerve impulses in response to sound waves

coefficient a number placed in front of a chemical symbol to balance a chemical equation

commutator a split ring that reverses current at a point in a motor

compound a substance formed by the chemical combination of two or more different elements in a fixed ratio

compression the part of a longitudinal wave where the particles are squashed together

conduction the transfer of thermal energy through collisions between particles

conductor (electricity) a substance or material that allows electrons to pass through it easily

conductor (heat) a substance or material that allows heat to pass through it easily

contagious of an infectious disease that can be passed from one human to another

continuous data quantitative (numerical) data points that have a value within a range; this type of data is usually measured against a scale that may include decimals or fractions

control centre often the brain or spinal cord, which receives signals from receptors and sends out signals to effectors to produce a response to a stimulus

control group a group that is not subjected to the independent variable in an experiment and therefore provides a baseline for comparison

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

convection the transfer of thermal energy due to the movement of particles in a liquid or gas

correlation a statistical measurement of the extent to which two variables change in relation to one another

crest the maximum displacement of a particle at the top of the wave

cross-pollination pollination that occurs when pollen is transferred from a flower on one plant to a flower on another plant

culturally responsive learning from and connecting respectfully with Aboriginal and Torres Strait Islander people from different language groups and communities; building strong, meaningful and collaborative relationships that value their knowledge and cultures

current the flow of electric charge, which may continue in a steady manner for a period of time

cycle one complete vibration or periodic movement of a particle through the crest and trough of a wave and back to its starting position; the length of a cycle is the wavelength

decomposers living organisms, such as bacteria and fungi, that break down dead organic matter

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

descriptive statistics mathematical tools used to summarise and describe datasets (e.g. measures of centre and spread)

differentiation the process by which cells become specialised

direct current (DC) a form of electricity in which the current flows in one direction

discrete data quantitative (numerical) data points that tend to have whole numbers; this type of data is usually counted

disease an illness that causes specific symptoms

displacement the distance a particle has moved away from its rest position on the midline of the wave

effector a muscle, gland or organ that carries out a response or action in response to a stimulus

electric motor a device that converts electrical energy to kinetic (movement) energy

electricity a form of energy that results from the accumulation or the flow of charge

electrode a structure, usually solid, that makes contact with the electrolyte in a battery and takes part in the chemical reactions that power the battery; it serves as a terminal, where a load can be connected; one is positive (the anode) and the other is negative (the cathode)

electrolysis a process in which an electric current is used to decompose a chemical compound

electrolyte a liquid or paste in a battery through which ions travel to take part in the chemical reactions that power the battery

electromagnet a magnet consisting of a current-carrying coil surrounding a piece of iron

electromagnetic induction the production of current in a wire due to a moving magnetic field

electromagnetic radiation the transfer of energy by electromagnetic waves

electromagnetic wave a wave with electric and magnetic components that can travel through matter or a vacuum

electromagnetism the interaction between magnetic fields and electric currents

electron a subatomic particle with a negative charge, found outside the nucleus of an atom; it has a relative mass of $\frac{1}{1836}$ of a proton or neutron

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electrostatic charge a charge that stays on an object

embryo a fertilised egg cell in the early stages of growth and differentiation; in humans, 2–8 weeks after fertilisation

embryo sac the female gamete in flowering plants

endocrine system the system of glands that controls hormones in the body

enhanced greenhouse effect the intensifying of the natural greenhouse effect due to human activity

epidemic an outbreak of an infectious disease that has spread to the wider community

excretion the process of eliminating waste products, excess water and other unnecessary substances from the body

exponential a growth or decline that becomes increasingly rapid with time (or relative to another variable)

external fertilisation a method of fertilisation in which gametes are released into the environment and fertilisation occurs outside the body

extraneous variable a variable other than the independent variable that may affect the dependent variable; if not controlled, it can influence experimental results and lead to false conclusions

extrapolation extending a trend, pattern or relationship observed in a limited range of data to estimate values beyond that range; predictions can lack reliability

fermentation a chemical process by which energy is produced in the absence of oxygen

fertilisation the fusion of the male and female gametes (sperm and egg)

fragmentation a type of asexual reproduction in which a parent organism splits into multiple fragments, each of which can potentially develop into an independent individual

free electron an electron that is not attached to an atom

frequency the number of cycles of a wave per second; measured in hertz (Hz)

fungi (singular: fungus) single-celled or multicellular organisms that contain a nucleus and a cell wall made of chitin

gamete a sex cell (egg or sperm); it contains half the genetic material required to make an organism

gamma ray a type of electromagnetic radiation; it has high energy and a very short wavelength; it is produced when certain radioactive atoms decay

generator a device that converts kinetic (movement) energy into electricity

geosphere all Earth's geological materials, including magma, lava, rocks and minerals

gestation the pregnancy period, when offspring are developing inside the mother

glacial period a period in Earth's history when a reduction in global temperatures is sustained for a long period

global warming the long-term rise in the average temperature on Earth, primarily caused by the increase of greenhouse gases in the atmosphere

glucagon a hormone secreted by the pancreas that triggers the liver and muscle cells to convert glycogen into glucose, raising blood glucose levels

gonad the reproductive organ where gametes are produced; testis in males and ovary in females

green (environmental) something that has a reduced impact on the environment

greenhouse effect the trapping of the Sun's warmth by a layer of gases in the lower atmosphere

greenhouse gas a gas that contributes to the greenhouse effect

half-life the time taken for half of the atoms in a sample of radioactive material to decay

heat thermal energy transferred from hotter objects or regions to colder objects or regions

hertz a unit for measuring the number of cycles that happen every second (frequency); abbreviation Hz

homeostasis the process by which an organism maintains a stable internal environment despite changes in the external environment

hormone a chemical messenger secreted by endocrine glands that controls and regulates different processes in the body

hydrosphere all of the water found on Earth (e.g. oceans, lakes and rivers)

hypothalamus a part of the brain that plays a key role in maintaining homeostasis, acting as a link between the nervous and endocrine systems

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

immune system the system of cells, tissues and organs that enables the body to protect itself against disease

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

infection the growth of a pathogen inside the body

infectious disease a disease caused by a pathogen

inferential statistics mathematical tools that allow scientists to make claims regarding cause-and-effect relationships between variables by analysing the changes in datasets

infrared radiation the type of electromagnetic radiation that lies between microwaves and visible light; also known as heat radiation

insulator (electricity) a substance or material that does not allow current to flow through it easily



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insulator (heat) a substance or material that does not allow heat to pass through it easily

insulin a hormone secreted by the pancreas that triggers cells to take up glucose from the bloodstream and the liver, which is then stored as glycogen, lowering blood glucose levels

interglacial period a period in Earth's history when an increase in global temperatures is sustained for a long period

internal fertilisation a method of fertilisation in which male gametes are delivered into the female reproductive system and fertilisation takes place inside the female

interneuron a nerve cell that transmits information within the brain and spinal cord (central nervous system)

interpolation using a line of best fit to make predictions within an existing dataset; predictions tend to be reliable

inverter an electronic device that converts DC to AC

investigable able to be tested through research or experimentation

ion a charged version of an atom that has either gained electrons (and become negatively charged) or lost electrons (and become positively charged)

ionic compound a type of compound generally made up of both metal and non-metal atoms

ionising radiation higher-frequency ultraviolet rays, X-rays and gamma rays that can turn atoms and molecules into ions, and that can potentially damage living cells

isotopes atoms of the same element with the same number of protons but a different number of neutrons

keystone species a species that has a significantly large role/impact on a particular ecosystem relative to its population

kinetic energy the energy an object or particle has due to its motion

Law of Conservation of Mass a scientific law that states that matter can be neither created nor destroyed

linear a straight line plotted on a graph

lithosphere the geological parts of Earth's crust and upper mantle only

longitudinal wave a wave with vibrations that move in the direction of travel instead of transversely (e.g. sound waves)

lymphocyte a white blood cell that is involved in fighting disease; some produce antibodies

lysis the breakdown of a cell due to the disruption of its membrane

magnet a material containing iron and other elements that attracts similar materials or objects; it aligns with an external magnetic field

magnetic field the region in which a magnet can exert a force on other magnets

magnetic field line a visual tool to represent the direction of magnetic fields

magnetic induction the process by which an object is magnetised by an external magnetic field

magnetism the ability to attract or repel objects that are magnetic

mass number the sum of the protons and neutrons in the nucleus of an atom

mean the total of a set of values divided by the number of values in that set

mechanical wave a disturbance in a medium that transfers energy through that medium

median the middle value of the dataset after all the values have been ranked (sorted in ascending order); there should be as many values below the median as above it

medium the matter through which a mechanical wave travels

memory cell a lymphocyte formed after exposure to a pathogen; it can produce a faster and stronger immune response upon re-infection

menstrual cycle a cycle controlled by hormones to prepare a female body for fertilisation of an egg; if fertilisation does not occur, menstruation will follow

menstruation the cyclical shedding of the uterine lining; also known as the menstrual period

microbe an organism that is too small to see with the naked eye

microwave the type of electromagnetic radiation used for cooking, communications and Wi-Fi; it lies between radio waves and infrared radiation

mitosis a process in which a single eukaryotic cell divides into two identical daughter cells

mode the most frequently occurring value or values in a dataset

molecule a chemical species made up of two or more atoms; it can be elemental or a compound

motor neuron a nerve cell that transmits messages from the central nervous system to effectors

native metal a metal that exists in its elemental form in the environment

nectar a sweet liquid produced by flowers to attract pollinators

negative feedback a regulatory process that reduces the output of a system in response to a deviation from a set point

nervous system the body system consisting of the brain, spinal cord and peripheral nerves and receptors that communicate messages quickly within the body

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neuron a nerve cell

neurotransmitter the chemical messenger that is released from one neuron and travels across the synapse to bind to the next neuron

neutron a subatomic particle with a neutral charge found in the nucleus of an atom; it has a relative mass of 1

nominal data qualitative (categorical) data where the categories have no clear order

non-infectious disease a disease that is not caused by a pathogen

non-linear a plot on a graph that is not a straight line

normal flora a population of microbes that permanently inhabits the human body and that do not usually cause disease

nuclear fission reaction the process by which an atom splits into two parts

nucleus (plural: nuclei) the central part of the atom containing its protons and neutrons

nuclide notation a symbol notation in which the mass number is shown at the top left of an element symbol and the atomic number is shown at the bottom left

open system an environment from which matter can escape

ordinal data qualitative (categorical) data where the categories have an order

origin the point on a graph where the *x*-axis and *y*-axis intersect (0, 0)

oscillating moving back and forth with periodic motion, somewhat like vibration

osmoregulation the regulation of water levels in the blood/body

outbreak a sudden increase in the incidence of an infectious disease within a certain area

outlier an extreme data point – a number that is very different from the rest of the data collected

ovulation the release of an ovum (egg) from the ovary into the fallopian tube

ovule a structure in a flowering plant where the female gamete is produced and where seeds develop

ovum egg, or female gamete

pandemic an outbreak of an infectious disease that has spread across multiple continents

parasite an organism that lives on or in a host that causes harm by extracting nutrients from the host

parthenogenesis a type of asexual reproduction in which an egg develops into an embryo without being fertilised by a male gamete

pathogen any organism that can cause disease, such as bacteria, viruses or fungi

periodic motion movement of a particle or an object that returns to its starting position and repeats in the same time interval, like a swing

permanent magnet a magnet that retains its magnetic properties outside a magnetic field

personal error a type of random error that arises from mistakes or miscalculations by the person conducting the experiment

phagocytosis a cellular process in which a white blood cell wraps around and ingests a cell or large particle to break it down using enzymes

photon an electromagnetic wave carrying a specific amount of energy related to its frequency or wavelength

photovoltaic (PV) panel a thin flat structure made of two materials (usually silicon-based) that, when photons of light are absorbed, have the property of separating electric charges; it creates a flow of electrons that produce a direct current

pitch how high or low a sound seems to our ears on a music scale

pole the end point of a magnet

pollen the male gamete in flowering plants

pollination the process by which pollen, containing the male reproductive cells of a plant, is transferred from the male part of a flower to the female part of a flower

positive feedback a mechanism that maintains the direction of a stimulus and accelerates its effect

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

product a substance that is formed in a chemical reaction

prokaryote a cell that lacks membrane-bound organelles (such as a nucleus)

proton a subatomic particle with a positive charge found in the nucleus of an atom; it has a relative mass of 1

puberty the time of transition from juvenile form to adult form

***p*-value** a value that determines the statistical significance of results by gauging the level of probability that the difference between two group's results is due to chance

radiation the transfer of energy without the presence of particles

radio wave a type of electromagnetic radiation; it has the longest wavelength

radioactive decay when an unstable nucleus emits radiation (alpha and beta particles or gamma rays) and breaks down to form another element

radioisotopes the radioactive isotopes of an element



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

rarefaction the part of a longitudinal wave where the particles are spread out

reactant a substance that is reacting in a chemical reaction

reaction conditions the conditions required for a chemical reaction to proceed

rearrange move things into a different order

receptor a specialised structure that allows the body to detect and respond to stimuli

reflex action a fast, involuntary motor action that protects the body from harm

relative atomic mass the average mass of an atom when considering all natural isotope masses and their abundances

repeatability how consistent the results are when the same scientist repeats the experiment under the same conditions as the original experiment

response the reaction to a stimulus

right-hand grip rule a way to show the direction of the magnetic field of a current-carrying wire

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

scrotum a sac that encloses the testes

secondary sexual characteristic any physical characteristic developing at puberty that helps distinguish between the sexes but is not directly involved in reproduction

seed a plant embryo enclosed in a protective coating

seed dispersal the spread of seeds away from the parent plant

seismic wave a wave that travels through Earth and over its surface; caused by earthquakes

self-pollination pollination that occurs when pollen is transferred from the same flower or from another flower on the same plant

self-propagating refers to a wave that (unlike mechanical waves) once started, keeps going at a constant speed forever without needing the input of more energy

sensory neuron a nerve cell that transmits messages from the sensory receptors to the central nervous system

septic of tissue infected with bacteria

sexual reproduction a method of reproduction that involves two parent organisms and results in genetic variation in the offspring

slipring a copper ring at the end of the armature of an AC electric motor or generator that rotates in contact with the brushes

solenoid a wire coil wrapped in the shape of a tube or cylinder; in engineering, a coil that moves an iron core in its centre for a mechanical purpose

somatic nervous system the part of the peripheral nervous system involved with the voluntary control of body movements

sperm the male gamete

spore a reproductive body, produced by fungi and some plants, that develops into a new individual

stimulus (plural: stimuli) a change in the environment that is detected by the human body

stratosphere the layer of Earth's atmosphere above the troposphere; it contains the ozone layer

subatomic particle one of the particles that make up an atom

subscript a number, letter or symbol written below the line of text (e.g. the 2 in O_2)

sustainable a way of using natural resources responsibly so they are available for future generations

sustainable ecosystem a biological environment that can support itself without outside assistance

symbol equation a chemical reaction written using the symbols and formulas of the reactants and products involved

synapse the junction between two neurons

systematic error an error that causes measurements to differ from the true result by a consistent amount, often due to faulty or uncalibrated equipment

target cell a cell affected by a specific hormone

temperature a measure of the average random kinetic energy of the particles in an object

temporary magnet a magnet that does not retain its magnetism outside an external magnetic field

testes the male reproductive glands that produce sperm

thermal energy the total kinetic energy of all particles in a system

trait a characteristic belonging to an individual; under genetic control (although the environment may have an influence)

transmission the passing of a pathogen from one organism to another

transverse wave a wave in which the particles vibrate or move at right angles (perpendicular) to the direction of energy transfer

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troposphere the layer of Earth's atmosphere that is closest to Earth's surface and where most of the weather occurs

trough the maximum displacement of a particle at the bottom of the wave

turbine a type of machine that turns a wheel with blades to produce power

ultraviolet light the type of electromagnetic radiation that lies between visible light and X-rays; it is needed by our bodies to make vitamin D; short-wavelength ultraviolet light can cause sunburn and cancer

vaccine a chemical substance composed of a dead or weakened version of a pathogen that is injected into the body to make a person immune against that pathogen

vacuum a space completely devoid of matter

validity the extent to which a study accurately measures or tests what it was intended to measure or test

vegetative propagation a form of asexual reproduction in which only one plant is involved

virus an extremely small non-cellular pathogen comprised of infectious particles that are inactive outside a living host cell

visible light the part of the electromagnetic spectrum that we can see

voltage the difference in electrical potential energy between two points in an electric circuit; measured in volts (V)

wave a carrier of energy that travels through space or matter without the movement of matter as a whole

wavelength the distance from one wave crest to the next; measured in metres (m)

weather the atmospheric conditions (such as temperature, cloud, rain or wind) at a particular time over a particular area

word equation a chemical reaction written using the names of the reactants and products involved

X-ray a type of electromagnetic radiation; it has short wavelengths and can pass through flesh to give images of bones; it is hazardous and can cause cancer

zygote a fertilised egg cell



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